Simplified sensitivity analysis of uncertainties in common allocation methods – A practical approach

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Introduction

Join Industry Project

Wintershall Dea, Lundin Energy, DNO and NORCE

Goal: Foundation for Best practice for Allocation uncertainty and Risk-Cost-Benefit calculations

This presentation

A practical approach for investigating how allocation uncertainties depend on production rates, product quality and measurement uncertainties

Presentation outline

Motivation

Allocation systems

ORF and ORF uncertainty

System modelling – input / output

Practical implementation – examples of use

Mapping

Correlations

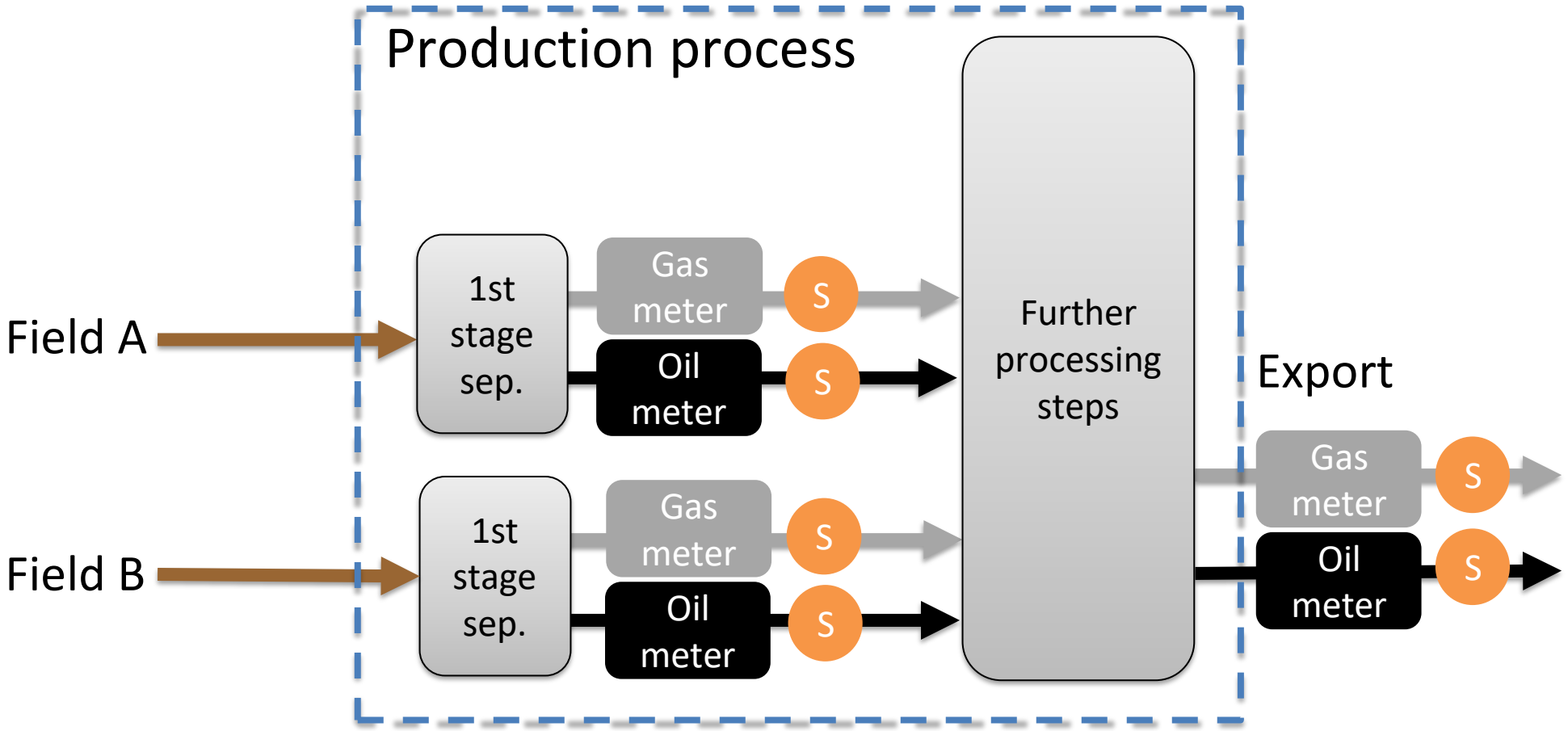
Way forward

All uncertainties are given at 95 % confidence level (k=2)

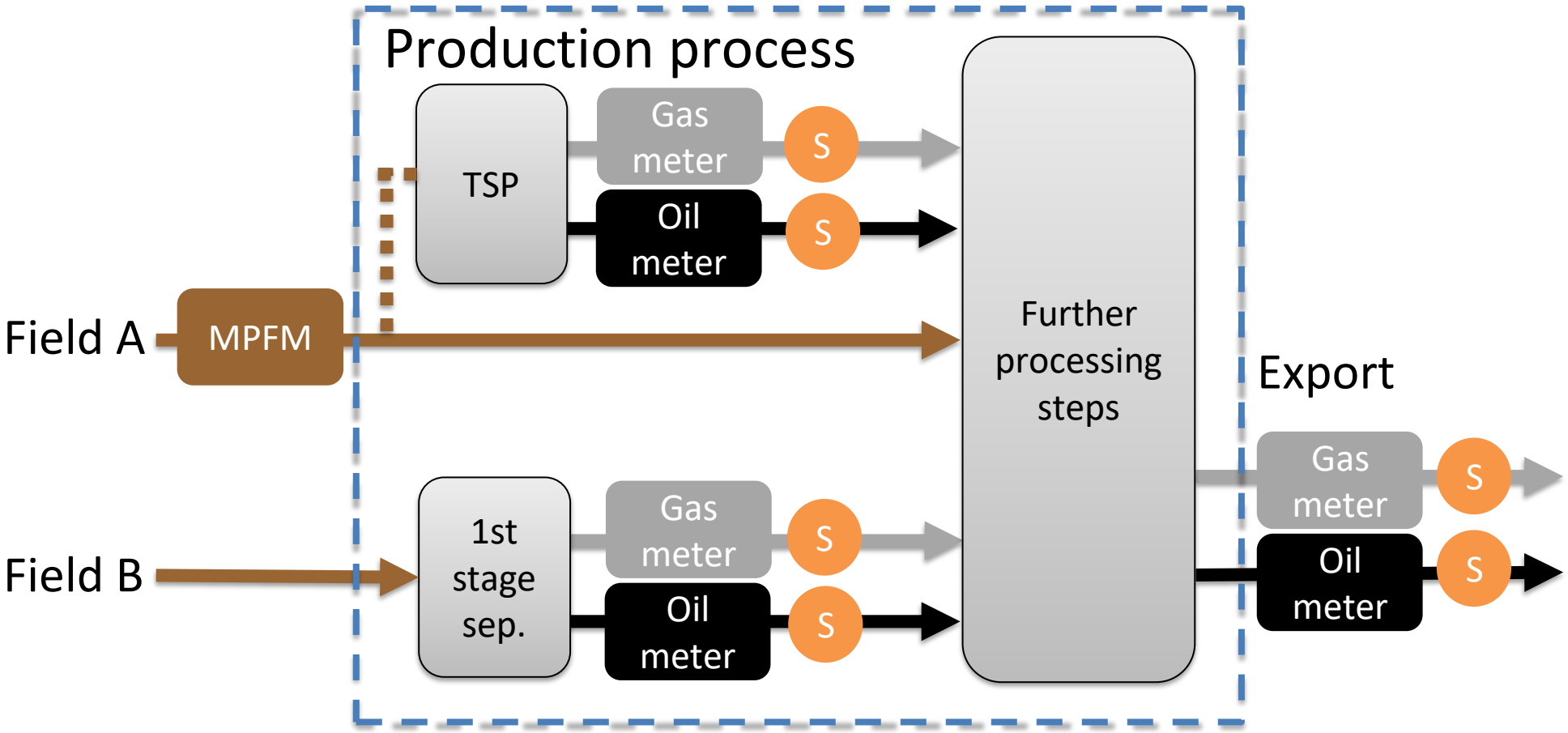
Motivation

- Early project phase planning: Identify and understand relations between production rates, measurement and allocation uncertainties
- Give nuances to and challenge existing understandings
- Establish «rules of thumb»

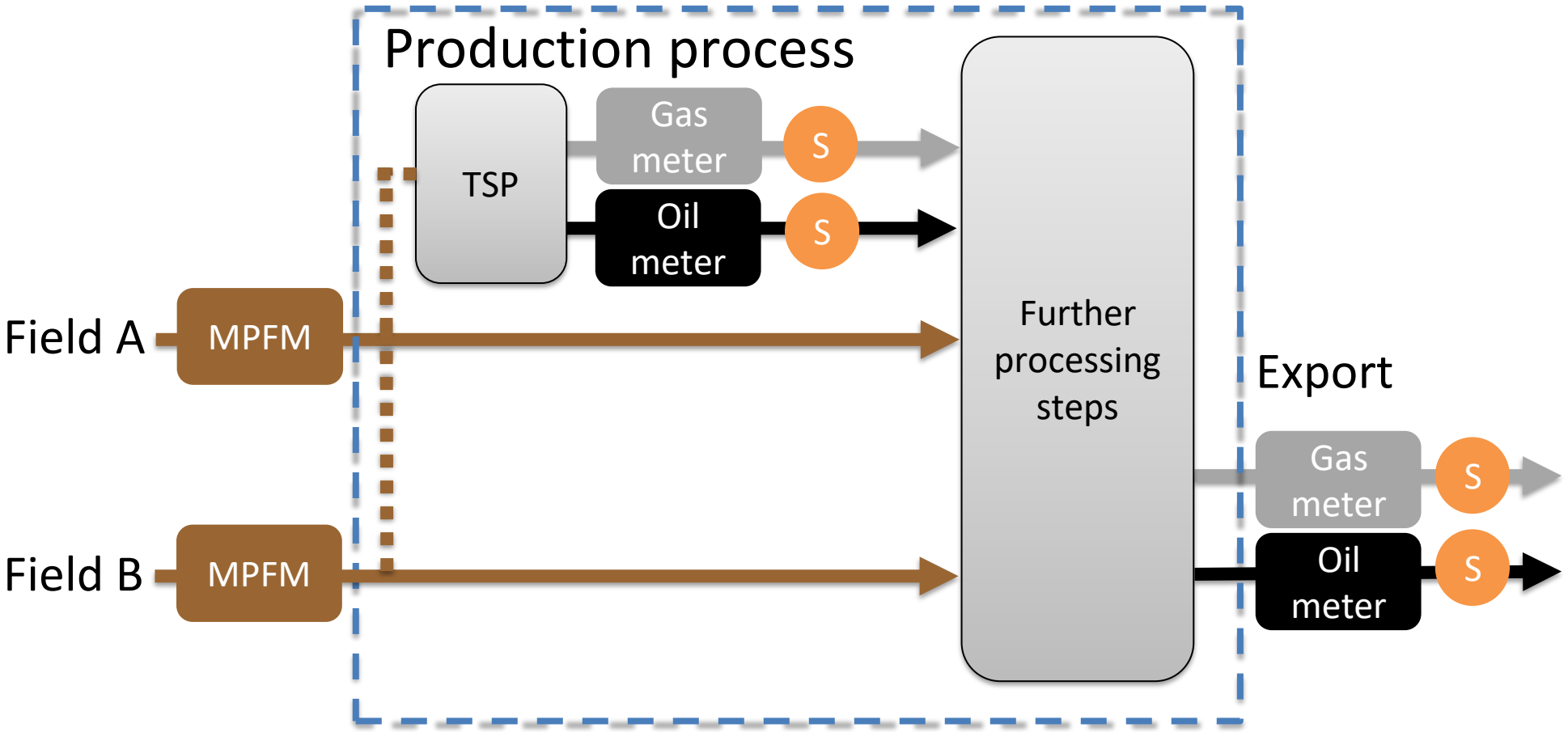
Allocation system



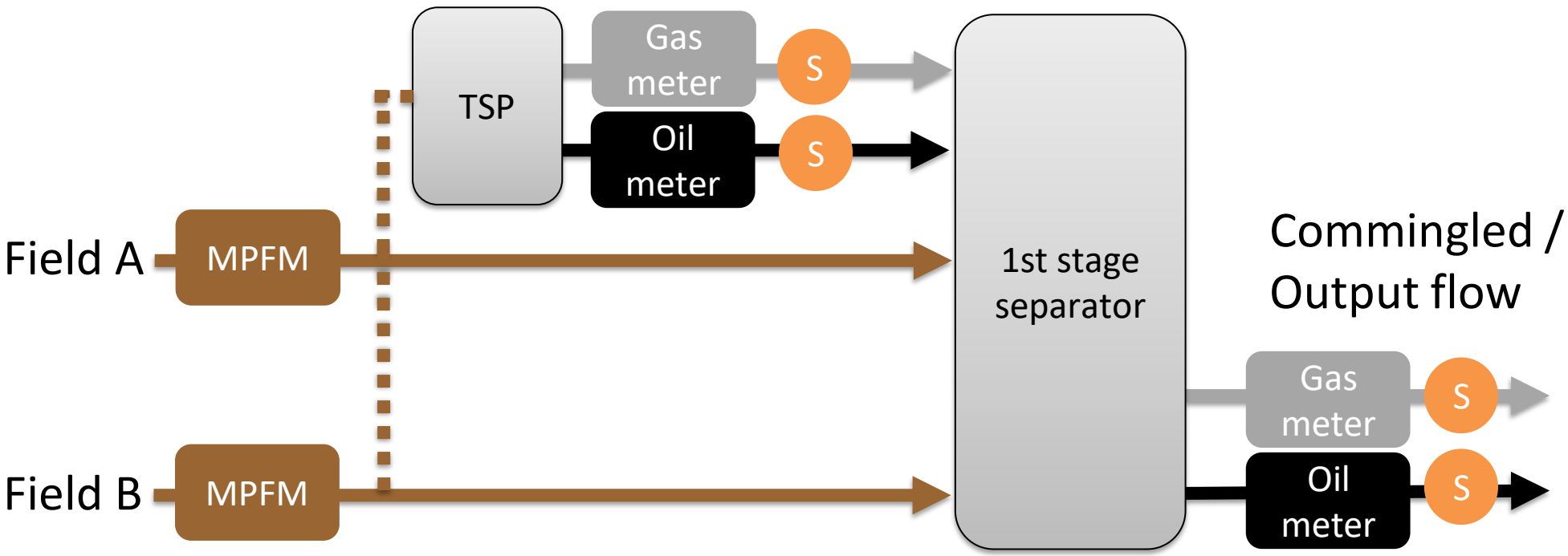
Allocation system



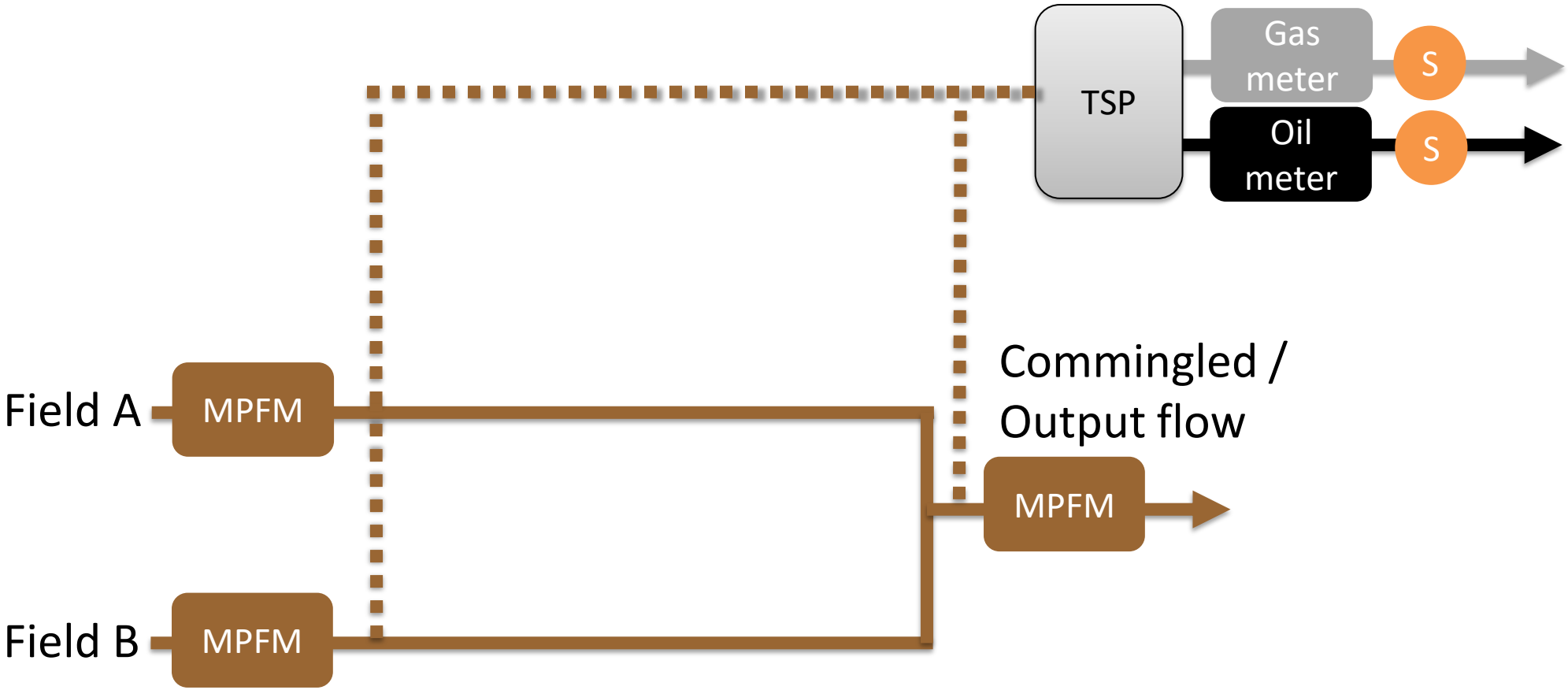
Allocation system



Allocation system



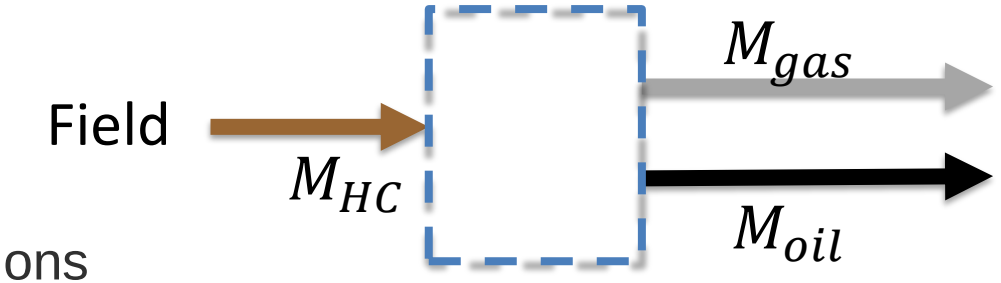
Allocation system



ORF

- Ratio of oil mass out of prosess and hydrocarbon mass in, for a certain field

$$ORF_{field} = \frac{M_{oil}}{M_{HC}}$$



- Can be estimated from stand-alone or all-in simulations
- Estimated by a model of the specific production proces, using simulation programs like HYSYS, UNISIM or PVTsim
- Can be evaluated for individual components (i.e C1, C2, C3, …)
- ORF uncertainty evaluations challenging
  - Here **absolute** ORF uncertainty is used, resulting in lower **relative** uncertainty for heavy products and higher **relative** uncertainty for lighter products

Allocation equations

By-difference, measured field

$$m_{Oil}^{A,all} = m_{Oil}^{A} = m_{HC}^{A} \cdot ORF^{A}$$

$$m_{Gas}^{A,all} = m_{Gas}^{A} = m_{HC}^{A}\left(1 - ORF^{A}\right) = m_{HC}^{A} - m_{HC}^{A} ORF^{A}$$

$$m_{HC}^{A,all} = m_{HC}^{A}$$

By-difference, unmeasured field

$$m_{Oil}^{B,all} = m_{oil}^{export} - m_{Oil}^{A,all}$$

$$m_{Gas}^{B,all} = m_{Gas}^{export} - m_{Gas}^{A,all}$$

$$m_{HC}^{B,all} = m_{oil}^{export} + m_{Gas}^{export} - m_{HC}^{A}$$

Pro-rata

$$m_{Oil}^{A,all} = m_{oil}^{export} \cdot \frac{m_{oil}^{A}}{m_{oil}^{A} + m_{oil}^{B}}$$

$$m_{gas}^{A,all} = m_{gas}^{export} \cdot \frac{m_{gas}^{A,calc}}{m_{gas}^{A,calc} + m_{gas}^{B,calc}}$$

$$m_{HC}^{A,all} = m_{HC}^{export} \cdot \frac{m_{HC}^{A}}{m_{HC}^{A} + m_{HC}^{B}}$$

Analytic uncertainty models, ISO GUM

By-difference, measured field

$$\left(\frac{u\left(m_{Oil}^{A,all}\right)}{m_{Oil}^{A,all}}\right)^2 = \left(\frac{u\left(m_{HC}^{A}\right)}{m_{HC}^{A}}\right)^2 + \left(\frac{u\left(ORF^{A}\right)}{ORF^{A}}\right)^2$$

$$\left(\frac{u\left(m_{Gas}^{A,all}\right)}{m_{Gas}^{A,all}}\right)^2 = \left(\frac{u\left(m_{HC}^{A}\right)}{m_{HC}^{A}}\right)^2 + \left(\frac{-ORF^{A}}{(1-ORF^{A})}\right)^2 \left(\frac{u\left(ORF^{A}\right)}{ORF^{A}}\right)^2$$

$$\left(\frac{u\left(m_{HC}^{A,all}\right)}{m_{HC}^{A,all}}\right)^2 = \left(\frac{u\left(m_{HC}^{A}\right)}{m_{HC}^{A}}\right)^2$$

By-difference, unmeasured field

$$\left(\frac{u\left(m_{Oil}^{B,all}\right)}{m_{Oil}^{B,all}}\right)^2 = \left(\frac{m_{oil}^{export}}{m_{oil}^{export} - m_{Oil}^{A,all}}\right)^2 \left(\frac{u\left(m_{oil}^{export}\right)}{m_{oil}^{export}}\right)^2 + \left(\frac{m_{Oil}^{A,all}}{m_{oil}^{export} - m_{Oil}^{A,all}}\right)^2 \left(\frac{u\left(m_{Oil}^{A,all}\right)}{m_{Oil}^{A,all}}\right)^2$$

$$\left(\frac{u\left(m_{Gas}^{B,all}\right)}{m_{Gas}^{B,all}}\right)^2 = \left(\frac{m_{Gas}^{export}}{m_{Gas}^{export} - m_{Gas}^{A,all}}\right)^2 \left(\frac{u\left(m_{Gas}^{export}\right)}{m_{Gas}^{export}}\right)^2 + \left(\frac{m_{Gas}^{A,all}}{m_{Gas}^{export} - m_{Gas}^{A,all}}\right)^2 \left(\frac{u\left(m_{Gas}^{A,all}\right)}{m_{Gas}^{A,all}}\right)^2$$

$$\left(\frac{u\left(m_{HC}^{B,all}\right)}{m_{HC}^{B,all}}\right)^2 = \left(\frac{m_{oil}^{export}}{m_{HC}^{B,all}}\right)^2 \left(\frac{u\left(m_{oil}^{export}\right)}{m_{oil}^{export}}\right)^2 + \left(\frac{m_{Gas}^{export}}{m_{HC}^{B,all}}\right)^2 \left(\frac{u\left(m_{Gas}^{export}\right)}{m_{Gas}^{export}}\right)^2 + \left(\frac{m_{HC}^{A}}{m_{HC}^{B,all}}\right)^2 \left(\frac{u\left(m_{HC}^{A}\right)}{m_{HC}^{A}}\right)^2$$

Pro-rata

$$\left(\frac{u\left(m_{HC}^{A,all}\right)}{m_{HC}^{A,all}}\right)^2 = \left(\frac{u\left(m_{HC}^{export}\right)}{m_{HC}^{export}}\right)^2 + \left(\frac{m_{HC}^{B,calc}}{m_{HC}^{A,calc} + m_{HC}^{B,calc}}\right)^2 \left(\frac{u\left(m_{HC}^{A,calc}\right)}{m_{HC}^{A,calc}}\right)^2 + \left(\frac{m_{HC}^{B,calc}}{m_{HC}^{A,calc} + m_{HC}^{B,calc}}\right)^2 \left(\frac{u\left(m_{HC}^{B,calc}\right)}{m_{HC}^{B,calc}}\right)^2$$

$$\left(\frac{u\left(m_{Oil}^{A,all}\right)}{m_{Oil}^{A,all}}\right)^2 = \left(\frac{u\left(m_{oil}^{export}\right)}{m_{oil}^{export}}\right)^2 + \left(\frac{m_{oil}^{B,calc}}{m_{oil}^{A,calc} + m_{oil}^{B,calc}}\right)^2 \left[\left(\frac{u\left(m_{HC}^{A}\right)}{m_{HC}^{A}}\right)^2 + \left(\frac{u\left(ORF^{A}\right)}{ORF^{A}}\right)^2\right] + \left(\frac{m_{oil}^{B,calc}}{m_{oil}^{A,calc} + m_{oil}^{B,calc}}\right)^2 \left[\left(\frac{u\left(m_{HC}^{B}\right)}{m_{HC}^{B}}\right)^2 + \left(\frac{u\left(ORF^{B}\right)}{ORF^{B}}\right)^2\right]$$

$$\left(\frac{u\left(m_{gas}^{A,all}\right)}{m_{gas}^{A,all}}\right)^2 = \left(\frac{u\left(m_{gas}^{export}\right)}{m_{gas}^{export}}\right)^2 + \left(\frac{m_{gas}^{B,calc}}{m_{gas}^{A,calc} + m_{gas}^{B,calc}}\right)^2 \left[\left(\frac{u\left(m_{HC}^{A}\right)}{m_{HC}^{A}}\right)^2 + \left(\frac{-ORF^{A}}{(1-ORF^{A})}\right)^2 \left(\frac{u\left(ORF^{A}\right)}{ORF^{A}}\right)^2\right] + \left(\frac{m_{gas}^{B,calc}}{m_{gas}^{A,calc} + m_{gas}^{B,calc}}\right)^2 \left[\left(\frac{u\left(m_{HC}^{B}\right)}{m_{HC}^{B}}\right)^2 + \left(\frac{-ORF^{B}}{(1-ORF^{B})}\right)^2 \left(\frac{u\left(ORF^{B}\right)}{ORF^{B}}\right)^2\right]$$

Input and output parameters

Measured HC mass per field, with uncertainty

Simulated ORFs per field, with uncertainty

Measured export or commingled / output HC mass, with uncertainty

m_{HC}^{A} $U^*(m_{HC}^{A})$

m_{HC}^{B} $U^*(m_{HC}^{B})$

$U^*(m_{HC}^{export})$

ORF^A $U^*(ORF^A)$

ORF^B $U^*(ORF^B)$

Allocation uncertainty equations

$$\left(\frac{u(m_{HC}^{A,all})}{m_{HC}^{A,all}}\right)^2 = \left(\frac{u(m_{HC}^{export})}{m_{HC}^{export}}\right)^2 + \left(\frac{m_{HC}^{B,calc}}{m_{HC}^{A,calc} + m_{HC}^{B,calc}}\right)^2 \left(\frac{u(m_{HC}^{A,calc})}{m_{HC}^{A,calc}}\right)$$

$$\left(\frac{u(m_{Oil}^{A,all})}{m_{Oil}^{A,all}}\right)^2 = \left(\frac{u(m_{oil}^{export})}{m_{oil}^{export}}\right)^2 + \left(\frac{m_{oil}^{B,calc}}{m_{oil}^{A,calc} + m_{oil}^{B,calc}}\right)^2 \left[\left(\frac{u(m_{HC}^{A})}{m_{HC}^{A}}\right)\right.$$

$$\left(\frac{u(m_{gas}^{A,all})}{m_{gas}^{A,all}}\right)^2 = \left(\frac{u(m_{gas}^{export})}{m_{gas}^{export}}\right)^2 + \left(\frac{m_{gas}^{B,calc}}{m_{gas}^{A,calc} + m_{gas}^{B,calc}}\right)^2 \left[\left(\frac{u(m_{HC}^{A})}{m_{HC}^{A}}\right)^2 + \left(\right.\right.$$

or Monte Carlo (MC) simulations

Pro rata and by-difference allocation uncertainty per field for

- HC mass
- Oil mass
- Gas mass

$U^*(m_{HC}^{A,all})$
$U^*(m_{HC}^{B,all})$

$U^*(m_{oil}^{A,all})$
$U^*(m_{oil}^{B,all})$

$U^*(m_{gas}^{A,all})$
$U^*(m_{gas}^{B,all})$

When input parameters are uncertain, is there any use in doing this analysis?

- Measurement uncertainties may be difficult to evaluate and often rely on assumptions
- Production profiles are uncertain and subject to change
- Such an analysis still enables deeper insight into
  - how the combined uncertainty is affected by involved parameters
  - the importance of assumptions regarding expected production profiles, product qualities, and measurement uncertainties

Putting it into practise

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,80	6,3 %	3 %
Field B	0,30	16,7 %	5 %
HC mass fraction A	0,70		
U ORF	0,05		
HC mass fraction B	0,30		

Commingled flow	0,7 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	3,0 %	6,9 %	25,2 %
	Field B	7,4 %	43,7 %	16,9 %
Pro rata	Field A	1,9 %	2,8 %	16,0 %
	Field B	4,1 %	16,2 %	10,7 %

Method for lowest allocation uncertainty	Pro rata	Pro rata	Pro rata
	Pro rata	Pro rata	Pro rata

Case description:

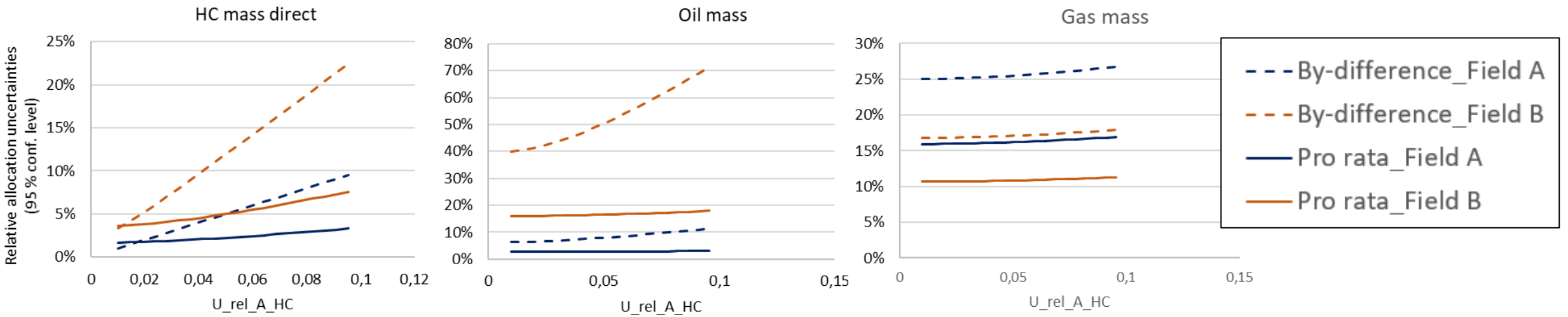
Field A oil producer with low uncertainty, Field B gas producer
Field A largest HC mass production
Low commingled flow measurement uncerainties (equivalent to fiscal measurements)

How will an improvement of field A measurement affect allocation uncertainties?

Case: Field A oil producer > field B gas producer, fiscal export measurements

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,80	6,3 %	3 %
Field B	0,30	16,7 %	5 %
HC mass fraction A	0,70		
U ORF	0,05		
HC mass fraction B	0,30		
Commingled flow			0,7 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	3,0 %	6,9 %	25,2 %
	Field B	7,4 %	43,7 %	16,9 %
Pro rata	Field A	1,9 %	2,8 %	16,0 %
	Field B	4,1 %	16,2 %	10,7 %
Method for lowest allocation uncertainty		Pro rata	Pro rata	Pro rata
		Pro rata	Pro rata	Pro rata

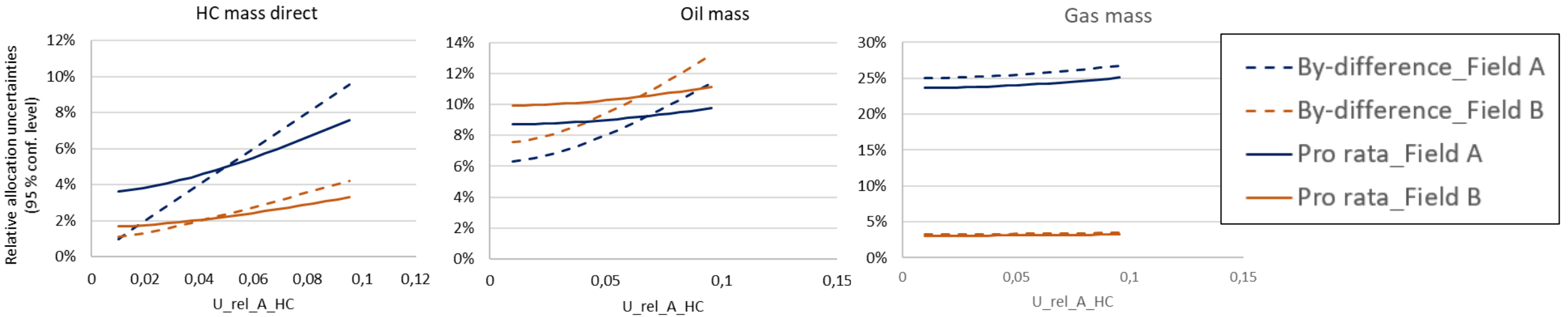


How will an improvement of field A measurement affect allocation uncertainties?

Case: Field A oil producer < field B gas producer, fiscal export measurements

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,80	6,3 %	3 %
Field B	0,30	16,7 %	5 %
HC mass fraction A	0,30		
U ORF	0,05		
HC mass fraction B	0,70		
Commingled flow			0,7 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	3,0 %	6,9 %	25,2 %
	Field B	1,6 %	8,2 %	3,3 %
Pro rata	Field A	4,1 %	8,8 %	23,8 %
	Field B	1,9 %	10,0 %	3,1 %
Method for lowest allocation uncertainty		By-diff	By-diff	Pro rata
		By-diff	By-diff	Pro rata



When will by-difference be the preferred choice?

Case: Mixed producers with comparable production

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,50	10,0 %	5 %
Field B	0,50	10,0 %	17 %
HC mass fraction A	0,50		
U ORF	0,05		
HC mass fraction B	0,50		

Commingled flow	0,7 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	5,0 %	11,2 %	11,2 %
	Field B	5,2 %	11,4 %	11,4 %
Pro rata	Field A	8,9 %	11,4 %	11,4 %
	Field B	8,9 %	11,4 %	11,4 %

Method for lowest allocation uncertainty	By-diff	By-diff	By-diff
	By-diff	By-diff	By-diff

Case description:

Field A mixed producer, Field B mixed producer with high uncertainty
Comparable HC mass production
Low commingled flow measurement uncerainties (equivalent to fiscal measurements)

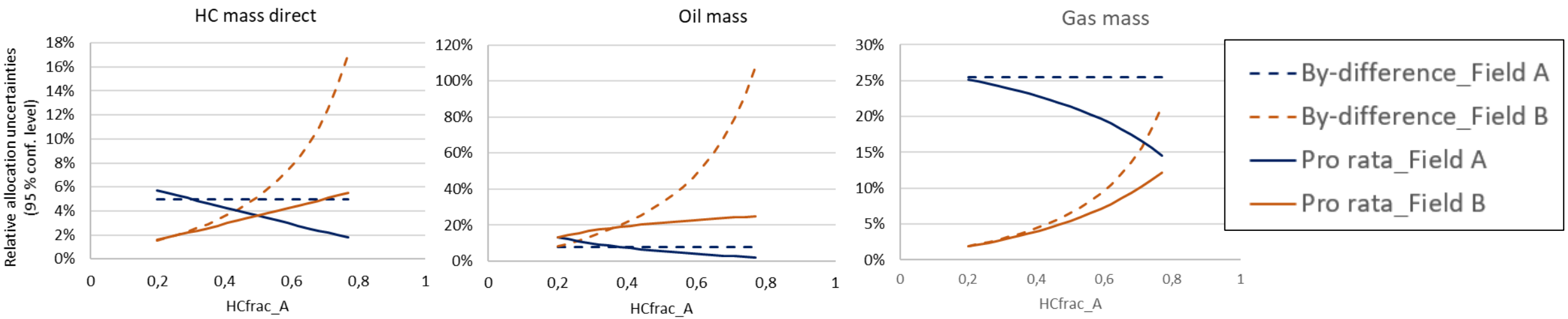
How will the allocation uncertainties evolve with a decreasing field A HC mass fraction?

Case: Field A oil producer, field B gas producer, well-followed up MPFMs, fiscal export measurements

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,80	6,3 %	5 %
Field B	0,20	25,0 %	5 %
HC mass fraction A	0,20		
U ORF	0,05		
HC mass fraction B	0,80		
Commingled flow			0,8 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	5,0 %	8,0 %	25,5 %
	Field B	1,6 %	8,3 %	1,9 %
Pro rata	Field A	5,7 %	13,4 %	25,2 %
	Field B	1,6 %	13,4 %	1,9 %

Method for lowest allocation uncertainty			
	By-diff	By-diff	Pro rata
	By-diff	By-diff	Pro rata



How high can the commingled uncertainty be before field A is better off by-difference?

Case: Mixed producers with comparable production

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,50	10,0 %	5 %
Field B	0,50	10,0 %	5 %
HC mass fraction A	0,50		
U ORF	0,05		
HC mass fraction B	0,50		
Commingled flow			5,7 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	5,0 %	11,2 %	11,2 %
	Field B	12,4 %	19,5 %	19,5 %
Pro rata	Field A	6,7 %	11,2 %	11,2 %
	Field B	6,7 %	11,2 %	11,2 %

Method for lowest allocation uncertainty			
	By-diff	By-diff	By-diff
	Pro rata	Pro rata	Pro rata

Case description:

Field A mixed producer, Field B mixed producer
Comparable HC mass production
High commingled flow measurement uncertainties (equivalent to MPFM)

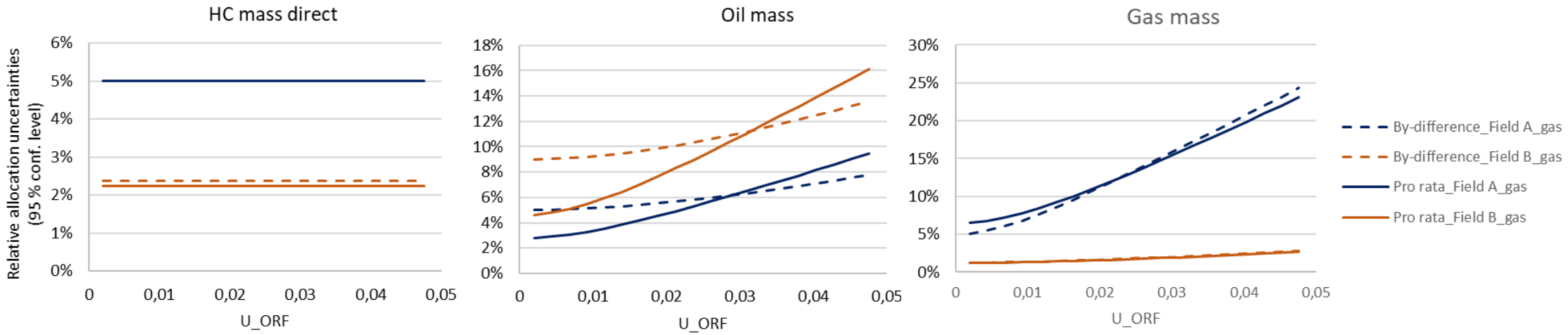
How much are the results affected by assumptions on ORF uncertainty?

Case: Field A oil producer with slightly lower production than field B gas producer

Input parameters	ORF	ORF U*	HC mass U*
Field A	0,80	1,3 %	5 %
Field B	0,20	5,0 %	5 %
HC mass fraction A	0,30		
U ORF	0,01		
HC mass fraction B	0,70		
Commingled flow			0,7 %

Allocation uncertainties		HC mass direct	Oil mass	Gas mass
By-difference	Field A	5,0 %	5,2 %	7,1 %
	Field B	2,4 %	9,2 %	1,3 %
Pro rata	Field A	5,0 %	3,4 %	8,0 %
	Field B	2,2 %	5,6 %	1,3 %

Method for lowest allocation uncertainty	By-diff	Pro rata	By-diff
	Pro rata	Pro rata	Pro rata



Mapping

1. Set realistic limits for all input parameters:

	Field A				Field B			«Export»
	ORF	ORF U	HC mass fraction A	HC U*	ORF	ORF U	HC U*	HC U*
Min	0,01	0,1 %	0,05	1 %	0,01	0,1 %	1 %	0,25 %
Max	0,99	10 %	0,95	30 %	0,99	10 %	30 %	30 %

2. Calculate all output parameters from thousands of different (random) combinations of input parameters

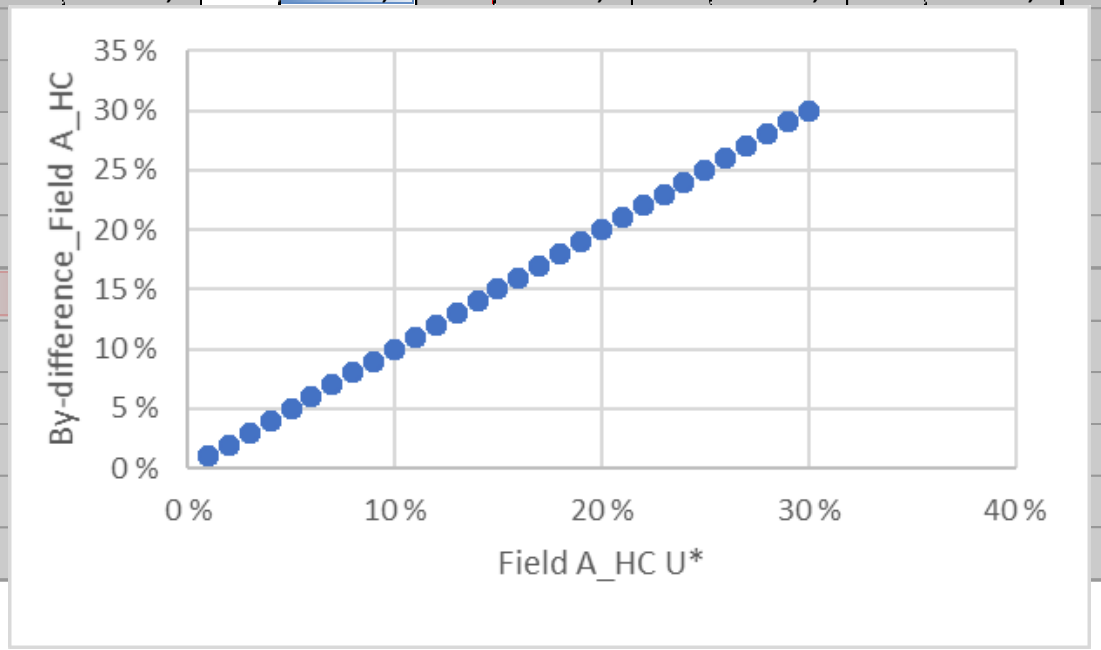
3. Investigate correlations between the inputs and generated outputs. Visualize.

Correlations between input parameters and allocation uncertainties

Allocation uncertainties	Field A_ORF	Field A_ORF U	Field A_HC mass fraction A	Field A_HC U*	Field B_ORF	Field B_ORF U	Field B_HC U*	Mix_HC U*
By-difference_Field A_HC	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0
By-difference_Field A_Oil	-0,4	0,2	0,0	0,1	0,0	0,0	0,0	0,0
By-difference_Field A_Gas	0,4	0,2	0,0	0,1	0,0	0,0	0,0	0,0
By-difference_Field B_HC	0,0	0,0	0,7	0,2	0,0	0,0	0,0	0,2
By-difference_Field B_Oil	0,1	0,0	0,2	0,0	-0,2	0,0	0,0	0,1
By-difference_Field B_Gas	-0,1	0,0	0,3	0,0	0,3	0,0	0,0	0,1
Pro rata_Field A_HC	0,0	0,0	-0,6	0,3	0,0	0,0	0,3	0,6
Pro rata_Field A_Oil	-0,4	0,1	-0,1	0,0	0,0	0,1	0,0	0,1
Pro rata_Field A_Gas	0,4	0,2	-0,1	0,0	0,0	0,0	0,0	0,1
Pro rata_Field B_HC	0,0	0,0	0,6	0,3	0,0	0,0	0,3	0,6
Pro rata_Field B_Oil	0,0	0,0	0,2	0,0	-0,4	0,2	0,0	0,1
Pro rata_Field B_Gas	0,0	0,0	0,2	0,0	0,4	0,1	0,0	0,1

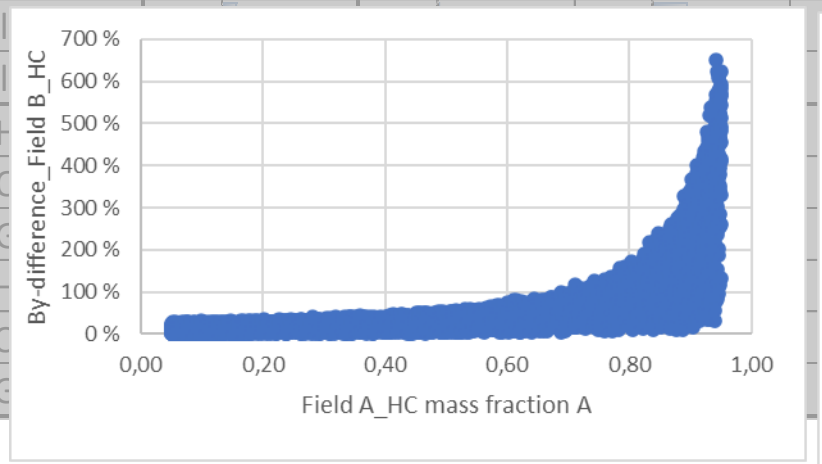
Correlations between input parameters and allocation uncertainties

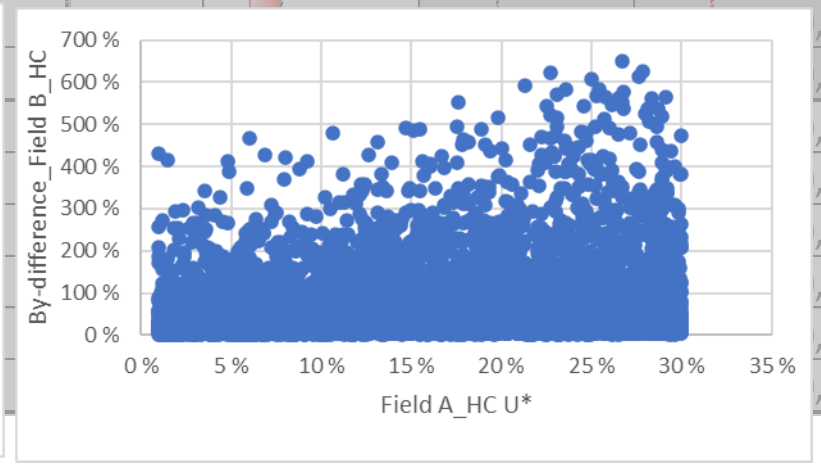
Allocation uncertainties	Field A_ORF	Field A_ORF U	Field A_HC mass fraction A	Field A_HC U*	Field B_ORF	Field B_ORF U	Field B_HC U*	Mix_HC U*
By-difference_Field A_HC	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0
By-difference_Field A_Oil	-0,4	0,2						0,0
By-difference_Field A_Gas	0,4	0,2						0,0
By-difference_Field B_HC	0,0	0,0						0,2
By-difference_Field B_Oil	0,1	0,0						0,1
By-difference_Field B_Gas	-0,1	0,0						0,1
Pro rata_Field A_HC	0,0	0,0						0,6
Pro rata_Field A_Oil	-0,4	0,1						0,1
Pro rata_Field A_Gas	0,4	0,2						0,1
Pro rata_Field B_HC	0,0	0,0						0,6
Pro rata_Field B_Oil	0,0	0,0						0,1
Pro rata_Field B_Gas	0,0	0,0						0,1



Correlations between input parameters and allocation uncertainties

Allocation uncertainties	Field A_ORF	Field A_ORF U	Field A_HC mass fraction A	Field A_HC U*	Field B_ORF	Field B_ORF U	Field B_HC U*	Mix_HC U*
By-difference_Field A_HC	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0
By-difference_Field A_Oil	-0,4	0,2	0,0	0,1	0,0	0,0	0,0	0,0
By-difference_Field A_Gas	0,4	0,2	0,0	0,1	0,0	0,0	0,0	0,0
By-difference_Field B_HC	0,0	0,0	0,7	0,2	0,0	0,0	0,0	0,2
By-difference_Fiel							,0	0,1
By-difference_Fiel							,0	0,1
Pro rata_Field A_H							,3	0,6
Pro rata_Field A_C							,0	0,1
Pro rata_Field A_G							,0	0,1
Pro rata_Field B_H							,3	0,6
Pro rata_Field B_C							,0	0,1
Pro rata_Field B_G							,0	0,1





How will an increase in field As mass fraction affect the pro rata allocation uncertainties?

Allocation uncertainties	Field A_ORF	Field A_ORF U	Field A_HC mass fraction A	Field A_HC U*	Field B_ORF	Field B_ORF U	Field B_HC U*	Mix_HC U*
By-difference_Field A_HC	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0
By-difference_Field A_Oil	-0,4	0,2	0,0	0,1	0,0	0,0	0,0	0,0
By-difference_Field A_Gas	0,4	0,2	0,0	0,1	0,0	0,0	0,0	0,0
By-difference_Field B_HC	0,0	0,0	0,7	0,2	0,0	0,0	0,0	0,2
By-difference_Field B_Oil	0,1	0,0	0,2	0,0	-0,2	0,0	0,0	0,1
By-difference_Field B_Gas	-0,1	0,0	0,3	0,0	0,3	0,0	0,0	0,1
Pro rata_Field A_HC	0,0	0,0	-0,6	0,3	0,0	0,0	0,3	0,6
Pro rata_Field A_Oil	-0,4	0,1	-0,1	0,0	0,0	0,1	0,0	0,1
Pro rata_Field A_Gas	0,4	0,2	-0,1	0,0	0,0	0,0	0,0	0,1
Pro rata_Field B_HC	0,0	0,0	0,6	0,3	0,0	0,0	0,3	0,6
Pro rata_Field B_Oil	0,0	0,0	0,2	0,0	-0,4	0,2	0,0	0,1
Pro rata_Field B_Gas	0,0	0,0	0,2	0,0	0,4	0,1	0,0	0,1

Way forward

- **This work:**
  - Explore additional sensitivity analysis methods
  - Publish in peer-reviewed journal
- **Follow-up JIP**:
  - Current JIP allocation project terminates 2022
  - A continuation can be set up if interest in industry, new partners welcome
  - Forum for collaboration towards establishing industry best practice
- **Some of the open issues which could be further investigated in follow-up JIP**
  - ORF uncertainties
  - Comparison of different allocation methods (per component versus total, use of ORF or not)
  - …

Thank you.

Questions?
Comments?

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