Uncertainties in techno-economic evaluation of innovative processes

Effect of technology maturity and preparation effort

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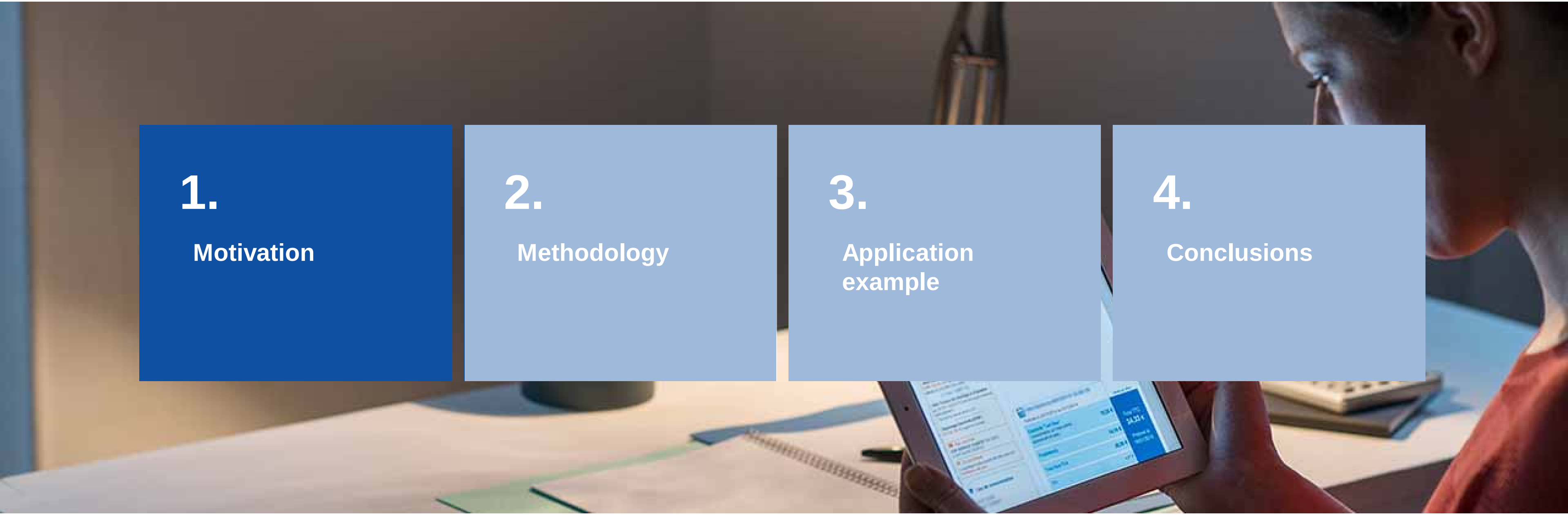
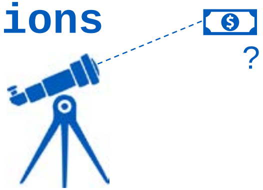


1. Motivation
2. Methodology
3. Application example
4. Conclusions

Conception or evaluation of **innovative process** ⇨ Determination of **economic projections** among other indicators



Innovation vs. existing (mature) process

 vs. 

Innovation vs. other innovations

 vs. 

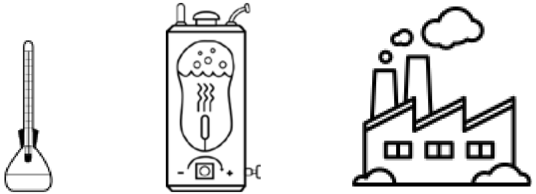
Innovation and techno-economic

Innovative process : **partial information** → strong hypotheses

Uncertainties during the
techno-economic analysis
of an **innovative process ?**

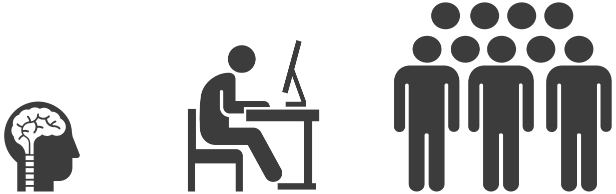
focus on

Technology maturity

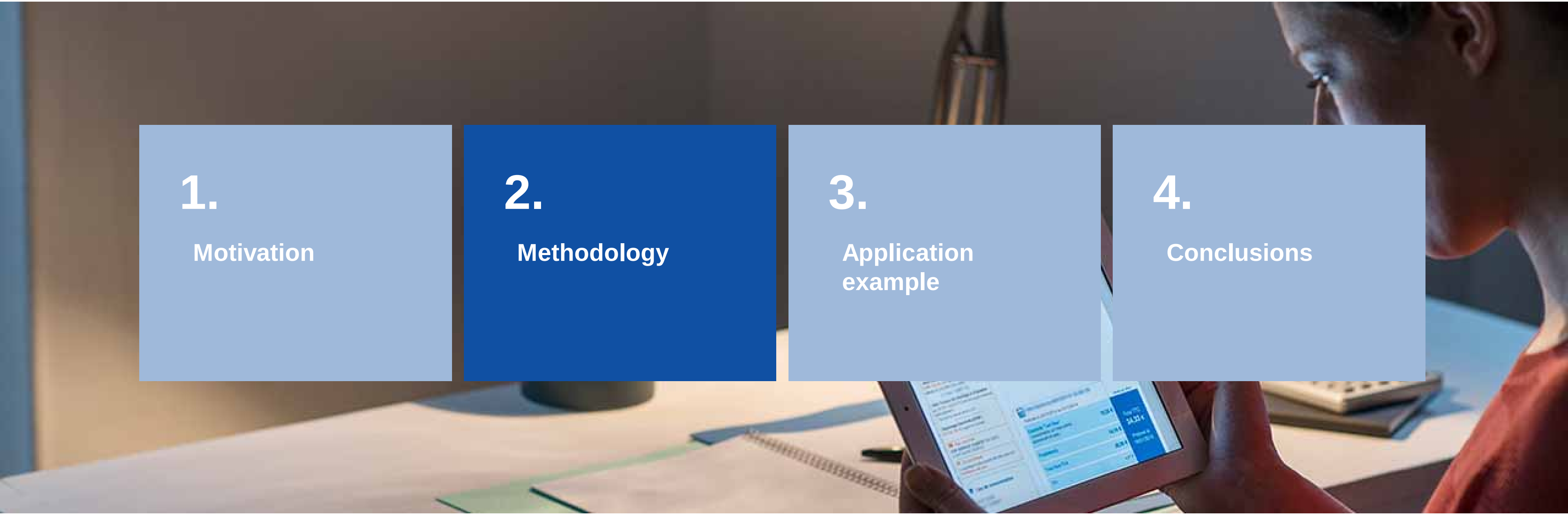


lab. scale | *pilot scale* | *commercial scale*

Preparation effort



conceptual design | *basic design* | *detailed design*



1. Motivation

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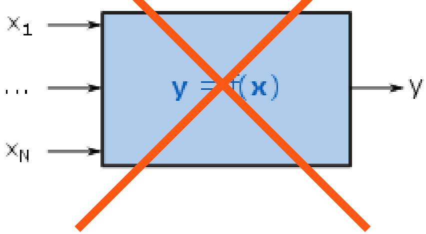
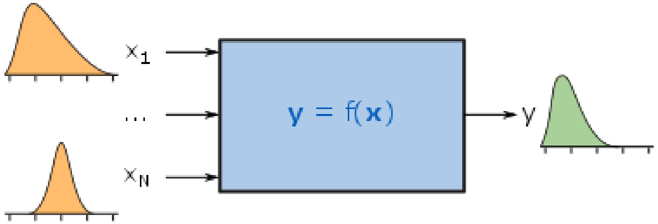
Process aspects
Equipment, installation, reactants, utilities, …
Project environment
Site adaptation, studies, licences, owner’s cost, …
Financial aspects
Levelization, taxes, …

Deterministic techno-economic model



Economic performance indicators
Levelized cost of production
Net actual value
Return on investment
Internal rate
…

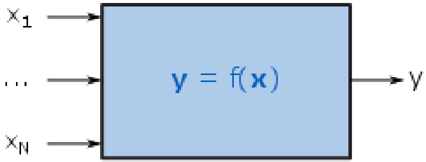
Stochastic techno-economic model



General approach

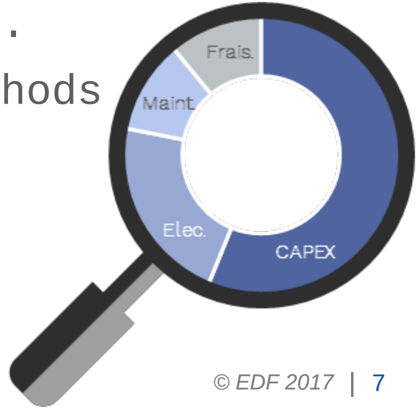
1. Economic model creation
2. Uncertainties, nature and quantification
3. Uncertainties propagation
4. Indicators analysis

Requirement : y = f(x) function for the calculation of the chosen economic indicator



For CAPEX (Capital Expenditure) → <u>Existing methods</u>

- Extrapolation, factorial, detailed etc.
- Internal, commercial and/or public methods



Process maturity

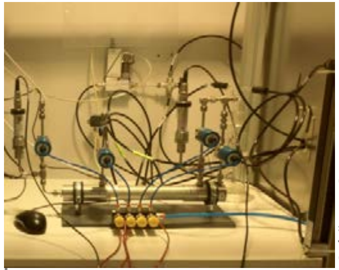
1. Economic model creation

2. Uncertainties, nature and quantification

3. Uncertainties propagation

4. Indicators analysis

3 TRL



Crédit : LRGP

6 TRL

Crédit : Vattenfal

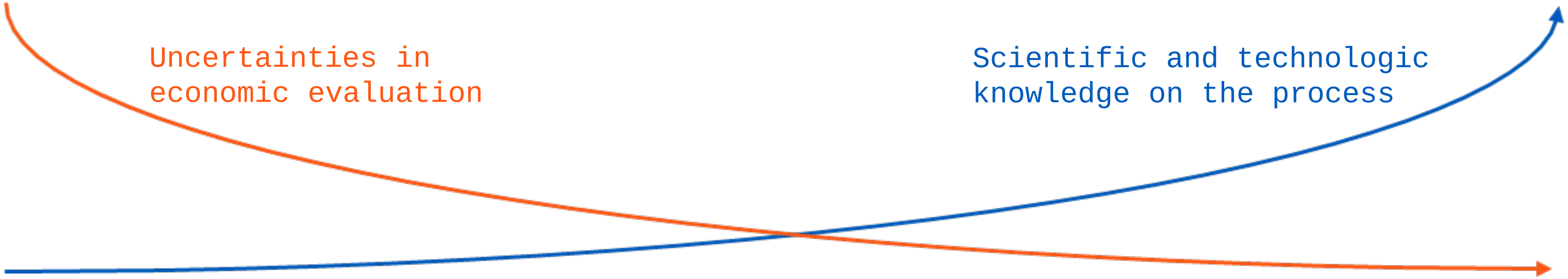
9 TRL

Crédit : IDE technologies

Feasibility of critical component (analytical and experimental)

Pilot-plant in representative conditions

Commercial process



Process maturity: uncertainties

1. Economic model creation

2. Uncertainties, nature and quantification

3. Uncertainties propagation

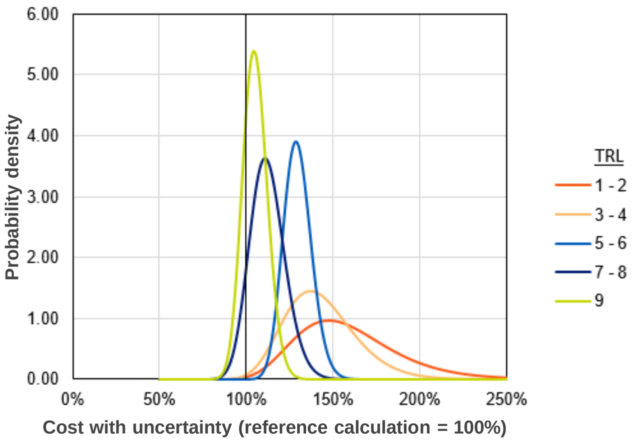
4. Indicators analysis

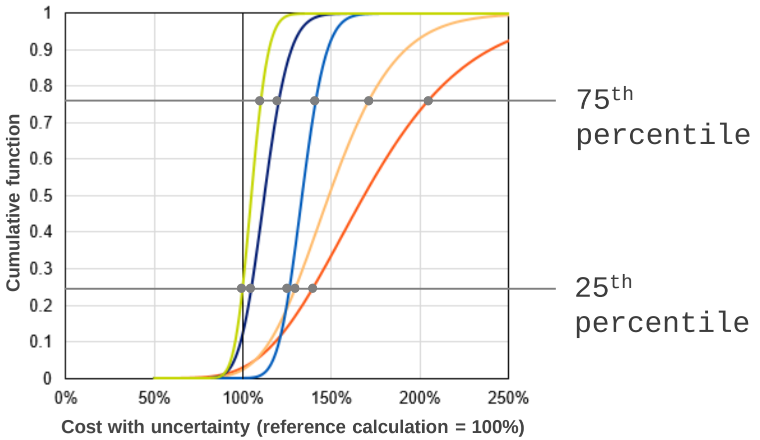
Recommandations of AACE International
(*Association for the Advancement of Cost Engineering*) *[1]*

	TRL	Uncertainties
New concept	1 – 2	> +40 %
Bench-scale	3 – 4	+30 à +70 %
Pilot-plant	5 – 6	+20 à +35 %
First of a kind	7 – 8	+5 à +20 %
Nth of a king	9	0 à +10 %

Uncertainties = 25^{th} et 75^{th} percentiles

Here: identification of log-normal distributions

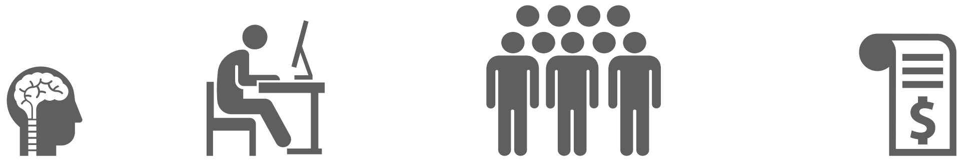


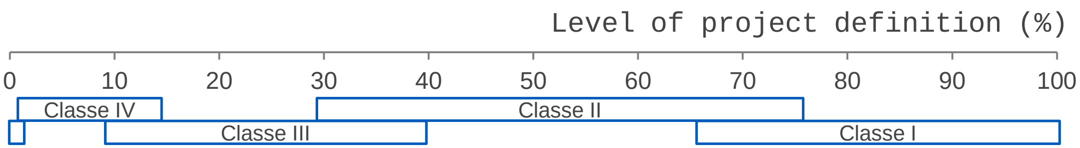


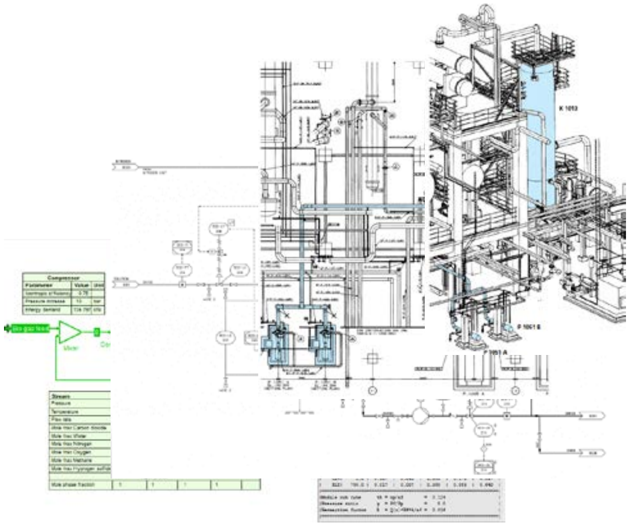
[1] AACE, 2003, Conducting technical and economic evaluations – As applied for the process and utility industries, AACE International Recommended Practice No. 16R-90.

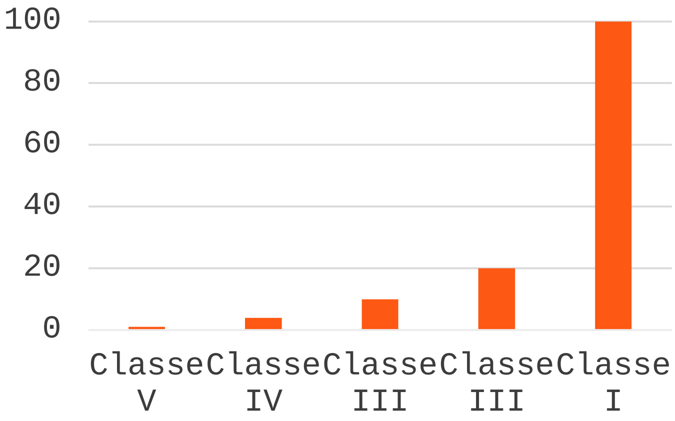
Preparation effort

1. Economic model creation
2. Uncertainties, nature and quantification
3. Uncertainties propagation
4. Indicators analysis









Relative efforts [2]

[2] AACE, 2011, Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries, No. 18R-97.

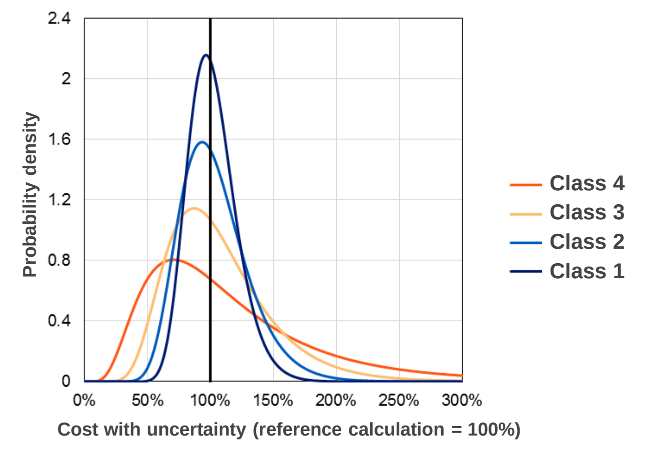
Preparation effort: uncertainties

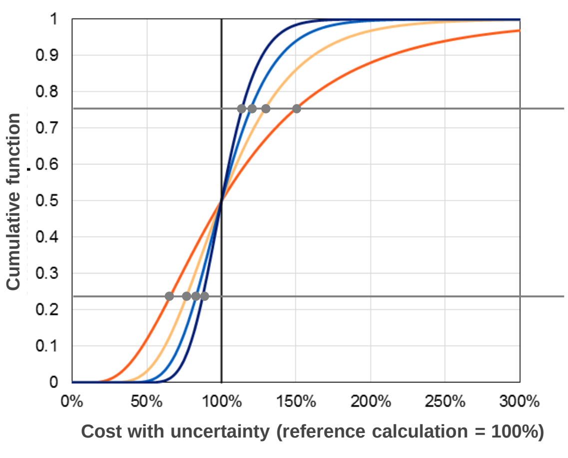
1. Economic model creation
2. Uncertainties, nature and quantification
3. Uncertainties propagation
4. Indicators analysis

Recommandations of AACE International [2]

Class	Level of project definition	Purpose	Uncertainties
5	0 à 2 %	Concept screening	-50 à +100%
4	1 à 15 %	Feasibility, studies	-30 à +50 %
3	10 à 40 %	Budget authorization	-20 à +30 %
2	30 à 70 %	Budget control	-15 à +20 %
1	70 à 100 %	Check estimate	-10 à +15 %

Evaluation of innovative processes
Mostly class 4 factorial method





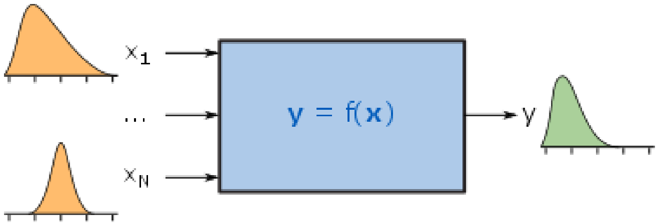
75th percentile

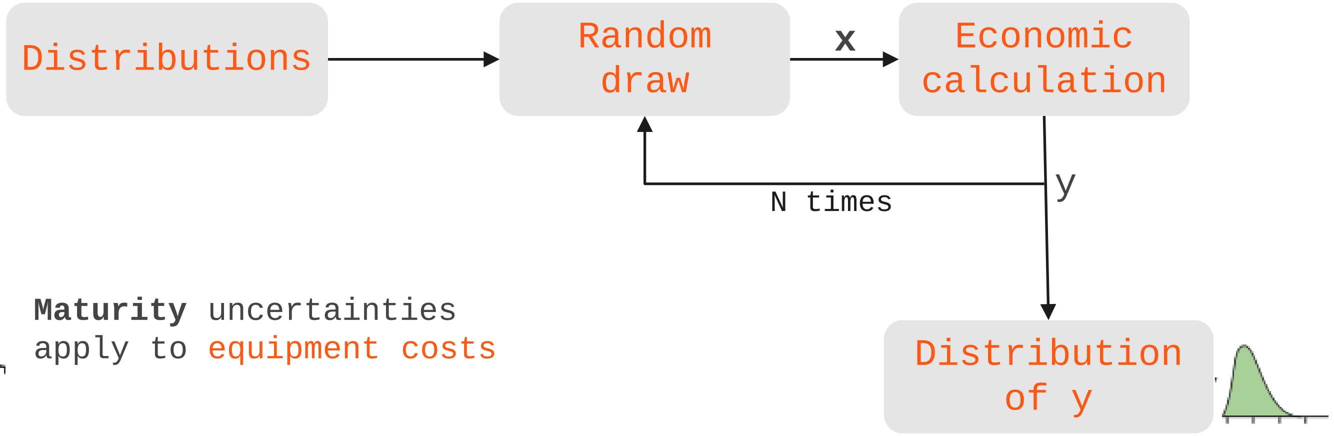
25th percentile

[2] AACE, 2011, Cost Estimate Classification System – As Applied in Engineering, Procurement, and Construction for the Process Industries, No. 18R-97.

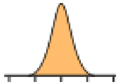
Uncertainties propagations

Monte-Carlo method





Maturity uncertainties apply to equipment costs



Effort uncertainties apply to fixed capital

Representation and analysis

1. Economic model creation
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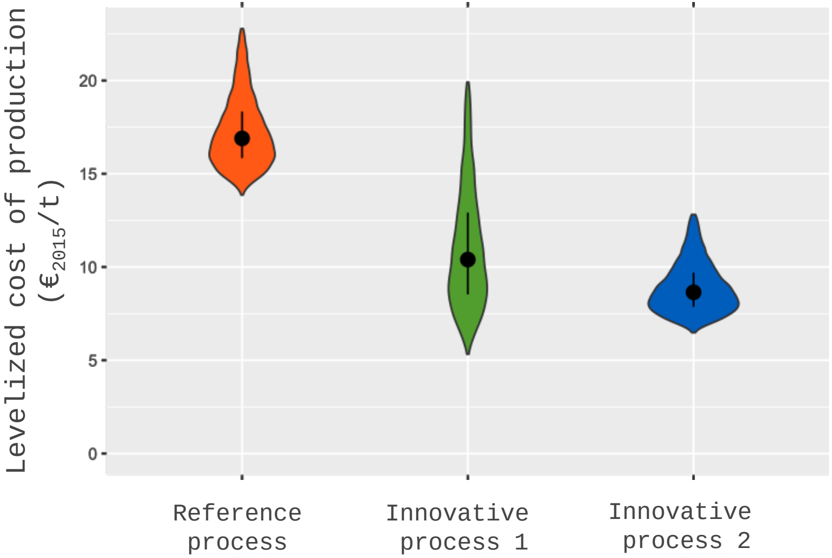
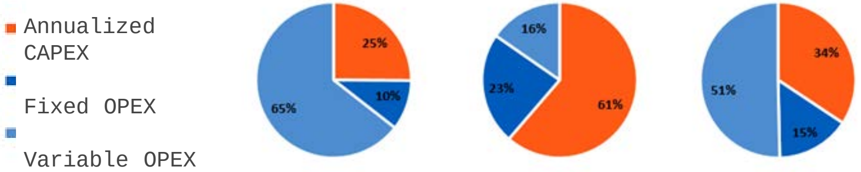
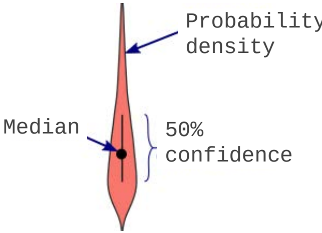
4. Indicators analysis

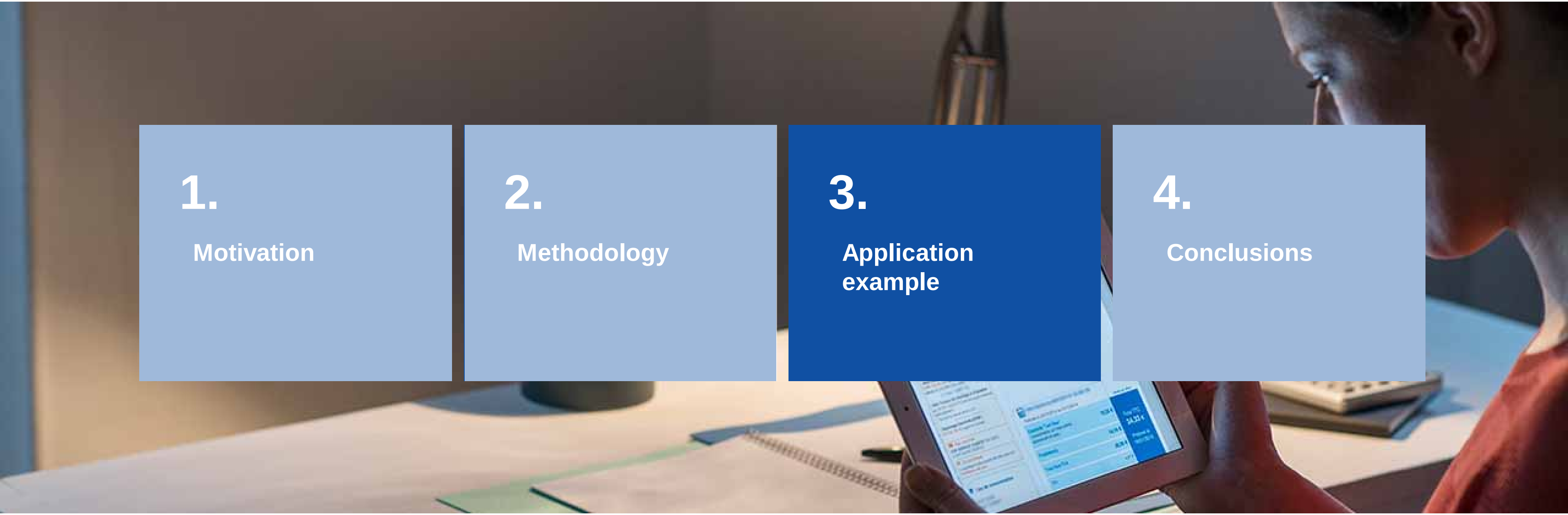






$\mathbb{P}(C < C_{ref})$	-	90%	99%
$\mathbb{P}\big(C < C_{ref}(1 - 30\%)\big)$	-	56%	73%

Support for decision-making



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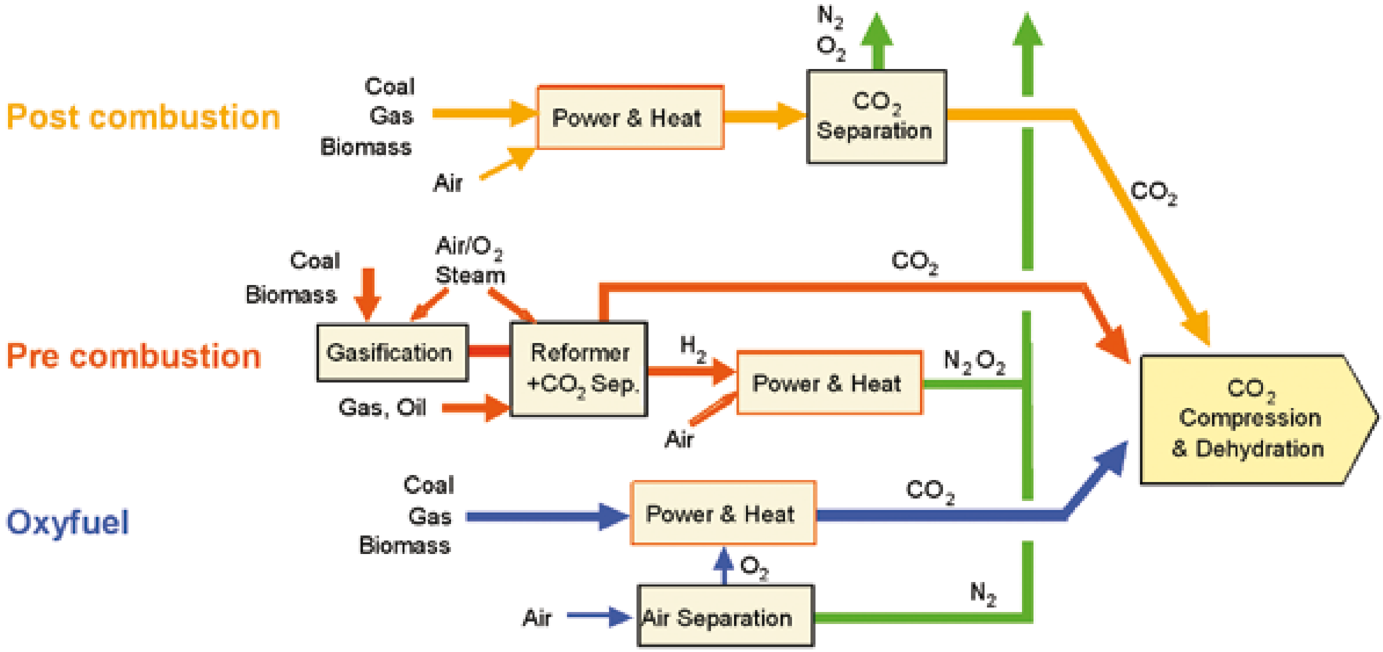
CO_2 Capture



CO2 capture systems for thermal power-plants [3]

[3] *Carbon Capture and Storage, technical summary, IPCC 2005*

Example of criteria

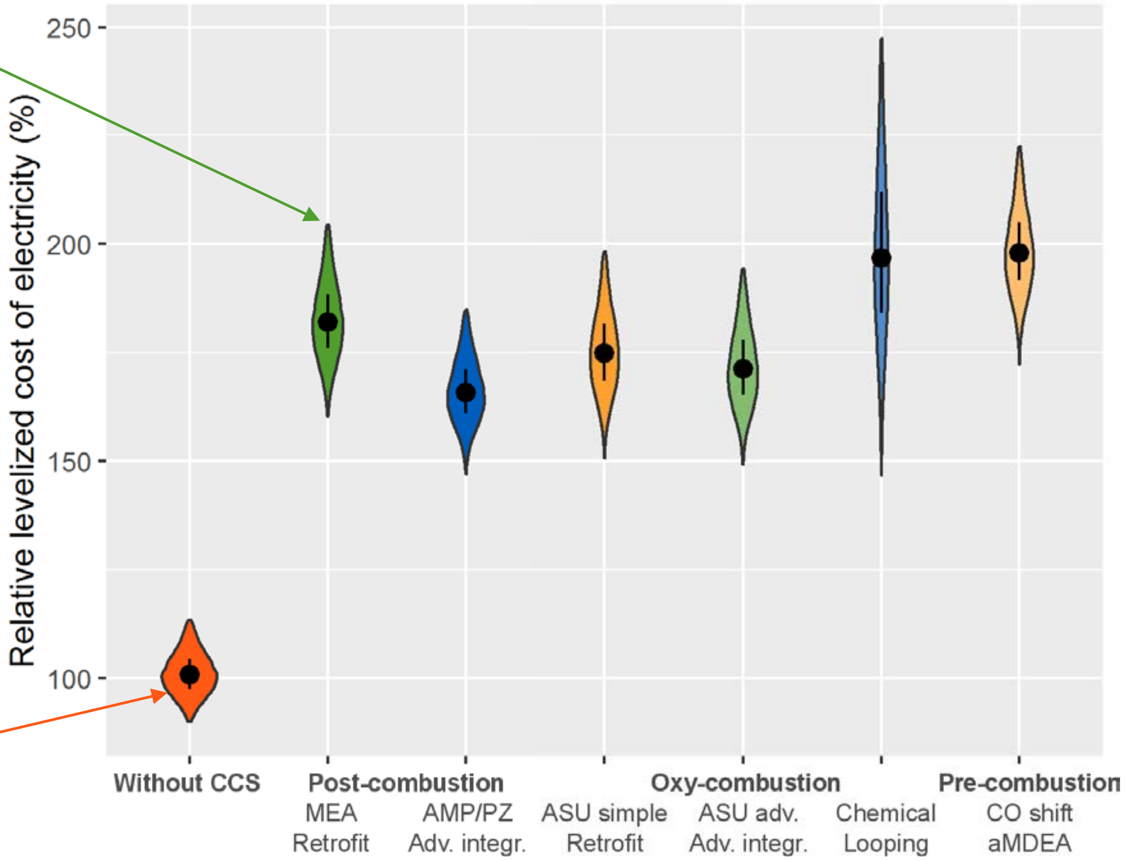
Pathway	Post-combustion		Oxy-combustion		Pre-combustion
Technology	**Amine absorption**	**NH_3 absorption**	**Cryogenic**	**Chemical Looping**	**Chemical absorption**
Maturity (TRL)	6-7	6-7	6-7	4-5	7
Net efficiency loss	7-8 %-pts	7-8 %-pts	7-8 %-pts	4-5 %-pts	6-7 %-pts
Energy performance	😐	😐	😐	🙂	😐
Economic performance	😐	😐	😐	😐	☹️
Operability	😐	☹️	😐	☹️	☹️
Flexibility	🙂	😐	😐	☹️	☹️
Risk	😐	☹️	🙂	😐	😐
Market	Retrofit New built	Retrofit New built	(Retrofit) New built	New built	New built
Interest	Maturity	Stable and cheap solvent	Maturity No chemicals	Performance	Maturity Polygen. possible
Technological gap	Pollutant emission Solvent degrad.	Seasonal variation Precipitation	Start-up duration	Complexity O_2 carrier solid	Operability Flexibility

[4] *Kanniche M, Le Moullec Y, Authier O, Hagi H, Bontemps D, Neveux T, Louis-Louisy M.* Up-to-date CO_2 Capture in Thermal Power Plants. *Communication au GHGT-13 (nov. 2016, Lausanne), to appear in Energy Procedia*

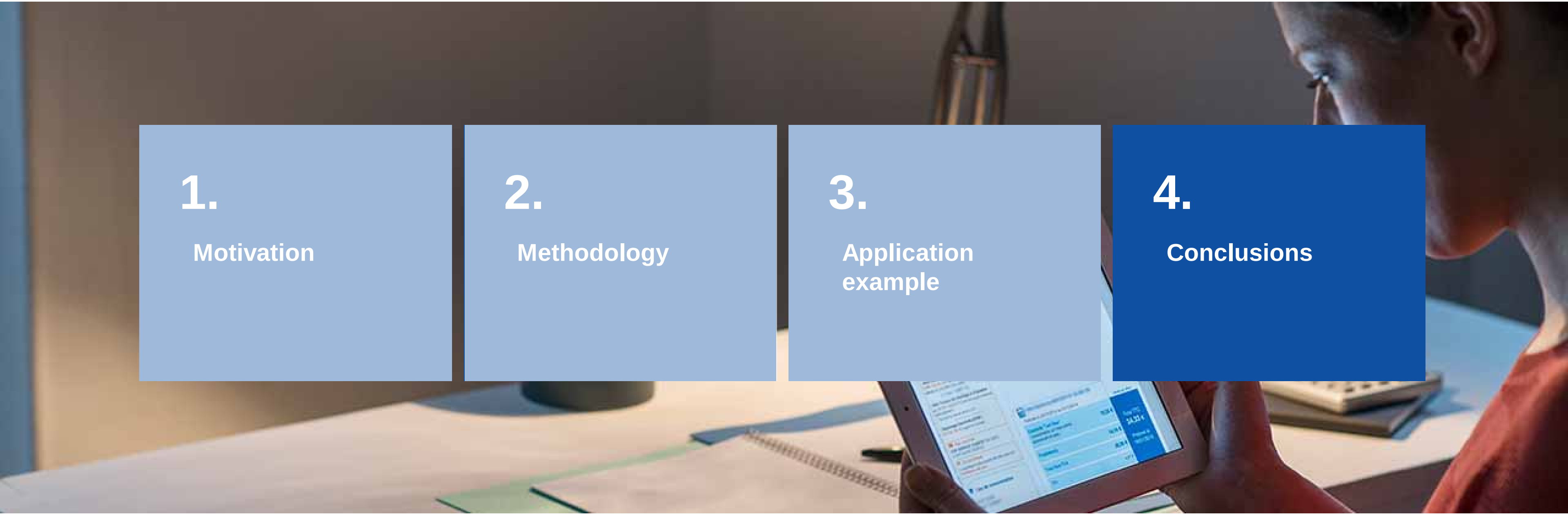
Cost comparison

Reference (historical) capture process

Coal-fired power plant without CO_2 capture



$\mathbb{P}(C < C_{\text{MEA retrofit}})$	-	84%	72%	80%	9%	27%



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Conclusions

Evaluation of innovative processes

- Variable maturity
  Concept, lab., pilot
- Variable efforts
  e.g. conceptual design
  → early stages

Sources of uncertainties

Uncertainties propagation

- Probability density function defined
- Propagation easy to implement

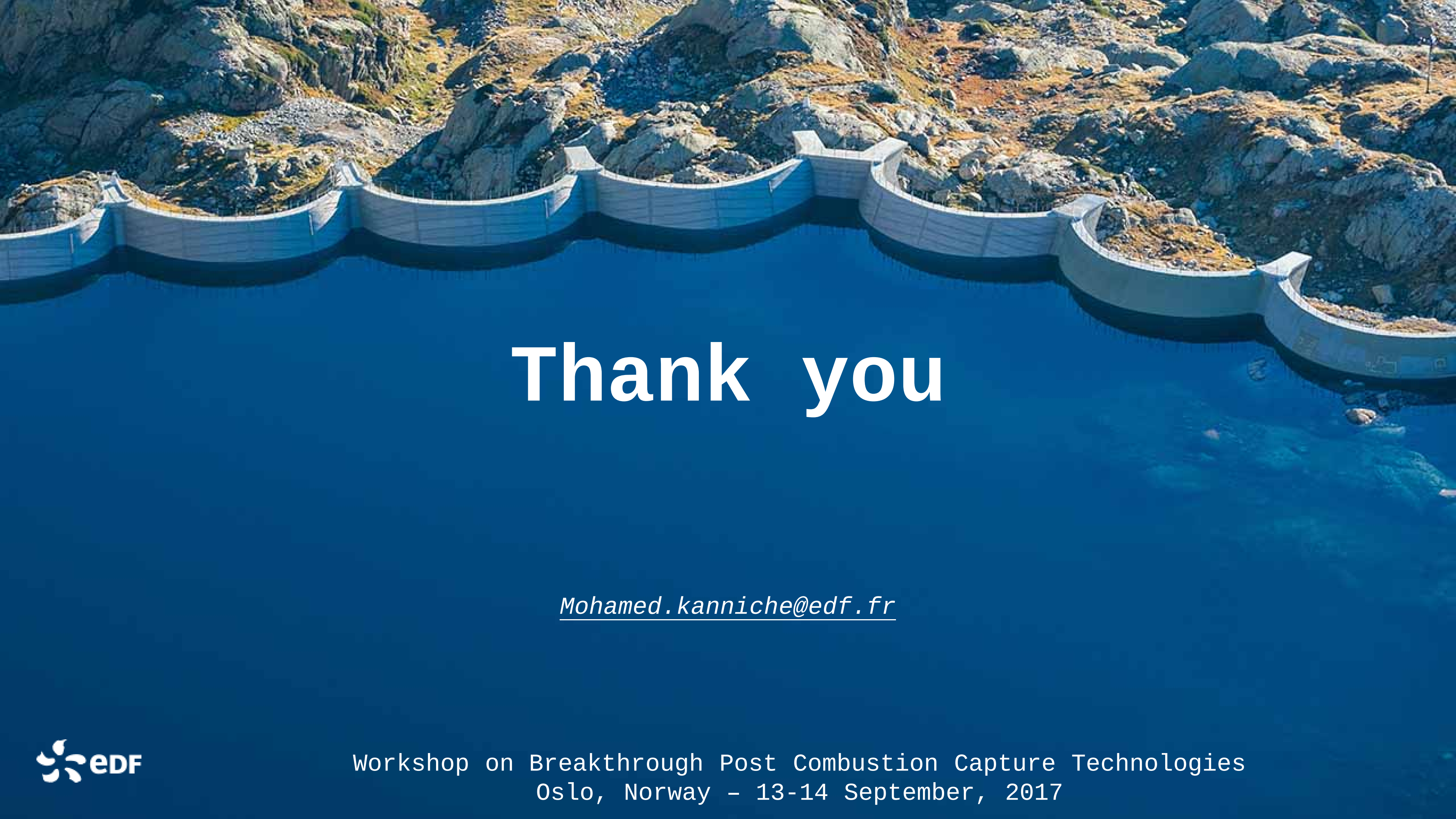
→ Step back on estimates

Possible extensions

- Other sources of uncertainties (e.g. price of reactants)
- Distinguished uncertainties (equipment, civil engineering etc.)

Limitations

- To be re-evaluated during technology development
- To be integrated with other indicators



Thank you

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Appendix

Fitted probability density

- **Log-normal** probability density function: $f(x) = \frac{1}{x\sigma\sqrt{2\pi}} exp\left(-\frac{(lnx-\mu)^2}{2\sigma^2}\right)$

- **Efforts**

		AACE data		Param.		Percentiles calculation				
Class	Project definition	P25	P75	μ	σ	P25	P50	P66	P75	P95
4	1 à 15 %	70%	150%	0	0.5887	67%	100%	127%	149%	263%
3	10 à 40 %	80%	130%	0	0.3733	78%	100%	117%	129%	185%
2	30 à 70 %	85%	120%	0	0.2606	84%	100%	111%	119%	154%
1	70 à 100 %	90%	115%	0	0.1880	88%	100%	108%	114%	136%

- **Process maturity**

		AACE data		Param.		Percentiles calculation				
Statut	TRL	P25	P75	μ	σ	P25	P50	P66	P75	P95
New concept	1 - 2	140%		0.5218	0.2748	140%	169%	189%	203%	265%
Bench scale	3 - 4	130%	170%	0.3965	0.1989	130%	149%	161%	170%	206%
Pilot unit	5 - 6	120%	135%	0.2891	0.0795	127%	134%	138%	141%	152%
First of a kind	7 - 8	105%	120%	0.1156	0.0990	105%	112%	117%	120%	132%
N^{th} of a kind	9	100%	110%	0.0477	0.0707	105%	105%	108%	110%	118%

Probabilities calculation

Knowing: the probability density functions of two processes costs (obtained by uncertainties propagation) f_C and $f_{C_{ref}}$ and associated cumulative functions F_C et $F_{C_{ref}}$

$\mathbb{P}(C \leq C_{ref} - a)$, the probability that the process cost (C) be inferior to the cost of reference process (C_{ref}) minus a margin (a), is given by:

$$\mathbb{P}(C \leq C_{ref} - a) = \int_{-\infty}^{\infty} F_C(t) f_{C_{ref}}(t+a)\, dt$$