An uncertainty analysis of the potential impact of shale gas on the global energy system

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Outline

- **The shale gas "revolution"**
- ETSAP-TIAM and the modelling of shale gas
- Introducing uncertainty in a energy system model
- (Preliminary) results

The shale gas “revolution”

Future global gas market and its drivers

Global uncertainties as opportunities? (IEA, 2011) **or large uncertainty around key factors?**

- **Widely divergent estimates of shale gas potential: resources** (e.g. USGS recent revisions) **+ cost** ➔ “two key questions about shale gas revolution in US: will it continue or fizzle out; and will it be replicated elsewhere? It is the answers to these questions that generate the enormous uncertainty that is engulfing the global gas market” (Stevens, 2011)
- Future GHG path, nuclear, …

Potential role of unconv./shale gas

- ✓ Natural gas as *ubiquitous* (developed near to markets), *cheap* (gaining market shares), *environmentally benign* source?
- ✓ Revolution in the world energy industry, transforming world energy trade, geopolitics and climate policy?
- ✓ Single global market and LNG deployment (current capacity under-utilization)?
- ✓ Lower gas prices (as in recent years)?
- ✓ Diversification EU energy system
- ✓ RES deployment?
- ✓ …

High uncertainty + “complexity” of global energy system
➔ very different possible directions for global gas market

The shale gas “revolution”

Types of unconventional gas (requiring non-standard drilling techniques)

- *Coal-bed methane (CBM)*
- *Tight gas*
- ***Shale gas***
- *Gas hydrates*
- *Aquifer gas*

Since 2000 shale gas production **from 1% of US production to 20%** in 2009:

“Production of ‘unconventional’ gas in the U.S. has rocketed in the past few years, going beyond even the most optimistic forecasts. It is no wonder that its success has sparked such international interest… A few years ago the United States was ready to import gas. In 2009 it had become the world's biggest gas producer. This is phenomenal, unbelievable.”

Anne-Sophie Corbeau, International Energy Agency

JRC-IET report

“to further enhance its security of supply, Europe’s potential for sustainable extraction and use of conventional and unconventional gas fossil fuels resources should be assessed” (European Council, 2011)

JRC-IET report: THE ECONOMIC IMPACT OF UNCONVENTIONAL GAS IN EUROPE

- European unconventional gas reserves in the global context
- Technology
- The Economic Impact of Unconventional Gas
- Indigenous Production: Understanding the viability unconventional gas
- Modelling the future economic impact of unconventional gas in Europe

Methodology:

- ✓ Evidence based policy and practice (EBPP), systematic review
- ✓ Energy system modelling

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ETSAP – TIAM: regions and Reference Energy System

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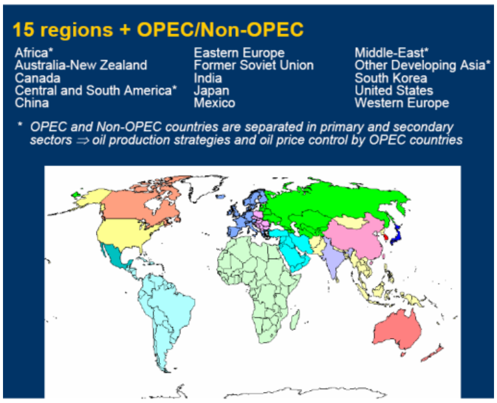

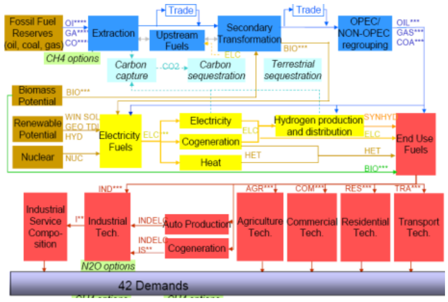

Labriet, Loulou, Kanudia, 2007

Natural gas in TIAM (1): trade

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Review and update of global gas resources and trade (1):

i. Existing and projected infrastructures
ii. trade links for pipeline gas and LNG
iii. Transport costs for inter-regional energy trade: modeled through capacities (existing and new) for pipeline gas and LNG

…

Natural gas pipelines between world regions - 2005

Origin		Destination		Capacity	Capacity	Major Pipelines
Region	Country	Region	Country	PJ/a	bcm/a	
FSU	Russia	WEU	Finland	401	10.6	Finland Connector
FSU		**WEU**		**401**	**10.6**	
FSU	Belarus	EEU	Poland	1,242	33.0	Yamal Pipeline
	Ukraine	EEU	Poland	361	9.6	
	Ukraine	EEU	Slovakia	4,327	114.8	Brotherhood pipeline
	Ukraine	EEU	Hungary	601	15.9	
	Ukraine	EEU	Romania	1,322	35.1	Shebelynka-Izmail Pipeline
FSU		**EEU**		**7,853**	**208.4**	
FSU		**WEU+EEU**		**8,254**	**219.0**	
EEU	Poland	WEU	Germany	1,082	28.7	Yamal Pipeline
	Czech Rep.	WEU	Germany	2,244	59.5	Transgas Pipeline
	Slovakia	WEU	Austraia	2,003	53.2	Trans Austria Gaspipeline (TAG)
EEU		**WEU**		**5,329**	**141.4**	
EEU+FSU		**WEU**		**5,730**	**152.1**	
WEU	Austria	EEU	Slovenia	160	4.2	SOL Pipeline
	Austria	EEU	Hungary	160	4.2	Hungary Austria Gaspipeline (HAG)
WEU		**EEU**		**320**	**8.5**	
AFR	Algeria	WEU	Spain	441	11.7	Maghreb-Europe Gas Pipeline (MEG)
	Algeria	WEU	Italy	1,162	30.8	Transmeditteranean Pipeline (Transmed)
	Libya	WEU	Italy	240	6.4	Green Stream Pipeline
AFR		**WEU**		**1,843**	**48.9**	
FSU	Russia	MEA	Turkey	641	17.0	Blue Stream Pipeline
FSU		**MEA**		**641**	**17.0**	
MEA	Iran	FSU	Azerbaijan	881	23.4	Baku-Astara Pipeline
MEA		**FSU**		**881**	**23.4**	
EEU	Bulgaria	MEA	Turkey	441	11.7	Shebelynka-Izmail Pipeline
EEU		**MEA**		**441**	**11.7**	
CAN		**USA**		**6,868**	**182.2**	
USA		**MEX**		**1,482**	**39.3**	

Natural gas in TIAM (2): resources

… Review and update of global gas resources and trade (2):

iv. Natural gas resources / reserves

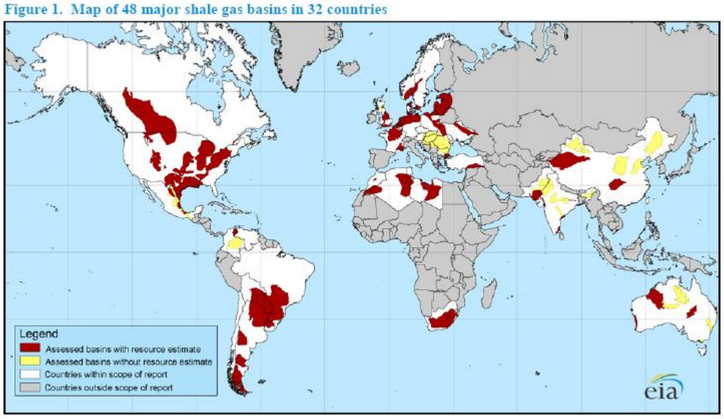
v. Natural gas production costs

IEA - WEO 2011		Africa	Asia /Pacific	Latin Am.	E.Europe & Eurasia	Middle East	OECD North Am.	OECD Europe	WORLD
TOTAL GAS (bcm)		66,000	116,000	73,000	230,000	139,000	137,000	38,000	799,000
Conventional	bcm	28,000	33,000	23,000	136,000	116,000	45,000	22,000	403,000
Non-conventional	bcm	38,000	83,000	50,000	94,000	23,000	92,000	16,000	396,000
tight gas	*bcm*	*9,000*	*20,000*	*15,000*	*11,000*	*9,000*	*16,000*		*80,000*
shale gas	*bcm*	*29,000*	*51,000*	*35,000*		*14,000*	*55,000*	*16,000*	*200,000*
coal-bed methane	*bcm*		*12,000*		*83,000*		*21,000*		*116,000*
Production costs*									
Conventional	*$ / Mbtu*	3 - 7	4 - 8	3 - 8	2 - 6	2 - 7	3 - 9	4 - 9	2 - 9
tight gas	*$ / Mbtu*		4 - 8	3 - 7	3 - 7	4 - 8	3 - 7		3 - 8
shale gas	*$ / Mbtu*						3 - 7		3 - 7
CBM	*$ / Mbtu*		3 - 8		3 - 6		3 - 8		3 - 8

**including phased finding and development capital costs, operating expenditures and decommissioning costs*

Shale gas resources in TIAM: uncertainty

Figure 1. Map of 48 major shale gas basins in 32 countries



bcm	AFR	AUS	CAN	CHI	CSA	EEU	FSU	IND	JPN	MEA	MEX	ODA	SKO	USA	WEU	WORLD
Shale gas (mean)	1,093	-	-	1,922	1,319	-	-	-	-	528	-	-	-	2,073	603	*7,537*
max	*1,386*	*527*		*1,922*	*1,630*	*335*				*528*				*2,569*	*603*	*9,499*
min	*277*	*158*		*425*	*407*	*111*				*6*				*771*	*124*	*2,279*

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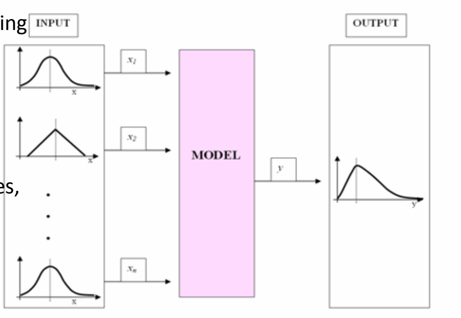
Uncertainty analysis

Uncertainty analysis important part of analyses for complex systems: uncertainty in elements of y resulting from uncertainty in elements of x

A conventional approach: Monte Carlo sampling, by sampling repeatedly from the assumed joint probability density function of the *Xs and evaluating Y for each* sample
➔ reasonable estimates for distribution of Y **if *n is large***



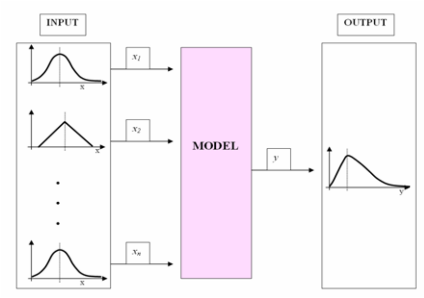
Sampling procedures:
- Simplest ***random*** **sampling**: from uncorrelated variables, each sample element generated independently of all other elements
- **Stratified sampling** has the advantage of forcing the inclusion of specified subsets of sample space while maintaining the probabilistic character of random sampling
- Alternative: constrained Monte Carlo sampling scheme, **Latin hypercube sampling ➔ efficient stratification across the range of each sampled variable**

Uncertainty analysis and TIAM

Objective: to explore a range of possible uncertainties (associated to model inputs)

1. Identification main uncertain parameters
2. Characterize their probability distribution
3. Two methodological requirements:
   - limited number of runs of huge complex models like TIMES
   - for meaningful results, good coverage of the input parameters space

   ➔solution: to sample the joint distribution of the input parameters by space-filling latin hypercube sampling.
4. Model runs as sample size
5. Model results to statistically characterizes the distribution(s) of the outputs



Uncertain parameters

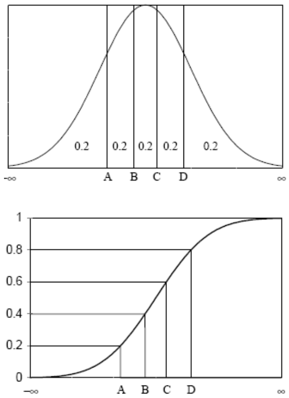
<u>10 input parameters:</u>

- **<u>Shale gas resources</u>** for 8 regions of the model (Africa, Australia, China, Central & South America Eastern Europe, Middle East, USA, Western Europe) ➔ 8 input parameters; *<u>uniform</u>* distributions (equal probability between min & max values)
- **<u>Production cost</u>** ➔ 1 input parameter; *<u>triangular</u>* distribution
- **<u>GDP growth</u>** ➔ 1 input parameter; *<u>triangular</u>* distribution

Sampling

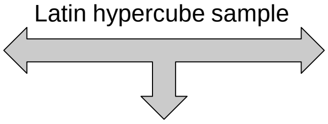
- Generation of the sample for which the model is run : **n** points in 10 dimensional space
- How to generate? ➔ experimental design
- Here ➔ space-filling design ➔ maximin Latin Hypercube Sampling (efficient stratification properties, LHS primarily intended for use with long running models)
  - each input parameter has all portions of its distribution represented (the range of each input parameter is divided into n strata of equal marginal probability and sample once from each stratum)
  - the input space is optimally filled in (here maximizing the minimum distance between the samples points

LHS – a two dimensional representation



Intervals Used with a Latin Hypercube Sample of Size n = 5 in Terms of the Density Function and Cumulative Distribution Function for a Normal Random Variable

A simple example:
Input variables = 2
n = 5
two dimensional representation of the Latin hypercube sample



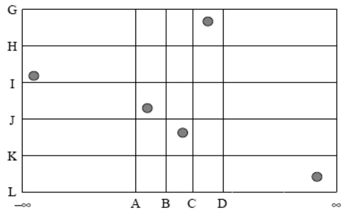
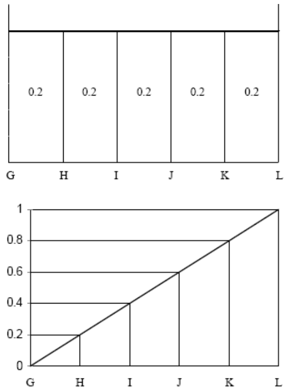
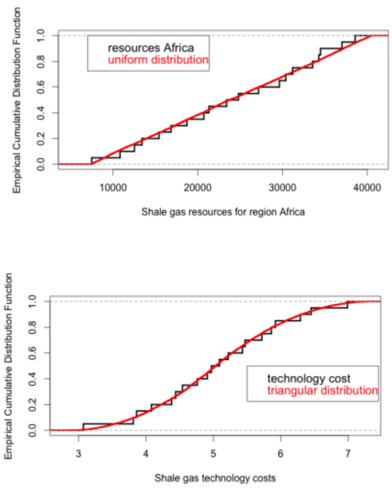


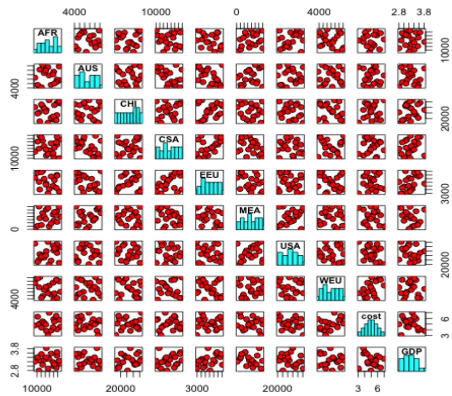
Figure 2-3: A Two-Dimensional Representation of One Possible Latin Hypercube Sample of Size 5 Utilizing X_1 and X_2



Intervals Used with a Latin Hypercube Sample of Size n = 5 in Terms of the Density Function and Cumulative Distribution Function for a Uniform Random Variable

Complete Latin Hypercube Sampling, n=20





- *Pairwise projections*
- *Histograms on the diagonal*
- *Gradually add other points up to n=20, 30, …, 70*

First attempt: design with n=10

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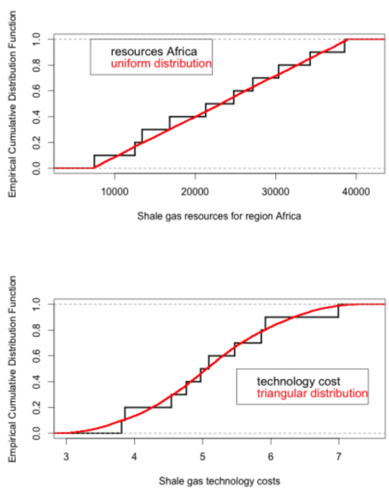

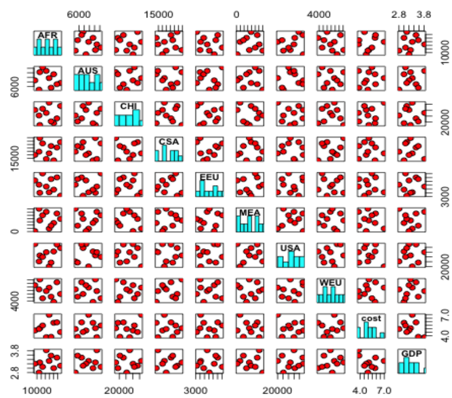

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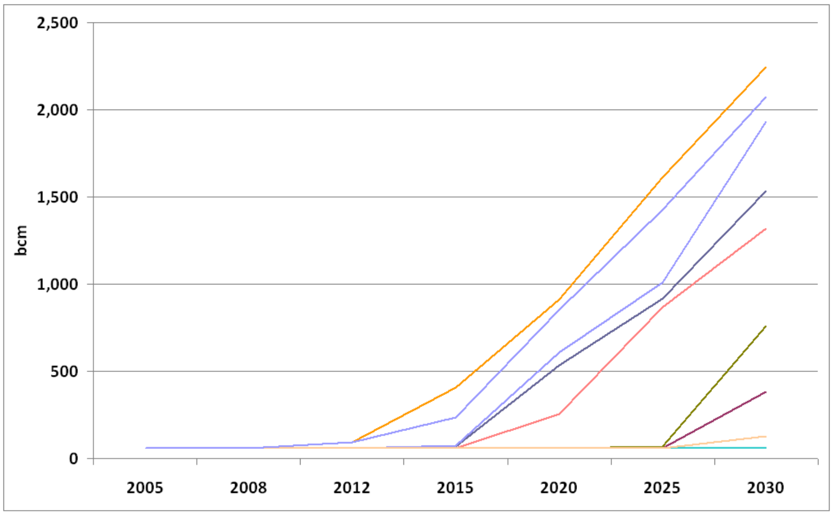
Global shale gas production (n=10)



Global shale gas production: 2 cases

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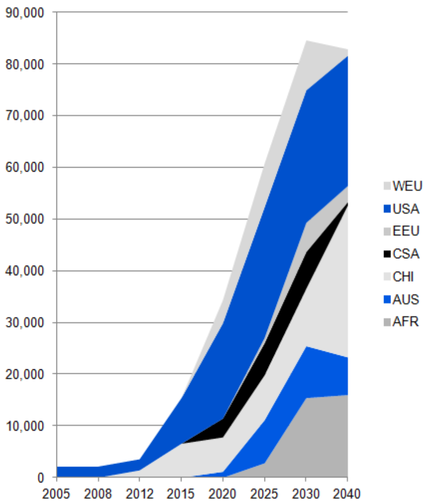

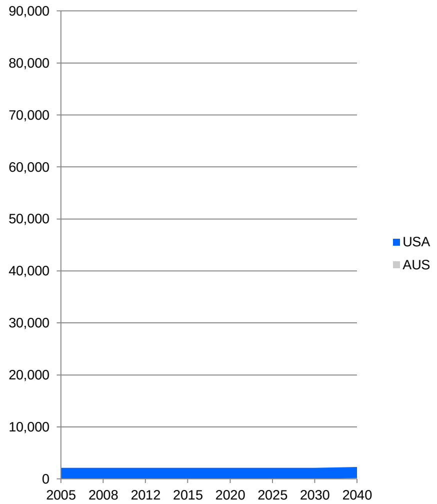

Uncertainty characterization of the outputs (a)

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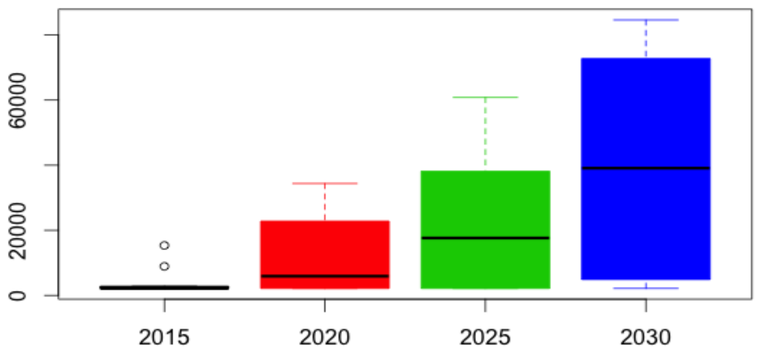
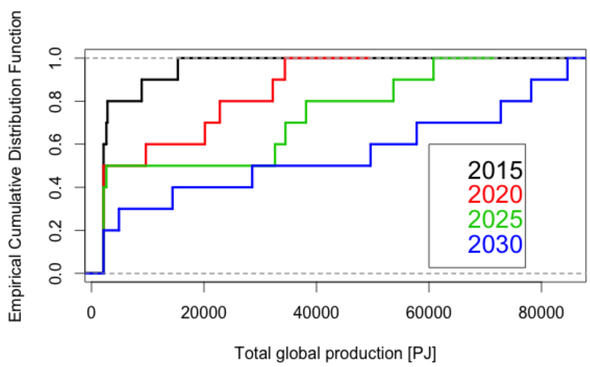
Boxplots for the total global production



A boxplot pictures groups of numerical data using five of their summaries : the smallest observation, lower quartile, median (here in black), upper quartile, largest observation (+outliers)

Uncertainty characterization of the outputs (b)

	2015	*2020*	*2025*	*2030*
mean	4260	12996	23092	39511
median	2142	5904	17633	39091
standard deviation	4425	13228	23518	33021



Pipeline gas - 2005

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Natural gas - Trade Movements 2005 by pipeline

	From															
Billion cubic metres	USA	CAN	MEX	CSA	WEU	EEU	FSU	MEA	Africa	India	China	Japan	South Korea		ODA	Total
To																
USA		104.2	0.0													104
Canada	10.1															10
Mexico	10.1															10
S. & Cent. America																-
Western Europe							91.5		41.8							133
EEU					5.4		44.6		0.4							50
Former Soviet Union																-
MEA							23.6		1.1							25
AFR																-
India																-
China																-
Japan																-
South Korea																-
Australia																-
ODA																-
	20.3	104.2	0.0	-	5.4	-	159.7	-	43.4	-	-	-	-	-	-	332.9

Impact of shale gas on trade

Natural gas - Trade Movements by pipeline 2030

To	USA	CAN	MEX	CSA	WEU	EEU	FSU	MEA	Africa	India	China	Japan	South Korea	Australia	ODA	Total
USA		30	0	0												30
Canada	67															67
Mexico	46															46
CSA																-
WEU				0		98	25	0	291							414
EEU					2		55	0								57
FSU																-
MEA							7		0							7
AFR																-
India								95	0							95
China							190									190
Japan							0									-
South Korea							0				12					12
Australia																
ODA							90									90
	113	30	-	-	2	98	366	95	291	-	12	-	-	-	-	1,005

Shale gas resources = 6,072 EJ
Prod. Cost (avg) = 3.8 $/MBtu
GDP growth (world) = 3.8% p.a.

- **Shale gas production = 2245 bcm**

Natural gas - Trade Movements by pipeli 2030

To	USA	CAN	MEX	CSA	WEU	EEU	FSU	MEA	Africa	India	China	Japan	South Korea	Australia	ODA	Total
USA		30	0	0												30
Canada	86															86
Mexico	39															39
CSA																-
WEU				0		248	161	0	36							445
EEU					2		154	169								324
FSU																-
MEA							7		0							7
AFR																-
India								95	0							95
China							190									190
Japan							0									-
South Korea							0				0					-
Australia																
ODA							89									89
	126	30	-	-	2	248	600	263	36	-	-	-	-	-	-	1,304

Shale gas resources = 5,547 EJ
Prod. Cost (avg) = 5.9 $/MBtu
GDP growth (world) = 3.3% p.a.

- **Shale gas production = 57 bcm**

thanks