Technical and Economic Uncertainties Assessment to Derive a High Enthalpy Geothermal Project Optimal Development Scheme*

Thomas Schaaf[1], Claude Bontemps[1], Delphine Patriarche[1], and Patrick Egermann[1]

Search and Discovery Article #80684 (2019)**
Posted June 24, 2019

*Adapted from oral presentation given at 2019 AAPG European Region, 3rd Hydrocarbon Geothermal Cross Over Technology Workshop, Geneva, Switzerland April 9-10, 2019

[1]STORENGY (ENGIE Group), Bois-Colombes, France (thomas.schaaf@storengy.com)

Abstract

Like in the oil and gas business or gas storage industry, getting reliable production and temperature forecasts is a key aspect of any geothermal project. The field assessment phase prior to investment sanction is characterized by relatively large uncertainties at the time important decisions have to be made. It is, for instance, crucial to select an appropriate development strategy (e.g. number of producers, well architecture or re-injection pattern) to obtain optimal cumulative energy production whilst ensuring good profitability of the project. Reservoir evaluation as well as economic uncertainties and quantification of their impact on the project reserves and economics are needed before the field development concept selection. The proposed application case is about high enthalpy geothermal projects for electricity generation through ORC cycle, like the ones which might be found in Germany, Italy, Turkey or the United States for instance.

A fully integrated numerical modeling of the (well+pump+ORC) system was developed, including technical as well as economic inputs, ending up with a business model delivering typical economic figures for management decision making. Capitalizing on existing workflows from the oil and gas business to assess those subsurface and economic uncertainties, an optimal development scheme is then derived through an optimization process, while taking correctly into account both types of uncertainties. In more details, extensive use of: (1) advanced Design of Experiments techniques for optimal uncertainty space sampling (of both technical and economic parameters), (2) reliable proxy-models computations of technical and/or economic modeling outputs, (3) global sensitivity analysis to rank the most impacting parameters, and (4) optimization techniques under uncertainty to find the optimal values of controllable parameters (e.g. well architecture), ending up with an optimal development scheme. This allows, through a single study, to assess both the technical and economic uncertain parameters for uncertainty quantification and risk analysis for optimal decision making.

Technical and Economic Uncertainties Assessment to Derive a High Enthalpy Project Optimal Development Scheme

AAPG workshop - Geneva – 10 April 2019

Thomas SCHAAF*, C. Bontemps, D. Patriarche, P. Egermann,
STORENGY, ENGIE group

storengy
A company of ENGIE

Outline

- Common framework : geological reservoir characterization
- Common goal : reliable performance forecasts

- Full system (well+pump+ORC) modelling coupled to a business model
- Experimental Design & proxy model computation
- Sensitivity studies : Technical and economic parameters and outputs
- Optimization of controllable parameters to derive an optimal scheme

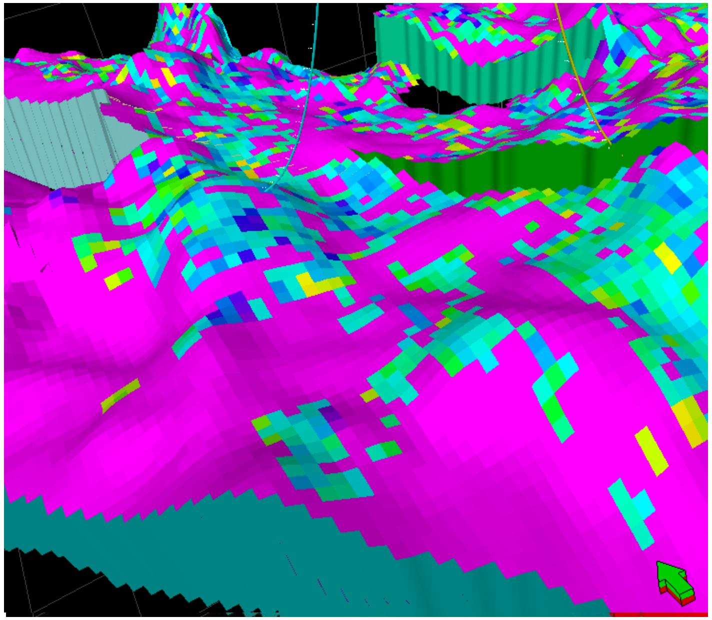
- Wrap up and perspectives

Common framework– Reservoir Characterization

- **Reservoir characterization : Obtain representative model(s!) of a geological object in an uncertain framework**
- **Our concern: subsurface uncertainties (up to economics possibly)**

Data from:

-Geophysics,
-Geology,
-Reservoir.



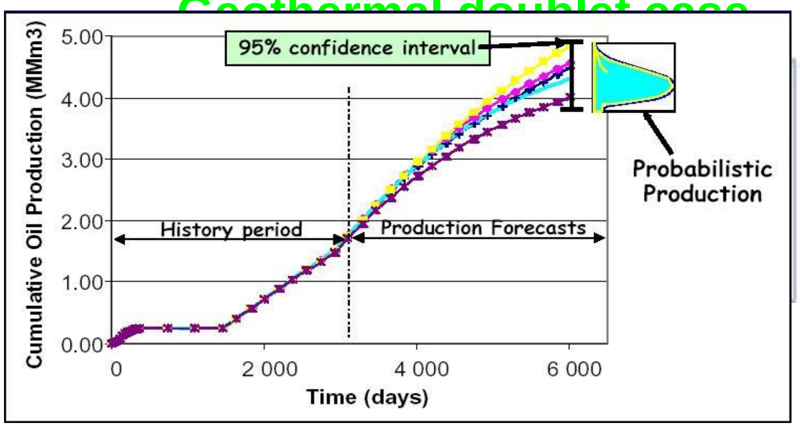
Modelling:

-Structural,
-Facies,
-Petrophysical,
-Dynamic Simulation.

Common goal – Reliable production forecasts

- Proper uncertainties quantification assessment and risk analysis
- Reliable production forecasts :

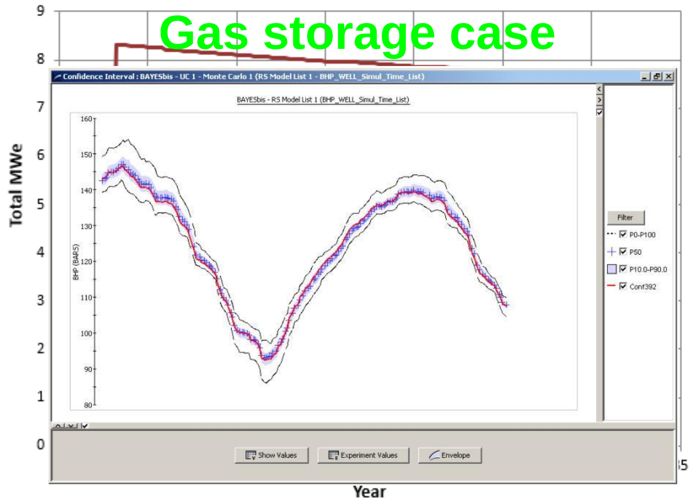
E&P application case



Cumulative oil production

Geothermal HT case

Gas storage case



Mean pressure

Outline

- Common framework : geological reservoir characterization
- Common goal : reliable performance forecasts

- Full system (well+pump+ORC) modelling coupled to a business model
- Experimental Design & proxy model computation
- Sensitivity studies : Technical and economic parameters and outputs
- Optimization of controllable parameters to derive an optimal scheme

- Wrap up and perspectives

Full well/pump/ORC System Modelling

- **Developed through an Excel multi tab spreadsheet (+ macros):**
  - **Technical inputs (number of wells, reservoir P&T, etc.),**
  - **Financial inputs (DRILLEX, CAPEX/OPEX, etc.)**

To end up with

  - **Key technical results (Gross, Net Power, pump consumption, etc.)**
  - **Key financial results (Cash Flow, NPV, WACC, etc.)**

Full well/pump/ORC System Modelling

- **Technical inputs :**

Storengy Case

Test		Development scheme	
		1	
Targeted producing well rate (l/s)=	150		
Number of producing well=	3	[illegible]	[illegible]
Number of injection well=	3	3	4
Production decline type=	0		
0 = low decline, 1= moderate decline, 2 sharp decline			
Pressure constraints:			
Minimum producer WHFP/inlet plant pressure (bar)=	17.5		
Injector WHFP/Outlet plant pressure (bar)=	15		
ORC Plant definition:			
Electricity power generation option (Y/N) =	y		
Temperature at outlet ORC plant (°C) =	60		
Plant consumption (%Gross) =	10%		
Plant efficiency (%)=	10%		
Reservoir definition:			
Net thickness (m)=	500		
Permeability (md)=	80		
Water salinity (g/l) =	40		
Produced fluid temperature (Bottom hole temp°C)=	135		
Reservoir pressure (bar)=	215		
Well data:			
Re (m)=	1000		
Rw inch=	4.20		
Total skin effect=	-3		
Permeability (Injectivity/productivity) ratio=	1.00		
Well pump efficiency (%)=	70%		

Production string (from top to bottom) :			Well Architecture	
delta MD m	delta TVD m	ID inch	1	
781	781	8.86	8.86	8.86
52	52	12.36	12.36	12.36
923	923	8.50	8.50	12.20
494	494	7.00	7.00	8.40
Injection string (from top to bottom) :				
delta MD m	delta TVD m	ID inch		
781	781	12.36	12.36	14.80
52	52	12.36	12.36	14.80
923	923	8.50	8.50	12.20
494	494	7.00	7.00	8.40

- Well flowrate, decline rate,
- Number producers/injectors

- Surface pressure constraints
- ORC definition

Reservoir data

Well data & architecture

Full well/pump/ORC System Modelling

- **Financial inputs :**

Storengy Case

Planning:	
Initial date	01/01/2016
Duration of Exploration phase (yr)=	0.25
Duration of Appraisal phase (yr)=	0.25
Duration of Development phase (yr)=	2.50
E&A phase (Subsurface):	
Number of appraisal well =	1
Nb of well not recovered (excluding coredrill)=	0
Exploration well cost including well test (M$)=	0.0
Appraisal well cost (M$)=	2.845
Average injection/production development well cost (M$)=	3.0
G&G study, data acquisition including, core drill.... (M$)=	1.00
Permitting & EIA (M$)=	0.39
Surface Engineering before development/FID (M$)=	0.50
Project management during exploration & appraisal phase (M$)=	1.00
Contingencies for well (%) =	10%
Development phase (ORC Plant & surface):	
Electricity connection (M$) =	2.0
Plant ORC CAPEX (M$/Mwe installed) =	2.8

Timing - Project phases

Well costs, etc.

Plant CAPEX, etc.

⋮

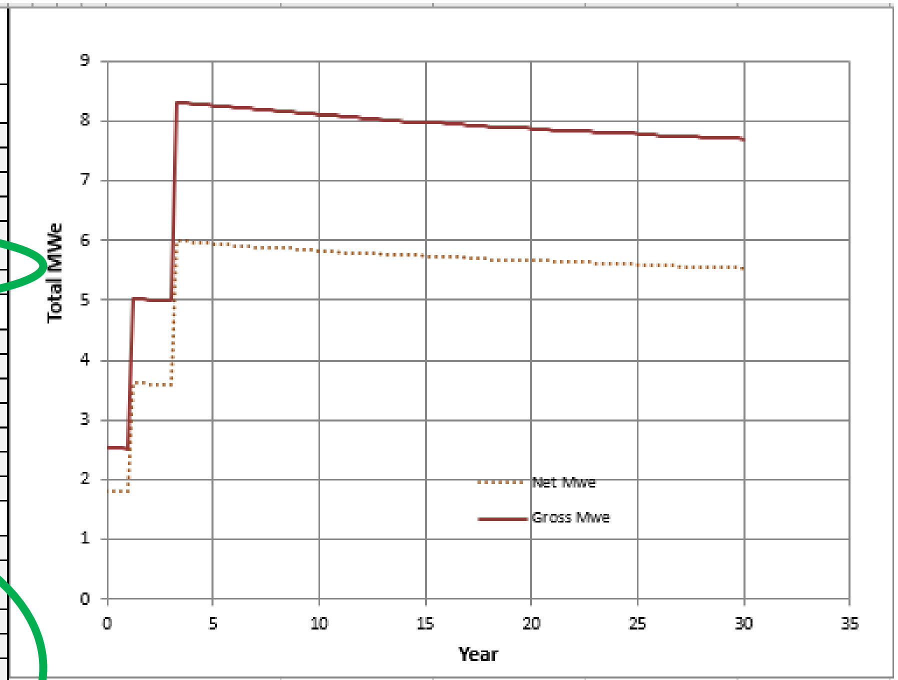
Pump or well maintenance operation cost=	0.6
Frequency of pump/well operation (time/year/well)=	0.15
Overhead for permanent staff=	50%
Overhead & insurance for equipment =	1%
Financial data:	
FIT on sales $/Mweh (electricity)	200
Revenue from internal consumption (Y/N)	n
FIT on consumption $/Wwh (electricity)	0
Discount rate (%)	0.09
FIT on sales $/Mwth thermal)	70

Feed In tariff, discount rate, etc.

Full well/pump/ORC System Modelling

- **Key Technical outputs e.g. pump power (kW), Plant Net power (MWe)**

Storengy Case	
Production well	
Q l/s (per well) =	**100**
IP_m3dbar=	1585
dp drawdown bar=	5
BHFP bar=	210
Pi bar=	215
dp pump bar =	26.2
Pump power kW=	509
Injection well	
Q l/s (per well) =	**100**
II_m3dbar=	743
dp drawdown bar=	12
BHFP resquested bar=	227
BHFT temp °C=	61
dp pump needed bar =	0
Pump power kW=	0
ORC Plant & Well	
Nb of production wells	3
Nb of injection wells	3
Gross Mwe per well (ORC)	**2.81**
Plant consumption	10%
Per producing, pumping consumption KWe	509
Per injector well, pumping consumption KWe	0
Gross Mwe	**8.4**
Plant consumtion Mwe	0.8
Total well pump consumption Mwe	1.5
Net plant Mwe	**6.06**
Net/Gross	71.[illegible]%



code for decline curve		0	1	2
		Low	moderate	high
Débit initial (m3/j)		1	1	1
Déclin initial (1/an)		0.005	0.02	0.05
n		10	5	3

Full well/pump/ORC System Modelling

- **Key Economic outputs e.g. cash flow(M$), NPV (M$)**

Storengy Case

Electricity Generation Excluding District Heating part

Electricity power generation option (1/0) = 1

Project phasing					Cost recap		Revenue			CF	
No	Year	Q	Date	Period	Total expenditures (M$)	OPEX (M$)	Net Mwe	Revenue from sale (M$)	Revenue from consumption (M$)	Cashflow (M$)	Cumulative CF (m$)
4	1	Q4	30/09/2016	Develop	5.63	0.00	0.00	0.00	0.00	-5.63	-5.63
8	2	Q4	01/10/2017	Develop	9.98	0.00	0.00	0.00	0.00	-9.98	-15.61
12	3	Q4	01/10/2018	Develop	25.38	0.30	0.00	0.00	0.00	-25.68	-41.30
16	4	Q4	01/10/2019	Exploitation	0.00	1.19	3.62	3.78	0.00	2.59	-38.71
20	5	Q4	01/10/2020	Exploitation	10.39	1.59	3.60	6.02	0.00	-5.96	-44.67
24	6	Q4	01/10/2021	Exploitation	0.00	2.12	5.98	6.98	0.00	4.87	-39.80
28	7	Q4	01/10/2022	Exploitation	0.00	2.64	5.95	9.94	0.00	7.29	-32.51
32	8	Q4	01/10/2023	Exploitation	0.00	2.64	5.93	9.89	0.00	7.25	-25.26
36	9	Q4	01/10/2024	Exploitation	0.00	2.64	5.90	9.85	0.00	7.21	-18.05
40	10	Q4	01/10/2025	Exploitation	0.00	2.64	5.88	9.82	0.00	7.17	-10.87
44	11	Q4	01/10/2026	Exploitation	0.00	2.64	5.86	9.78	0.00	7.14	-3.74
48	12	Q4	01/10/2027	Exploitation	0.00	2.64	5.84	9.74	0.00	7.10	3.36
52	13	Q4	01/10/2028	Exploitation	0.00	2.64	5.82	9.71	0.00	7.07	10.43
56	14	Q4	01/10/2029	Exploitation	0.00	2.64	5.80	9.68	0.00	7.03	17.46
60	15	Q4	01/10/2030	Exploitation	0.00	2.64	5.78	9.65	0.00	7.00	24.47
64	16	Q4	02/10/2031	Exploitation	0.00	2.64	5.76	9.62	0.00	6.97	31.44
68	17	Q4	01/10/2032	Exploitation	0.00	2.64	5.75	9.59	0.00	6.94	38.38
72	18	Q4	01/10/2033	Exploitation	0.00	2.64	5.73	9.56	0.00	6.91	45.30

VAN (M$)	8.18
TRI (%)	11.09%
CAPEX @ Risk (M$)	0.36

Outline

- Common framework : geological reservoir characterization
- Common goal : reliable performance forecasts

- Full system (well+pump+ORC) modelling coupled to a business model
- Experimental Design & proxy model computation
- Sensitivity studies : Technical and economic parameters and outputs
- Optimization of controllable parameters to derive an optimal scheme

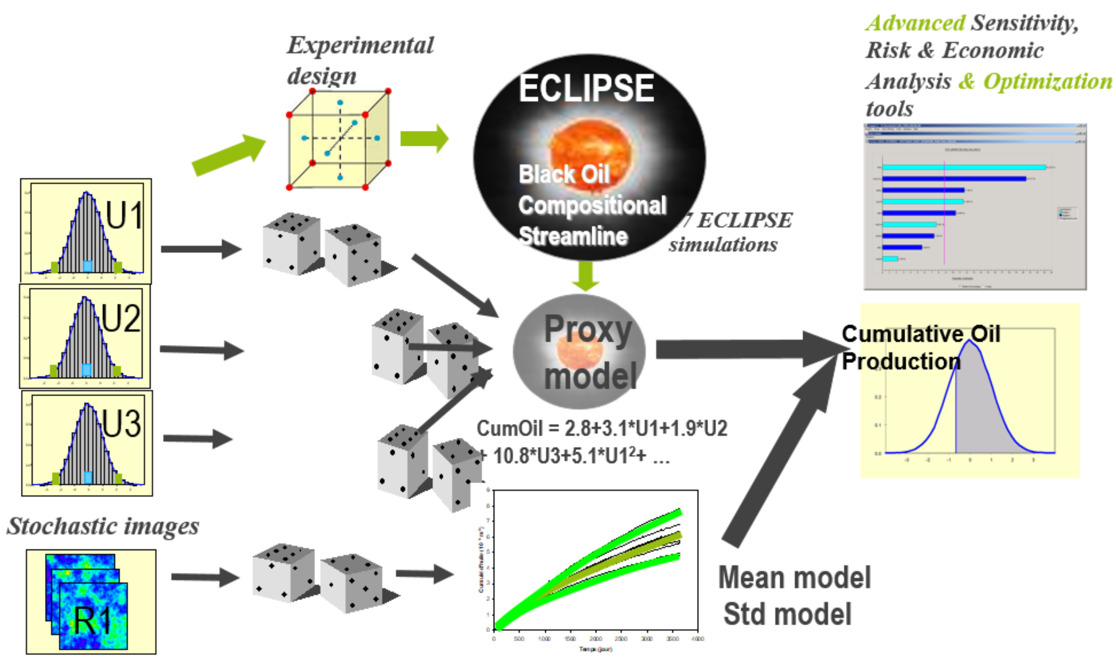
- Wrap up and perspectives

Experimental Design & Proxy models

- Capitalizing on existing soft/workflows from the Oil & Gas Industry
- ATOUT* software (soft deliverable from 4 IFPEN JIPs “COUGAR”)

* = Advanced Tools for Optimization and Uncertainty Treatment

Experimental Designs + Proxy Model Approach



+ Global Sensitivity analysis
+ Mixed-Integer Proxy
+ Bayesian framwork
+ Probabilistic decision tree

Outline

- Common framework : geological reservoir characterization
- Common goal : reliable performance forecasts

- Full system (well+pump+ORC) modelling coupled to a business model
- Experimental Design & proxy model computation
- Sensitivity studies : Technical and economic parameters and outputs
- Optimization of controllable parameters to derive an optimal scheme

- Wrap up and perspectives

Parameter set definition

- **Parameters:**
  - **(1) Geology and reservoir Engineering,**
  - **(2) Controllable**
  - **(3) Economic**

Parameters | Experimental Design | Spreadsheet Configuration | Responses | RS Modeling | Uncertainty Analysis & Optimization

Deterministic parameter specification table

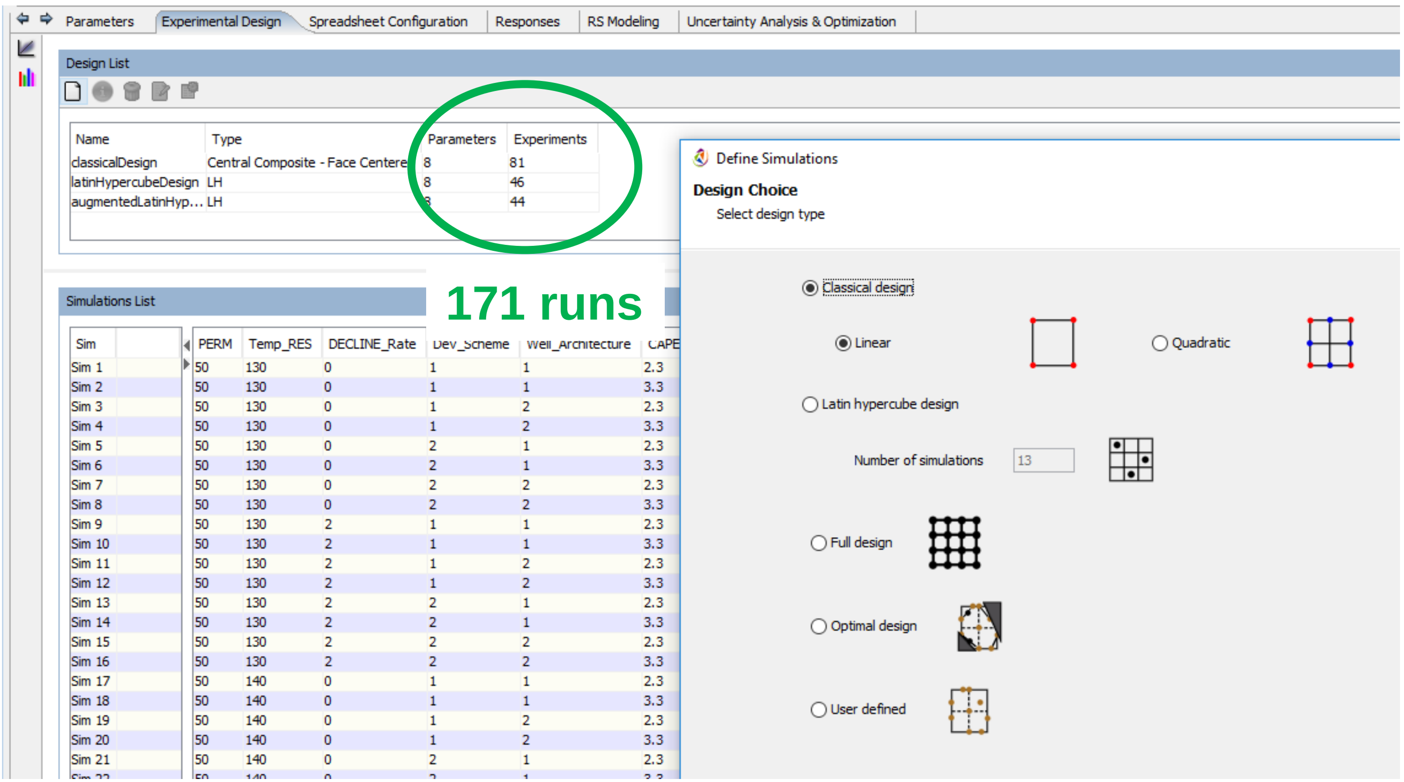
View

	Name	Min Val	Max Val	Mean Val	Type	Unit	Law	Comments	☐ Active	Controllable	Def Val
	PERM	50	100	75	Real		UNIFORM	mD	☑	☐	
(1)	Temp_RES	130	140	135	Real		UNIFORM	°C	☑	☐	135
	P_Interference	0	30	15	Real		UNIFORM	bar	☐	☐	0
	DECLINE_Rate	0	2	1	Integer		UNIFORM	Scalar	☑	☐	0
	FLOWRATE	70	110	90	Real		UNIFORM	l/s	☐	☑	90
(2)	Dev_Scheme	1	2	2	Integer		UNIFORM	Scalar	☑	☑	
	Well_Architecture	1	2	2	Integer		UNIFORM	Inch	☑	☑	
	CAPEX_ORC	2.3	3.3	2.8	Real		UNIFORM	M$/MWe	☑	☐	3
(3)	Pump_Replacement	0.33	2	1.165	Real		UNIFORM	time/y/well	☑	☐	0.5
	Discount_Rate	0.05	0.1	0.075	Real		UNIFORM	%	☐	☐	0.09
	Plant_UpTime	0.9	0.96	0.93	Real		UNIFORM	%	☑	☐	0.94

Real / Integer ; Uncertain / controllable ; active I/O

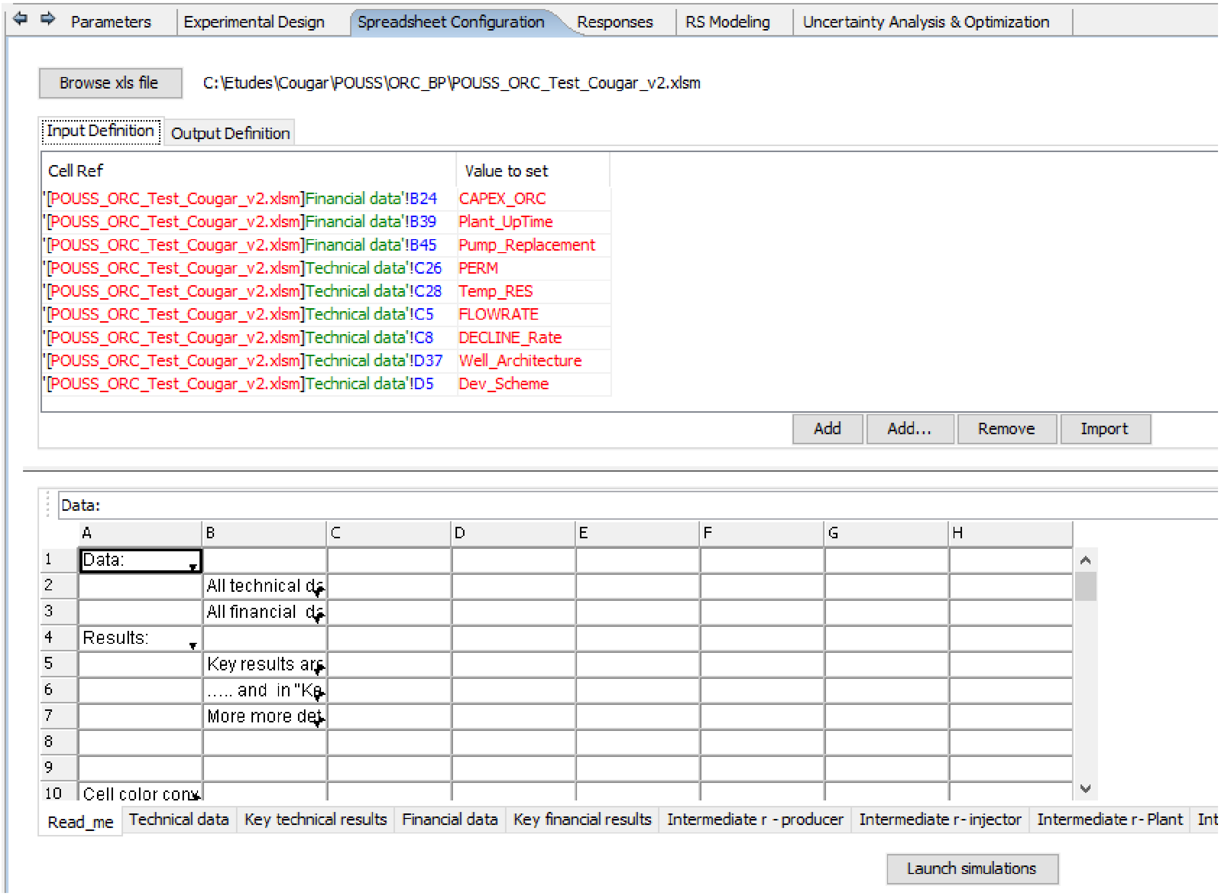
Experimental Designs

- Using Classical and Latin Hyper Cube Experimental Designs



Spreadsheet configuration

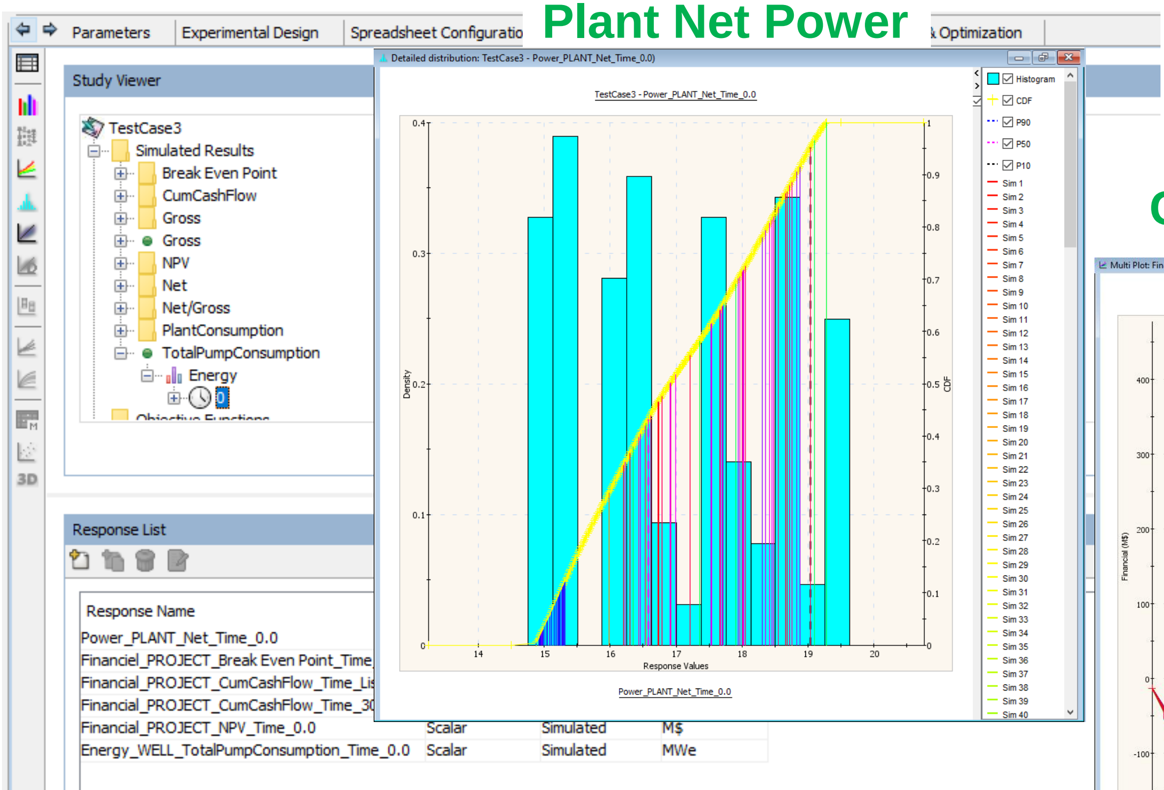
● Configure inputs as well as outputs :



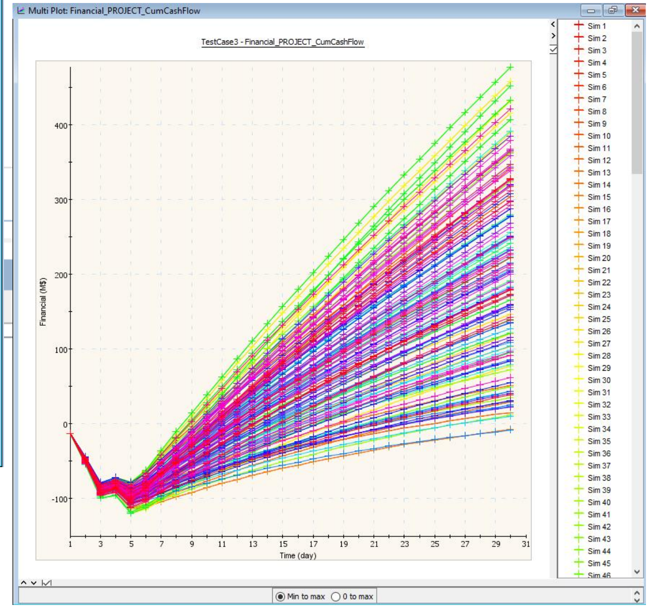
Responses

- Both technical and economic outputs/results from the 171 runs:

Plant Net Power



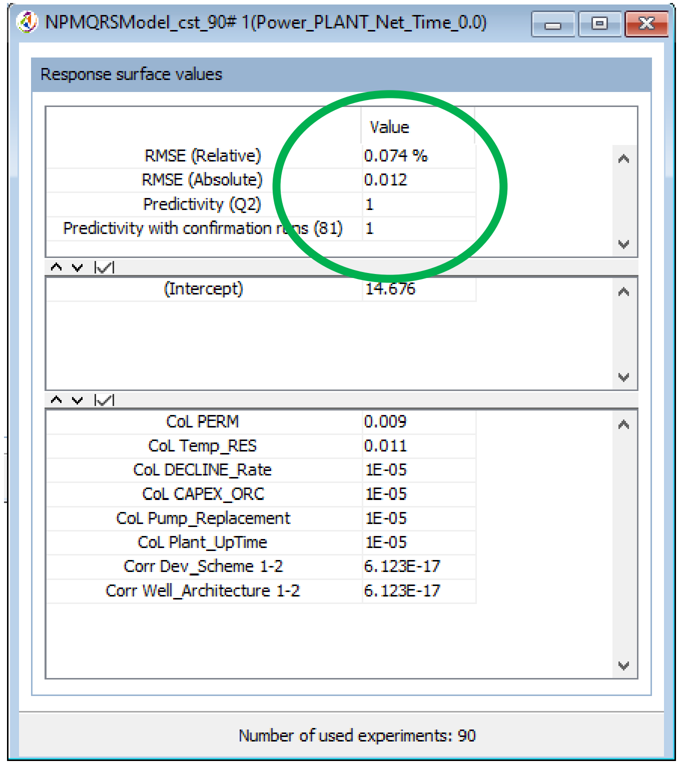
Cumulative Cash Flow



Proxy models computation

- **Mixed-Integer Proxy model computation:**

Key Quality Control steps


NPMQRSModel_cst_90# 1(Power_PLANT_Net_Time_0.0)

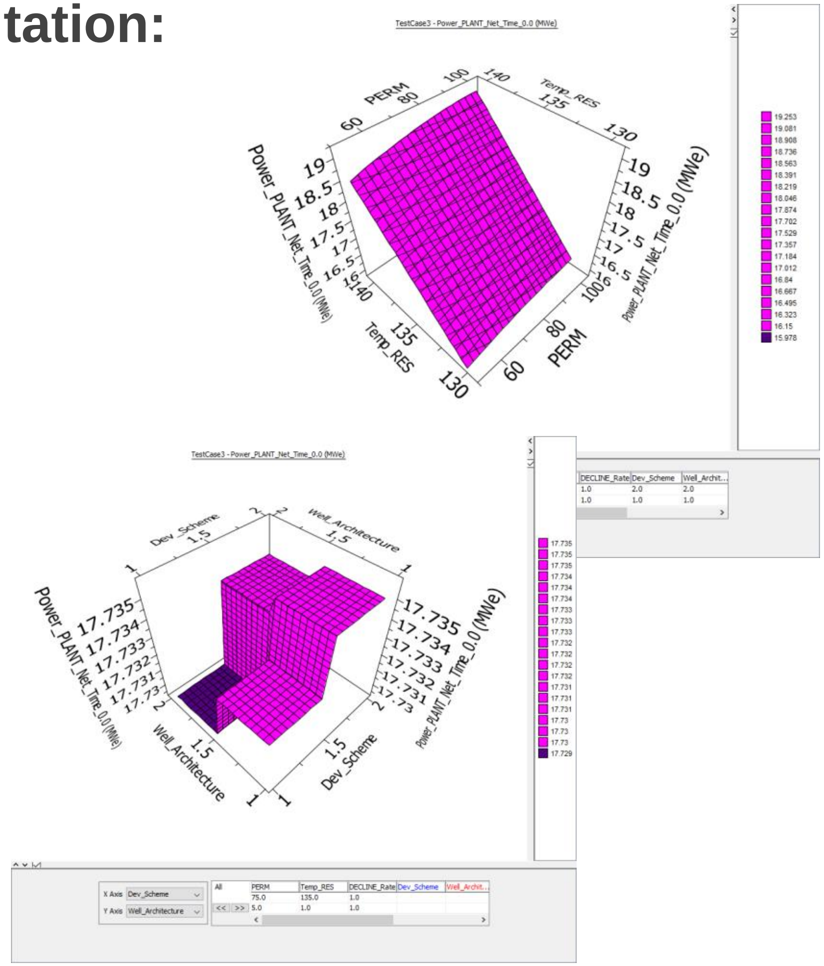
Response surface values

	Value
RMSE (Relative)	0.074 %
RMSE (Absolute)	0.012
Predictivity (Q2)	1
Predictivity with confirmation runs (81)	1

(Intercept)	14.676

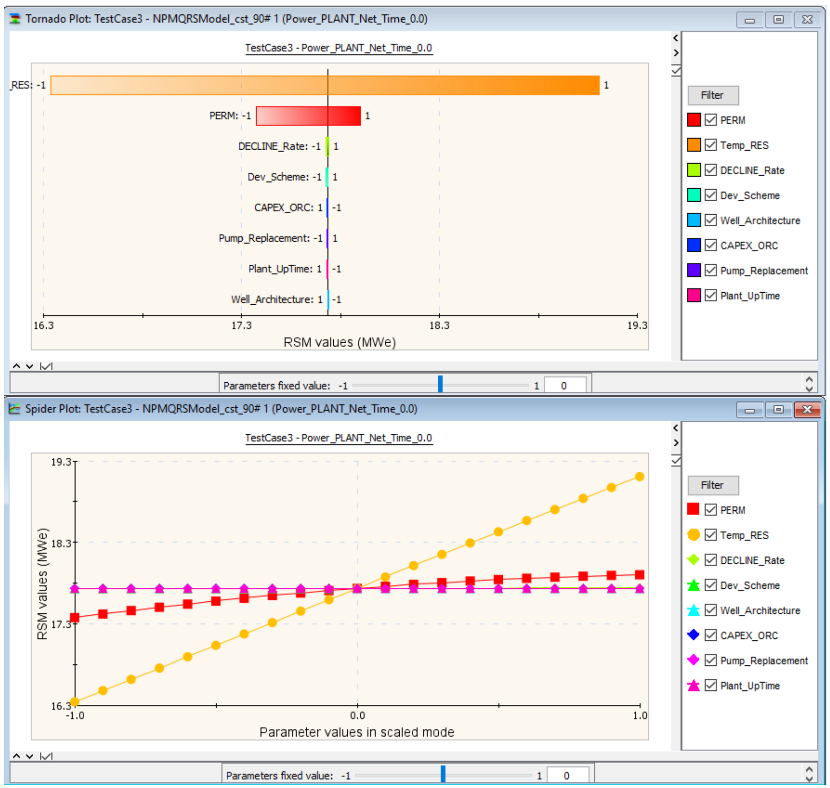
CoL PERM	0.009
CoL Temp_RES	0.011
CoL DECLINE_Rate	1E-05
CoL CAPEX_ORC	1E-05
CoL Pump_Replacement	1E-05
CoL Plant_UpTime	1E-05
Corr Dev_Scheme 1-2	6.123E-17
Corr Well_Architecture 1-2	6.123E-17

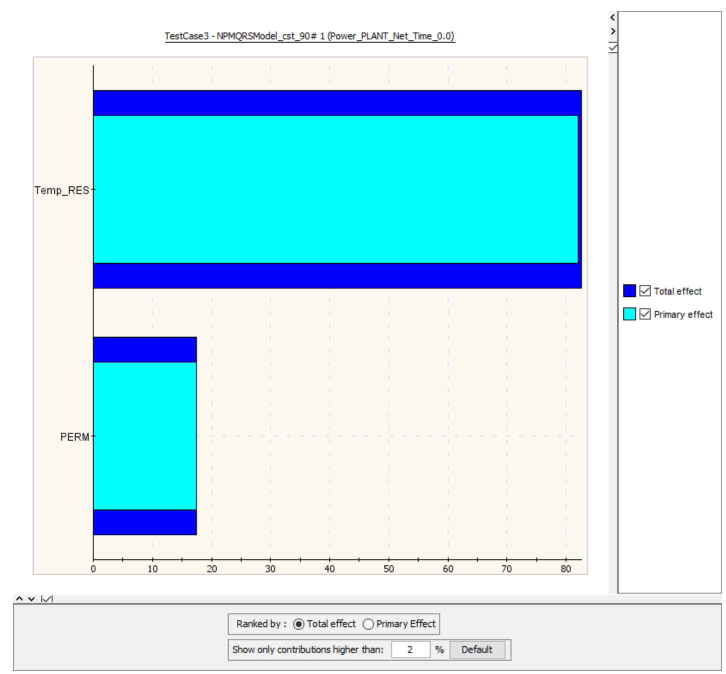
Number of used experiments: 90



Sensitivity Analysis – Technical outputs

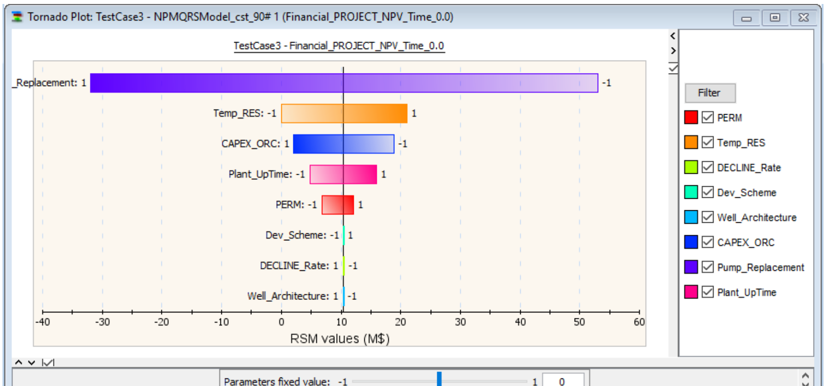
- Standard Tornado & Spider plots – Analysis of the Plant Net Power
- Global Sensitivity Analysis (Sobol coefficients computation)

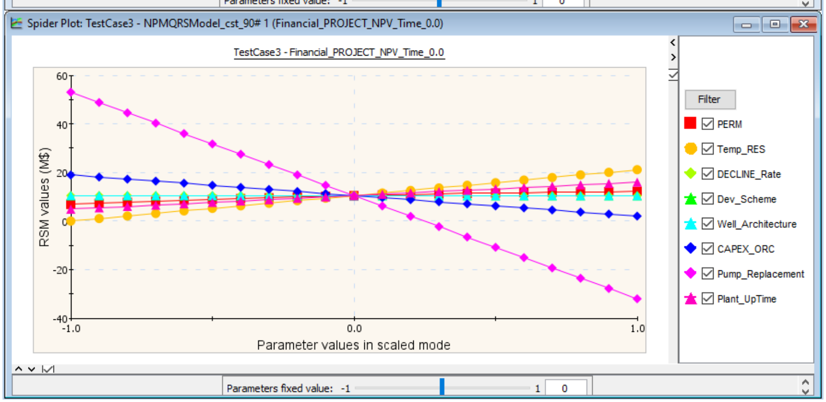


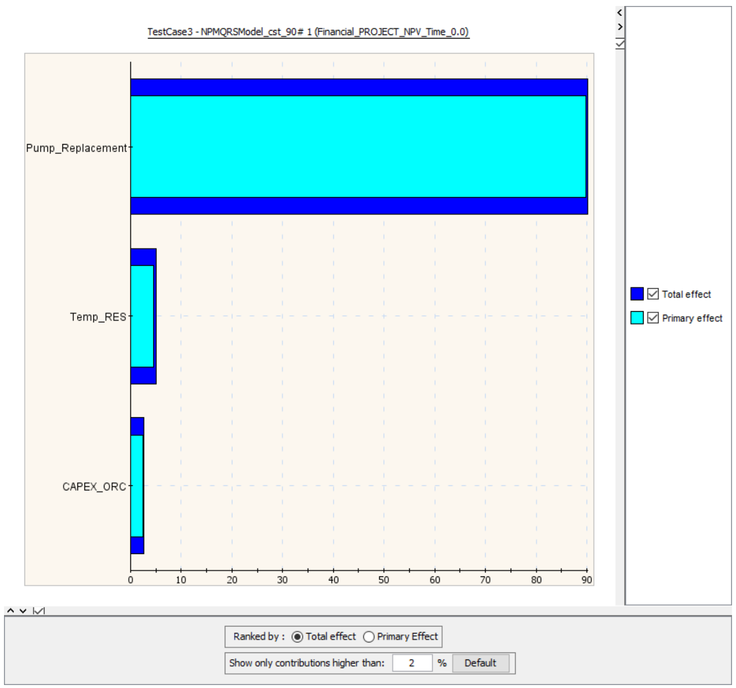


Sensitivity Analysis – Economic outputs

- Standard Tornado & Spider plots – Analysis of the NPV
- Global Sensitivity Analysis (Sobol coefficients computation)







Outline

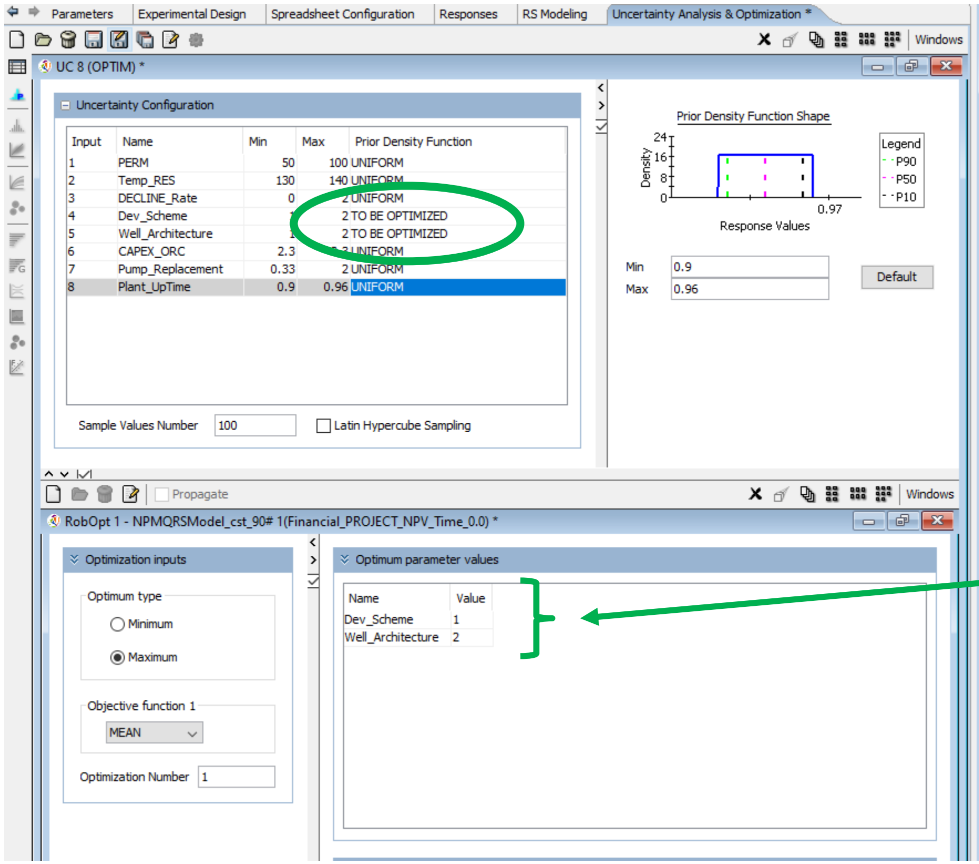
- Common framework : geological reservoir characterization
- Common goal : reliable performance forecasts

- Full system (well+pump+ORC) modelling coupled to a business model
- Experimental Design & proxy model computation
- Sensitivity studies : Technical and economic parameters and outputs
- Optimization of controllable parameters to derive an optimal scheme

- Wrap up and perspectives

Optimization of the development scheme

- Optimizing (<u>under uncertainty</u>) the controllable parameters – Maximizing the NPV



- 3+3 wells development scheme
- Large diameter wellbores

Wrap-up & Perspectives

- **Able to derive an optimal development plan for a HT ORC project**
- **Sensitivity studies and risk analysis were conducted considering:**
  - Technical uncertain and controllable parameters,
  - As well as economic ones,
  - Thus leading to a integrated technical & economic analysis
- **Looking at both technical and economic key outputs**
- **Way forward:**
  - Using multi-objectives optimization : Pareto front
  - On-going discussion with Business Dev. to fine tune the financial part