Shale gas revolution in Poland – challenges with replication of the US success

Jacek Hendel, Szymon Kuczyński, and Andrzej P. Sikora

Abstract**—**In 2011, International Energy Agency announced that the world is entering a golden age of natural gas. Due to discovery of new hydrocarbons traps and large scale implementation of profitable unconventional gas extraction (tight, CBM, shale), global natural gas reserves to production ratio (R/P ratio) has been stagnated almost at this same level, for over 30 years, even though dramatic increases in gas production is evident. However, unconventional gas revolution started in US has not covered the rest of the world yet. In this review paper brief estimates of unconventional gas are discussed. Global shale gas potential as well as US basin production are pointed out. Shale gas revolution on North America and global energy markets are discussed. Main theme of this work is to compare US and Polish shale gas extraction experience. History data of drilling rigs working on American and Polish shale basins are presented. In addition, dropping of interest of shale gas extraction in Poland is illustrated and discussed.

Keywords**—**shale gas resources, unconventional hydrocarbons, concessions, natural gas resources.

I. Introduction

In 2011, the International Energy Agency (IEA) in World Energy Outlook contemplated if the world is entering a golden age of natural gas [1]. Instructively, IEA pointed out that natural gas is the most environmentally friendly source of energy derived from fossil-fuels and should have a greater role in the global energy mix. The use of natural gas as an energy carrier generates the least air pollution, as well as greenhouse gas (GHG) emissions derived from fossil fuels [1]-[4]. It should be noted that unconventional gas resources such as tight gas, coalbed methane (CBM) and especially shale gas, are much more widely dispersed and far-reaching than oil resources [1] as presented in many reports and scientific papers [5]-[10], all studies, reports and others papers concerning shale gas resources and reserves are reviewed and summarized by McGlade and others [11]. Moreover, references indicate a recoverable resources pyramid including unconventional natural gas and oil reserves presents a greater yield than the conventional only resource pyramid. The International Energy Agency calculated that conventional recoverable resources would provide supply for 120 years of global consumption, but when unconventional would be added, reserves will be sustain for over 250 years [1]. In 1993 natural gas proved reserves were estimated at 118,4 Tcm (trillion cubic meters). At the end of 2003 it was 155,7 Tcm and at the end of 2013 proved reserves was calculated at 185,7 Tcm [12]. At this time, the global natural gas production was at levels: 2,05 Tcm, (1993), 2,62 Tcm (2003) and 3,37 Tcm in 2013 respectively [12]. According to British Petroleum [12] due to discovery of new hydrocarbons traps and large scale implementation of profitable unconventional gas extraction (tight, CBM, shale), global natural gas reserves to production ratio (R/P ratio) has been stagnated almost at this same level, for over 30 years, even though dramatic increases in gas production is evident [12]. Because of technical developments and "shale fever", the global R/P ratio has never has fallen below the level 50 although natural gas production increased by 140% between 1980 (1,43 Tcm) and 2013 (3,36 Tcm) [12]. This unconventional hydrocarbons revolution has a significant impact on regional and global gas and energy markets [11]. The increased potential of energy generation from natural gas and national capability and increased opportunities offered by shale gas extraction will be considered within this paper.

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J. Hendel is employee of the AGH University of Science and Technology, Krakow, POLAND, Faculty of Drilling, Oil and Gas, Department of Natural Gas Engineering (corresponding author: phone: +48 609 048 739; e-mail: hendel@agh.edu.pl).

S. Kuczyński, is employee of the AGH University of Science and Technology, Krakow, POLAND, Faculty of Drilling, Oil and Gas, Department of Natural Gas Engineering (e-mail: szymon.kuczynski@agh.edu.pl).

A. P. Sikora, is employee of the AGH University of Science and Technology, Krakow, POLAND, Faculty of Drilling, Oil and Gas, Department of Natural Gas Engineering (e-mail: andrzej.sikora@agh.edu.pl).

II. Terms and Definitions Concerning to Natural Gas Resources

The best known mineral resource classification was created by Vincent Ellis McKeley and is called McKeley Box. There were several classifications systems used in the 20th century: the Former Soviet Union system in 1920s, Society of Petroleum (SPE) definition of proved reserves 1965; McKelvey Box 1972; SPE definitions for probable and possible reserves 1987; World Petroleum Congresses (WPC) resource systems and definitions 1987; SPE/WPC reserve definitions 1997, SPE/WPC/AAPG (American Association of Petroleum Geologists) resource definitions and classification systems from 2000 [13] and finally, the newest classification SPE/WPC/AAPG/SPEE/SEG (SPEE - Society of Petroleum

Evaluation Engineers; SEG - Society of Exploration Geophysicists). History of petroleum reserves and resources definitions are describe in SPE Guidelines [14]. Sometimes, other contradictions occur because of inappropriate terminology used by SPE and other institutions (e.g. term 'undiscovered' has divergent meaning in SPE and US Geological Survey terminology) [11], [14]. Based on McGlade et al. [11] work, several key definitions are explained in Table I.

Table I. Basic definitions for natural gas estimations [11]

Term	Abbreviation	Meaning
Original Gas In Place	OGIP	Total volume of natural gas that is trapped in gas reservoir (filed, play or region). The ratio of technically recoverable volume of gas to OGIP is known as *recovery factor*
Ultimate Recoverable Resources	URR	Volume of producible natural gas from well/play/region from beginning to the end of exploitation
Estimated Ultimate Recovery	EUR	Similar term to URR but commonly used to estimate single well gas potential, not region
Technically Recoverable Resources	TRR	Total volume of natural gas estimated to be producible with current technology, without consideration of exploitation profitability
Remaining Technically Recoverable Resources	RTRR	TRR with subtracted cumulative production from beginning to moment of RTRR estimation
Economically Recoverable Resources	ERR	ERR is a subset of TRR. It is total volume of gas that could be produced with current technology and makes project profitable. Other words, its estimated resource that are economically and technically producible.
Reserves		Part of discovered resources that have a particular chance to be produced.
Proved Reserves (1P)		Reserves that have 90% probability of being exceeded*
Proved plus **P**robable Reserves (2P)		Reserves that have 50% probability of being exceeded*
Proved plus **P**robable plus **P**ossible Reserves (3P)		Reserves that have 10% probability of being exceeded*

* there are also other definitions of 1P, 2P and 3P reserves. For more information see [14].

III. Short outlook of unconventional gas estimations

Between 1990 and 2012, more than 70 papers and official reports, estimating country, regional and global unconventional gas resources have been prepared [11]. Total number of reports (both official and unofficial) including academic articles and other analysis which concern US evolutions, evidences and challenges connected with shale revolution, has reached more than 167 papers till 16 August 2014 [15].The best known official reports are Annual Energy Outlooks drawn up by EIA and covered US hydrocarbons basins reserves. In 1997 and 1998 ERR were estimated. From 1999 till now TRR estimates are published [11]. Well recognized analysis and reports should be also pointed out. First European shale OGIP estimation was performed by Rogner [16] at 15,5 Tcm (549 Tcf). Wood Mackenzie and IHS Cambridge Energy Research Associates (IHS CERA) estimated TRR for Europe in January and February 2009 respectively. Wood Mackenzie reported shale gas TRR in Europe between 4,25 to 5,66 Tcm (150 Tcf and 200 Tcf) and IHS CERA between 3 to 12 Tcm [17]-[19]. World Energy Council assessed shale OGIP for nine continental regions in September 2010 [20], [11]. Other global estimates of shale gas potential were made by: Advanced Resources International (ARI) for EIA in April 2011 [9], by Medlock et al. in July 2011 [21], Bundesanstalt für Geowissenschaften und Rohstoffe in February 2012 [6], and McGlade [11]. For US and/or Canada, or other single countries, there were more than 30 estimations published. Extensive database and knowledge about shale gas reserves and estimates are covered in McGlade et al. article [11], as well as in Melikoglu paper [22]. In this paper shale gas potential will be estimated from EIA Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States from June 2013, prepared by EIA and ARI [23].

IV. Global shale gas potential

According to EIA [23], global shale gas risked TRR are estimated for 206,7 Tcm (7299 Tcf) and according to ARI, in this same report, 220,7 Tcm (7795 Tcf) The total amount of risked Gas In-Place (GIP) was assessed at 1013,2 Tcm (35782 Tcf). Shale gas reserves are divided between continents quite evenly. Estimates are presented in table II.

North America covered nearly 30% of worldwide share gas TRR. Shale gas shares of South America, Europe, Africa and Asia are in range between 13% to 18,4% of global TRR potential. Australia has almost 6% of global TRR [23]. Global recovery factor is approximately 21% (with ARI U.S.' TRR estimations) [23].

Presented in Table II, global shale gas TRR is rather equally distributed around the world, however, ten countries with the greatest risked TRR, control over 80% of global TRR. China with TRR estimated at 31,6 Tcm, has over 14% of global TRR, as well as U.S. (32,9 Tcm). China, behind US, is the largest shale gas reserves owner with the most energy-intensive market, what, with strongly determined government, makes China perfect destination for oil & gas companies [22], [24].

However, administrative, industrial and monopoly-created barriers [25], as well as environmental issues [26] could slow down a Chinese energy revolution. Argentina has assessed TRR at 22,7 Tcm (more than 10% of global) and it is the world's second biggest shale gas formation owner - Vaca Muerta [22], [27], Algeria 20 Tcm (9%), Canada and Mexico 16,2 Tcm and 15,4 Tcm respectively (7% each one), Australia

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and Republic of South Africa 5,6% and 5,0% of global (12,4 Tcm and 11,0 Tcm, respectively) and finally, Russia with 8,1 Tcm (3,7%) and Brazil 6,9 Tcm (3,1% of global TRR) [23]. Similar values were used to prepare Fig.1 by Chen [28].

Table II. Worldwide shale gas potential by continents [23]

Continent	Risked GIP [Tcf]	Risked GIP [Tcm]	Risked GIP % of total	Risked TRR [Tcf]	Risked TRR [Tcm]	Risked TRR % of total
North America (ex.US)	4647	131,6	13,0%	1118	31,7	14,3%
U.S. (according to ARI)	4644	131,5	13,0%	1161	32,9	14,9%
Australia	2046	57,9	5,7%	437	12,4	5,6%
South America	6390	180,9	17,9%	1431	40,5	18,4%
Europe	4895	138,6	13,7%	883	25,0	11,3%
Africa	6664	188,7	18,6%	1361	38,5	17,5%
Asia	6495	183,9	18,2%	1403	39,7	18,0%
TOTAL	**35781**	**1013,2**	**100%**	**7794**	**220,7**	**100%**

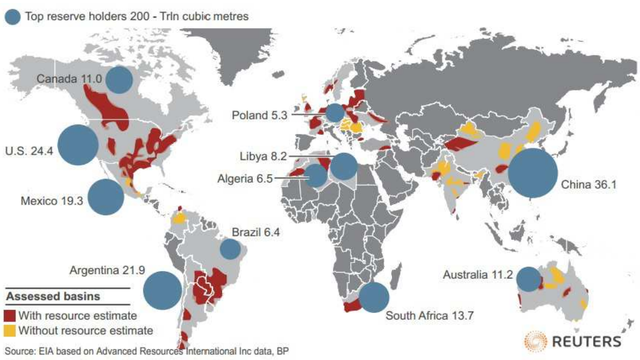

Fig. 1. Global top reserves holders after [28] (Thompson Reuters/ Catherine Trevethan), based on EIA and BP

There are little differences between Chen and EIA data presented because Chen utilized EIA estimates from 2011, as well as BP data from 2011. On Chen Fig.1 Poland and Libya are pointed out as key shale gas holders. In next paragraphs American and Polish unconventional natural gas basins will be taken into consideration. U.S. shale gas production and opportunities will be discussed more specifically as well.

V. United States Shale Gas Basins and Production

Due to implementation of profitable gas extraction and production from shale formations, United States has a supply of natural gas for over 100 years, assuming current gas consumption rate [15], [29]-[31]. There are several curial shale plays where the shale gas revolution was initiated. The potential of U S shale basins was assessed for EIA by ARI in 2011 and 2013 respectively. Table III and Table IV compares estimated made in 2011 [32] and 2013 [23]. The American shale basins are shown on Fig. 2.

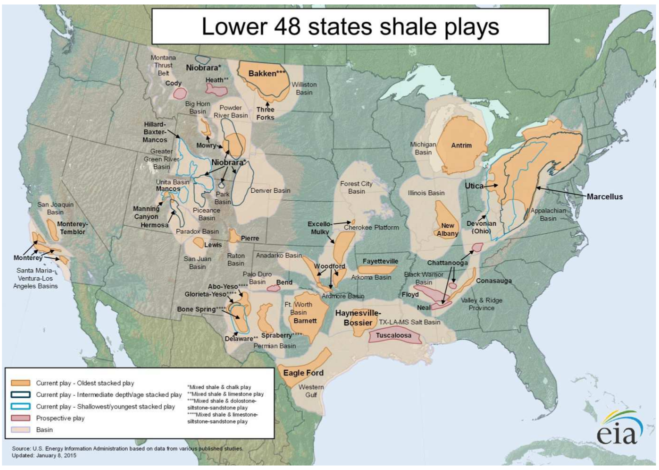

Fig. 2. 48 US Shale plays [23]

Table III. US Shale basins potential (TRR) [32]

Region	Basins	TRR [Tcf]	TRR [Tcm]	Share of total
Northeast	Marcellus	410	11,61	54,7%
	Antrim	20	0,57	2,7%
	Devonian Low Thermal Maturity	14	0,40	1,9%
	New Albany	11	0,31	1,5%
	Greater Siltstone	8	0,23	1,1%
	Big Sandy	7	0,20	0,9%
	Cincinnati Arch	1	0,03	0,1%
Gulf Coast	Haynesville	75	2,12	10,0%
	Eagle Ford	21	0,59	2,8%
	Floyd-Neal & Conasauga	4	0,11	0,5%
Southeast	Fayetteville	32	0,91	4,3%
	Woodford	22	0,62	2,9%
	Cana Woodford	6	0,17	0,8%
Mid-Continent	Barnett	43	1,22	5,7%
	Barnett Woodford	32	0,91	4,3%
Rocky Mountain	Mancos	21	0,59	2,8%
	Lewis	12	0,34	1,6%
	Williston-Shallow Niobrara (not assessed in INTEK report)	7	0,20	0,9%
	Hilliard-Baxter-Mancos	4	0,11	0,5%
U.S.	**TOTAL**	**750**	**21,24**	**100,0%**

Table IV. US Shale basins potential (TRR) [23]

Region	Basins	TRR [Tcf]	TRR [Tcm]	Share of total
Northeast	Marcellus	369	10,45	31,8%
	Utica	111	3,14	9,6%
	Other basins in Northeast	29	0,82	2,5%
Southeast	Haynesville	161	4,56	13,9%
	Bossier	57	1,61	4,9%
	Fayetteville	48	1,36	4,1%
Mid-Continent	Woodford (Ardmore+Arkoma+Anadarko)	77	2,18	6,6%
	Antrim	5	0,14	0,4%
	New Albany	2	0,06	0,2%
Texas	Eagle Ford	119	3,37	10,2%
	Barnett (+ the Barnett Combo)	72	2,04	6,2%
	Permian (includes Avalon, Cline, Wolfcamp in the Delaware and Midland)	34	0,96	2,9%
Rocky Mountain	Niobrara (includes Denver, Piceance and Powder River basins)	57	1,61	4,9%
	Lewis	1	0,03	0,1%
	Bakken/Three Forks	19	0,54	1,6%
U.S.	**TOTAL**	**1161**	**32,88**	**100%**

A. Marcellus basin

The biggest shale gas basin in US is definitely Marcellus (located in Northeast part of US, including parts of the states of New York, Pennsylvania, Ohio, Maryland, West Virginia and Virginia) and covers over 10 Tcm of TRR, more than 50% of total US shale TRR, in 2011 (according EIA in 2011) and more than 31% according estimation prepared by EIA/ARI in 2013. The daily gas rate from Marcellus measured through December 2014 (only from Pennsylvania and West Virginia) was 0,4 Bcm/day (14,2 Bcf/day) and It should be noted, that production from Marcellus has grown 14 times since May 2000 (nearly 1 Bcf/day) [33]. Increase in shale gas production from Marcellus is shown on Fig. 3. At February 6th, 2015, 71 gas rigs have been working on Marcellus shale formations. The peak in shale reservoir management was achieved in January 2011 when 143 rigs had been working [34].

B. Barnett basin

Barnett basin, located in Texas according to the newest estimates [23] has over 2,04 Tcm technically recoverable reserves. It represents more than 6% of total US shale gas TTR [23], previously TRR in Barnett was assessed at 1,22 Tcm [32]. More than 16 thousands wells have been drilled on Barnett Shale since early 1990s (vertical, horizontal as well as directional). By the end of 2012, 0,37 Tcm of gas have been produced from Barnett [35]. The daily gas production was 0,0057 Bcm/day (0,2 Bcf/day) in May 2000 and increased to 0,028 Bcm/day (1 Bcf/day) in February 2005. Production was doubled in next 2 years and was 0,057 Bcm/day (2 Bcf/day, February 2007), next, grew to 0,115 Bcm/day (4 Bcf/day) in October 2008 and finally reached the peak at 0,13 Bcm/day (5 Bcf/day) in November 2012. From that moment gas production rate is stable and amounts between 0,11-0,13 Bcm/day (3,9- 5,0Bcf/day) [33]. Barnett was the first extensively development play, thus in 2011 only 55-60 rigs were operated and by the end of 2012 this number has dropped to 29. By February 6th, 2015 only 9 rigs have been drilled [34].

C. Fayettteville basin

Located in Arkansas, stores 1,36 Tcm TRR [23] what is 4% of US TRR. Gas production form Fayetteville had increased from 0,0028 Bcm/day (0,1 Bcf/day) in January 2007 to more or less 0,07-0,08 Bcm/day (2,5-2,8 Bcf/day) and maintain that production level [33]. In 2011 about 30 rigs have been operated on Fayetteville. Since 2012, the number of active rigs has decrease from 30 to 13. In 2013 no more than 13 were active, and finally, the number of rigs does not exceeded 13 in 2014 [34].

D. Haynesville basin

Situated in Arkansas, Texas and Louisiana, stores near 4,56 Tcm of TRR (almost 15% of total US) [23], what makes it the second largest basin in US (after Marcellus). Total gas production form Haynesville was quite stabilized between 0,0037 Bcm/day (0,131 Bcf/day) in January 2000 and 0,0329 Bcm/day (1,16 Bcf/day) in July 2009 (with minimum at 0,002 Bcm/day; 0,07 Bcf/day). In middle 2008 production rate started growing and in November 2 Bcf/day was achieved. In April 2009 gas rate was equal to 3 Bcf/day, next in August production was at level 4 Bcf/day and at the end of 2010 it was 5 Bcf/day. In November 2011 production rate achieved maximum at 7,1 Bcf/day and from that moment constantly dropping to 4 Bcf/day by the end of 2014 (for details see fig. 3) [33]. In 2011 between 110 and 160 rotary rigs were constantly working. At the beginning of 2015, this number drop to 40 [34].

E. Other basins

Others major shale basins that should be considered within this article are: Utica, Woodford, Eagle Ford and Niobrara. Utica with 3,14 Tcm of TRR [23] is the fourth largest US basin. Production from Utica's fields has begun in middle of 2006. In June 2014, 1 Bcf/day was reached, and in February 2015, production increased to 0,05 Bcm/day (1,7 Bcf/day) [33]. Utica is still under development and number of working drilling rigs grows: from about 10 between 2011 and 2013 to more than 20 in 1Q of 2015 [34]. Woodford covers about 2,18 Tcm of TRR what contributes 6,6% of total US TRR [23]. The development of Woodford is going to the end. Only 9 rigs is currently working at fields [34]. The daily natural gas production rate from Woodford shale is shown on Fig.3. Eagle Ford located in Texas storages more than 10% of national shale gas TRR (3,37 Tcm) [23] and Niobrara 1,61 Tcm, which is nearly 5% [23]. Daily production of each basin and active drilling rigs are illustrated on Fig. 3 and Fig. 4 respectively.

VI. US Shale Gas Revolution Influence on North America and Global Natural Gas and Energy Market

As previously stated, the shale gas revolution in the US, preceded by the mastering of hydraulic fracturing has incontestable influence on global natural gas and energy markets. Daily production rate from the all shale gas plays increased from 0,1 Bcm/day in early 2000 to more than 1,2 Bcm/day (almost 40 Bcf/day) in December 2014 [33]. In that period of time, natural gas price, indexed on Henry Hub, was on similar price level $ 2,42 per MBtu in January 2000 and $ 2,99 per MBtu in February 2015 [33]. US consumption has grown from near 630 Bcm in 2001, through 659 Bcm in 2008 to almost 740 Bcm in 2013 [33].

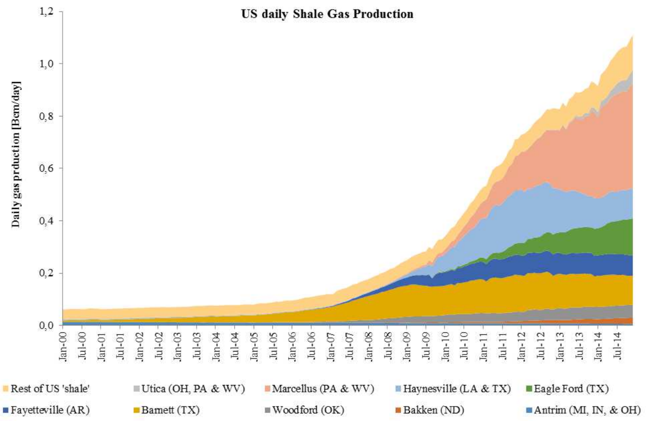

Fig. 3 Daily dry shale gas production [33]

The shale basins could be defined as "quite developed reservoir" because of dramatic drop of active drilling rigs on fields. (see fig. 4) [34].

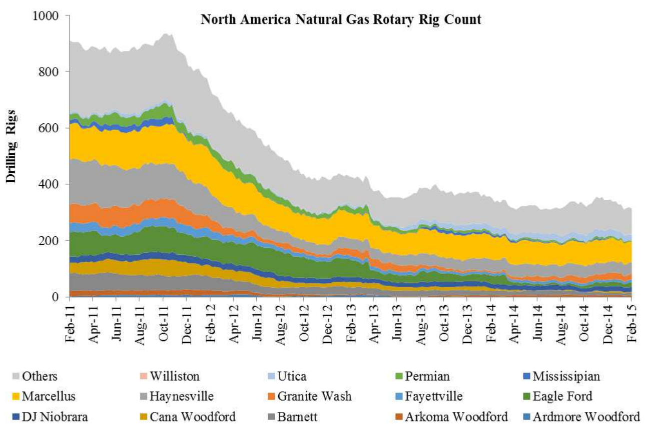

Fig. 4 North America Natural Gas Rotary Rig Count [34]

VII. POLISH SHALE GAS BASINS POTENTIAL AND PROSPECTING

Recently a few reports, which estimate Polish tight and shale gas resources, were announced. In 2014, estimations for tight gas reserves were prepared by Polish Geological Institute (PGI) (report published in March 2015) [36]. Shale gas resources, which are main aim of this paper, are discussed in details below.

Polish shale gas basins potential has been estimated in a few reports, resulting in a broad range of values. In 2009 Wood Mackenzie [18] and Advanced Resources International (Kuuskraa) [42] announced 1,40 Tcm and 3,00 Tcm, respectively. In 2010 Rystad Energy and state owned Polish Oil and Gas Company (PGNiG) announced 1,00 Tcm and 0,90 Tcm respectively [37]-[39]. In 2011, Advanced Resources International reported much higher assessment of Polish shale gas resources, equal to 5,30 Tcm [9]. Also in 2011 there were presented three other reports prepared by EUCERS - 1,87 Tcm [40], Medlock et al. [21] who reported 3,40 Tcm and Lane Energy Poland which reported 1,00 Tcm of recoverable gas for their 6 concession blocks in the Baltic Basin only. In 2012, the Polish Geological Institute estimated maximum recoverable resources of natural gas from shale deposits for Polish onshore and offshore basin to 1,92 Tcm [37] but the most probable range was estimated for 0,35-0,77 Tcm (onshore & offshore). Also in 2012 BGM and USGS reported 5,3 Tcm and 0,03528 Tcm respectively (about 10% what PGI estimated) [7], [41]. The latest ARI / EIA report from 2013 [23], estimates total recoverable reserves of natural gas from shale in Poland to 4,13 Tcm. All these reports present much higher estimates of shale gas resources than Polish conventional gas resources. It is planned that in 2015 new estimates for Polish shale gas recoverable resources will be generated [43]. Table V presents shale gas recoverable resource estimates for Poland.

Table V Shale gas recoverable resource estimates for Poland

Author / organization	Date of report	Resource estimate	Tcm	Tcf
ARI (for EIA)	Jun-13	TRR	4,13	146,00
			4,19	148,00
		OGIP	21,60	763,00
Mc Glade et al. / UKERC	Sep-12	"Resources"	4,30	151,85
USGS	Jul-12	TRR	0,03528	1,246
PGI	Mar-12	EUR - optimum - only onshore	0,23 - 0,62	8,14 - 21,87
		EUR - optimum (onshore & offshore)	0,35 - 0,77	12,22 - 27,11
		EUR - max (onshore & offshore)	1,92	67,79
BGR	Feb-12	"Resurces"	5,30	187,00
Medlock et. al.	Jul-11	TRR[a]	3,40[a]	120,00[a]
Khun and Umbach / EUCERS	May-11	TRR	1,87	66,10
		OGIP	23,90	844,00
ARI (for EIA)	Apr-11	TRR	5,30	187,00
		OGIP	22,41	792,00
Lane Energy (3Legs)	2011	"Resurces"	1,00	35,31
Rystad Energy	2010	"Resurces"	1,00	35,31
PGNiG	2010	"Resurces"	0,90	31,78
Kuuskraa / ARI	Dec-09	"Recoverable resources"	3,00	100,00
Wood MacKenzie	Jan-09	TRR	1,40	49,44

[a] - Medlock indicates that resources should be commercially viable so his definition, although described as technically recoverable resources, is in principle closer to ERR.

Most prospective of shale gas accumulations were the Upper Ordovician and Silurian formations of the Baltic Syneclise, the Marginal and Lublin Troughs, and the Podlasie Depression as well as the Narol-Biłgoraj zone. Less prospective are the Upper Cambrian and the Tremadocian sediments of the Baltic Syneclise. The most perspective shale gas bearing formations in east Central East Europe, Silurian black shales, are the main object of research currently performed by industrial and scientific institutions.

A. *Baltic Basin*

In the EIA report from 2011, the Baltic Basin total area was estimated at 263 172 km^2 and holds the Lower Silurian shale formation at Llandovery. The prospective area was estimated on 22 911 km^2 with an average depth of 3750 m. TOC [wt.%] was calculated at 4,0% and thermal maturity at 1,75% Ro. Clay content was assessed as medium. Risked recoverable GIP is 3,6 Tcm [44], [32].

B. *Lublin Basin*

Second described, Lublin Basin has a total area equal to 30 774 km^2 and prospective area of 30 199 km^2. Formation is dated as Lower Silurian, from Wenlock. Interval occurs between 3000-4100m of depth (average 3050m). An average TOC and thermal maturity was estimated at the level of 1,5% and 1,35% respectively. Clay content is medium rank and risked recoverable GIP was estimated at 1,2 Tcm [44], [32].

C. *Podlasie Basin*

The total area of Podlasie Basin was estimated at 11 153 km^2 with risked recoverable GIP at 0,4 Tcm. The prospective area was assessed at 3432 km^2. Lower Silurian formation is also from Llandovery age. Formation interval is between 1750-3460 m with average depth 2605 m. TOC was obtained at 6,0%, thermal maturity 1,25% and clay content as medium [44], [32].

The details of geology, tectonic setting, stratigraphy, as well as relationships between gas occurrence and petro-physical properties, were deeply investigated and published in many papers [45]-[50]. Prospective basins and concessions assigned along those basins are presented on Fig. 6a and Fig. 6b-f.

VIII. CONCESSIONS

During last few years, after a period of great interest in shale gas prospecting and exploration in Poland, there have been significant changes [39]. From the beginning of 2013, total number of concessions started to decrease (Fig. 5). According to Polish law, the Polish Ministry of the Environment, was issuing two types of concessions related to exploration for shale hydrocarbons. One concession was for prospecting and/or exploration of both: conventional and unconventional hydrocarbon deposits in Poland. A second concession was issued for prospecting and/or exploration of unconventional hydrocarbon deposits in Poland (authors' analysis does not apply to concessions for prospecting and/or exploration: only for conventional hydrocarbon deposits, coal-bed methane (CBM) deposits and "tight gas" deposits). Since January 1st, 2015, when the amended mining and geological law came into force, types of concession has been modified [51]. Currently these two types of concessions were expanded for production opportunity.

Within this paper, when shale gas concessions are taken into consideration, both types of concessions mentioned above are taken into account.

The first shale gas concession was issued by the Polish Ministry of the Environment in 2007. At the beginning of 2013 ("peak time") there were 113 concessions, whereas at April 1st 2015 there were 47 concessions issued by the Polish Minister of the Environment. These 47 concessions were granted to 12 Polish and foreign capital groups [43]. Most concessions - 11 - had PGNiG SA., Orlen Upstream Sp. z o.o had 8 concessions and Lotos Petrobaltic SA - 7 concessions (only offshore).

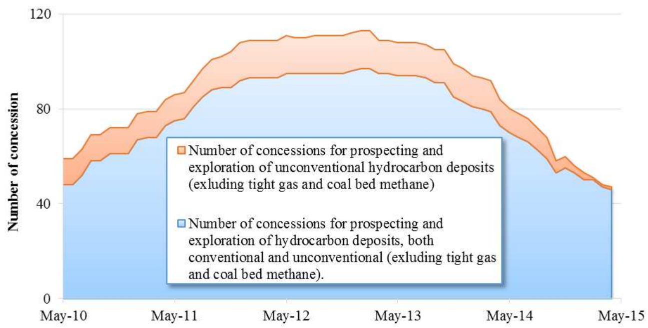

Fig. 5 Change in number of shale gas concessions in Poland (own study, based on MoE [43])

The decrease in the number of concessions is mainly caused by an exit from the Polish market of several important investors. Reasons for a loss of investors may be found in the absence of spectacular exploration and production success, unfavorable legal and bureaucratic environments, natural gas and oil prices.

At the beginning of 2013, there were active 19 capital groups which held 113 concessions. By April 1st 2015 the number of concession holders decreased to 12 and number of concessions dropped to 47.

At the beginning of 2015, Chevron Corp. the second-largest integrated energy producer in the US, announced an investment abandonment in Poland [52]. Chevron Corporation is not a first global player to quit exploration of hydrocarbons in Polish shale deposits. Exxon Mobil Corp. abandoned Polish shale in 2012 after drilling unsuccessful wells. Canadian Talisman Energy Inc. and U.S. Marathon Oil Corp. quit in May 2013. Eni SpA and French Total left in early 2014. At beginning of 2015, only ConocoPhillips, one of the biggest U.S. oil and gas producer, was still active in Poland holding 3 concessions for hydrocarbon exploration in Polish shale deposits. Fig. 6b-f provides an overview of investors' withdrawal from acquiring gas concessions in Poland.

Table VI shows the decreasing number of shale gas concessions held by a decreasing number of capital groups.

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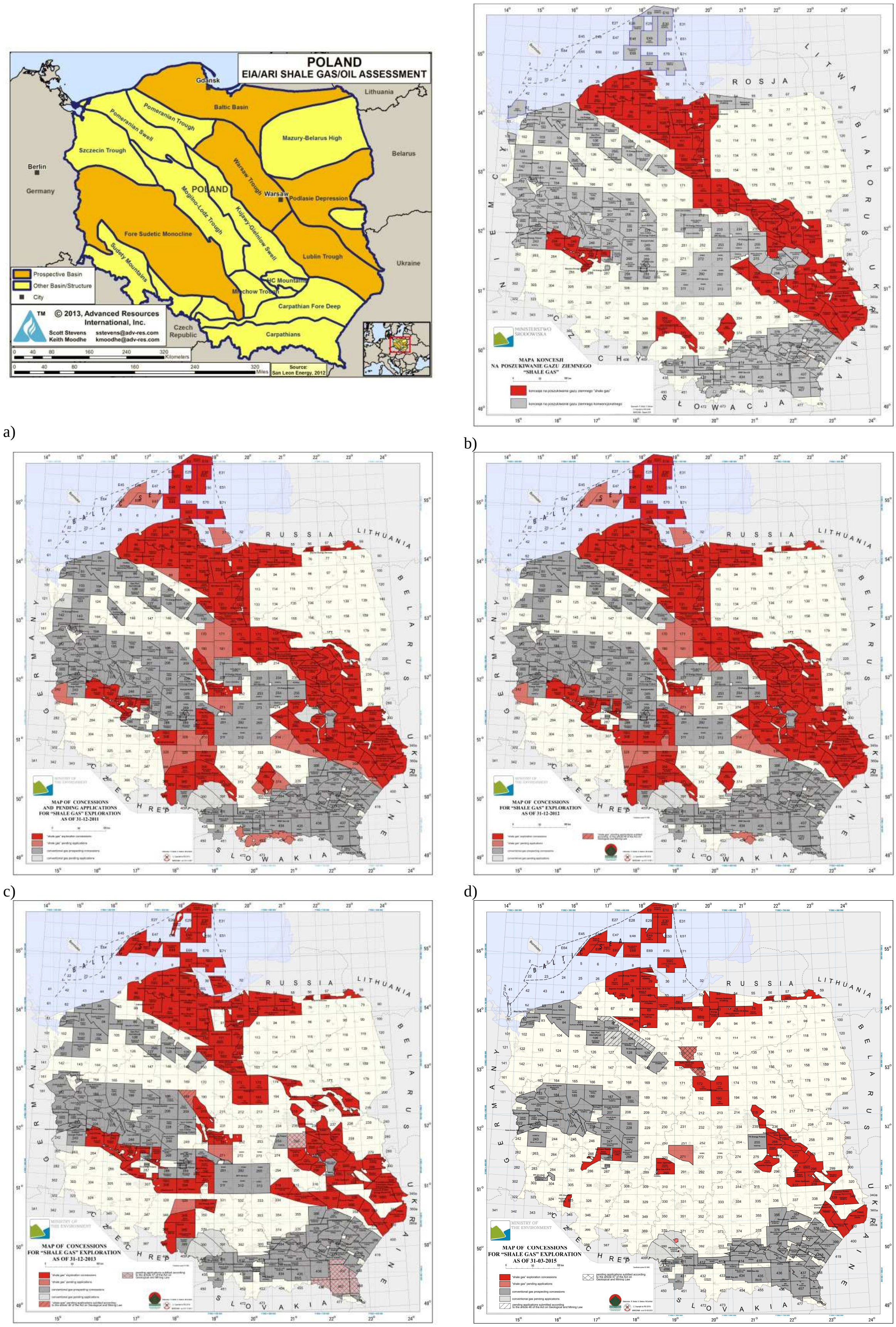

Fig. 6 a) Major Shale Gas Basins in Poland. Maps of concessions for shale gas exploration: b) as of 08/2010; c) as of 12/2011; d) as of 12/2012; e) as of 12/2013; f) as of 03/2015 (own study, based on ARI/EIA [32] and MoE [43])

Table VI Capital groups which holds concessions* for prospecting or exploration of shale gas in Polish deposits (own study, based on MoE [43])

Capital group	2013-01-01	2015-04-01
PGNiG S.A.	16	11
Polski Koncern Naftowy Orlen S.A.	7	8
Grupa LOTOS S.A.	7	7
San Leon Energy Plc	-	4
Wisent Oil & Gas Plc	4	4
ConocoPhilips B.V.	-	3
Stena AB	-	3
Chevron Corporation	4	2
PPI Chrobok S.A.	-	2
BNK Poland Holdings B.V. & Kaynes Capital S.a.r.l.	-	1
Cuadrilla Resources Limited	3	1
Palomar Capital Advisors Limited & San Leon Energy B.V.	-	1
San Leon Energy Plc & LNG Energy LTD	-	-
Marathon Oil Company	11	-
San Leon Energy & Realm Energy International	10	-
3Legs Resources Plc	9	-
PETROLINVEST S.A.	9	-
Basgas Pty Ltd	6	-
ExxonMobil Corporation	6	-
Emfesz	5	-
BNK Petroleum	6	-
Eni SpA	3	-
Talisman Energy Polska	3	-
Aurelian Oil and Gas PLC	2	-
Mac Oil Spa	1	-
Milejów LLP	1	-
TOTAL no. of capital groups	**19**	**12**
TOTAL no. of concesion*	**113**	**47**

*- concessions for prospecting and exploration of hydrocarbons (conventional and unconventional) in Polish deposits. Presented summary does not apply to entities that holds concessions for prospecting for or exploration: only for conventional hydrocarbon deposits, coal-bed methane (CBM) deposits, "tight gas" deposits)

IX. Exploration & Production Companies in Poland - Key Players and Their Capacities - Outlook for Development

Until 2010 E&P services in Poland have been provided exclusively by several PGNiG's (or POGC's) subsidiaries that were working independently. In February 2013 POGC finalized the completion of the formal and legal integration of the five providers of drilling and oilfield services of the PGNiG Group, which were merged to become a single entity – Exalo Drilling S.A.. Previously independent services companies of the PGNiG Group were: PNiG Kraków S.A., PNiG JASŁO S.A., PNiG NAFTA S.A., PN Diament Sp. z o.o. and ZRG Krosno Sp. z o.o. [53].

In spite of entry into the Polish market of companies (eg. Schlumberger, Weatherford, Halliburton (Including Baker Hughes acquired in 2014), or the United Oilfield Services), the dominant role of the PGNiG still remains unthreatened. It should be emphasized that the scale of action related to exploration and further production of natural gas from Polish shales requires an acceleration in drilling activities.

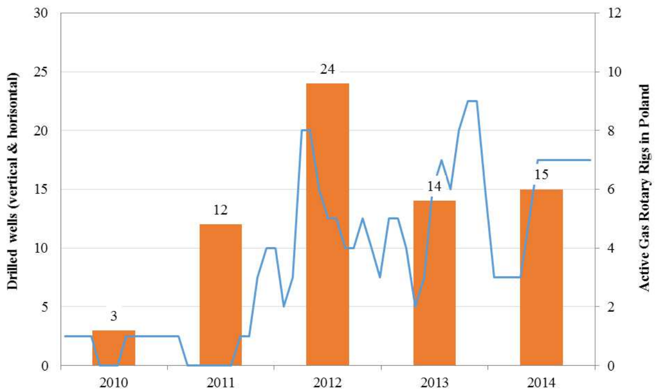

Fig. 7 Drilled exploration wells in Polish shale deposits and number of active gas rotary rigs in Poland (own study based on MoE, 2015 [43] and BHI, 2015 [54])

Since 2010, the number of wells drilled for shale gas extraction has grown (see, Fig. 7), but since 2013 drilling activity has declined and the growth rate has slowed down. Companies started to send their rigs elsewhere, both within Europe and beyond. Companies like MND, KCA Deutag, Ensign changed their plans: Czech MND rig went to Serbia, the Canadian Ensign rig was moved to Iraq, UK KCA Deutag rig returned to Western Europe [55]. Even, mention above, Polish service company Exalo Drilling S.A. has sent brand new walking rig to do work abroad. Other companies, such as Phoenix, who have a presence in other markets in Europe and Russia, and wanted to enter the Polish market, have reconsidered their plans [56].

At the beginning of 2015, apart from UOS which has a new CE-ATEX certified 2000 HP AC Pad Drilling Rig [57], only Exalo Drilling S.A. has ability to drill 3500+ m depth wells in Silurian shale formations [53].

From 2010 to the end of March 2015, 70 shale gas wells were completed (16 of this wells were horizontal; see fig. 7). In first quarter of 2015 another 2 exploration wells were drilled: Rawicz 12 SL-1 on Rawicz concessions held by San Leon Rawicz Sp. z o.o. and Pęclin - OU1 on Wołomin concession held by Orlen Upstream.

In the near future it is planned to start drilling another two wells for shale gas exploration: Jackowo LEP-1 (LEP 1ST1H) concession Lebork, investor: Lane Energy Poland Sp. z o.o. and Lewino-2h concession Gdańsk W, investor: Baltic Oil & Gas Sp. z o.o.

To perform initial assessment of shale gas production possibility, special treatments were applied. Hydraulic fracturing was performed at 25 wells (includes 12 horizontal wells). Fracture Injection Diagnostic Test (DIFT) was performed in 4 wells. Special treatments was not applied in 41 wells [43; entry date April 2015].

X. Conclusion

Several recent papers discussed profitability of American shale gas production [58]-[63] as well as European (Weijermars, 2013) [64]. Weijmars ranked European shale gas basins in accordance with expected benefits from production. Ranking methodology was described in details in article. Sequence of the most prospective (attractive) European shale basins is as follows: Silurian Poland, Shale Austria, Posidonia Germany, Shale Turkey and Alum Sweden. Weijmars estimated NPV for each country on following assumptions: development of 100 shale gas wells, specified EUR/well ratio, initial production rate, decline curve types, well CAPEX, OPEX, royalty and corporate taxes and depreciation, as well as discount rate. Including given parameters described in details in article, NPVs for each country amounts to: 737 M$ for Alum Sweden, 1497 M$ for Silurian Poland, 953 M$ for Posidonia Germany, 2427 $M for Shale Austria and 565 $M for Shale Turkey [64]. After consideration of other economics parameters as: IRR (different in various country), largest negative cash flow requirement and payback, Polish Shales were ranked at the first place and Weijermars pointed them as the most promising target to start European shale revolution. In mentioned article, Weijmars, implemented US shale gas wells as an analog to EU wells. He also assumed initial gas rate equal, for Polish Silurian, to 0,5 Bcf/year (1,37 Mcf/day; 0,38 Mcm/day) for single well [64], what is extremely optimistic values, as showed example from Polish wells described

So far, the biggest gas flows from Polish shale formations was announced by Lane Energy Poland (owner: ConocoPhillips) in Łebień LE-2H well (0,008-0,0011 Mcm/day) [65], [66] and Lublewo LEP-1STH (0,00145-0,00112 Mcm/day for shale gas and 157 bbl/day of light oil) [67], San Leon Energy on Lewino-1G2 (0,000843-0,00169 Mcm/day [68]-[70], after cleaning the well expected to 0,00566-0,011 Mcm/day) on BNK Petroleum Gapowo-B-1A (at the beginning 0,03 Mcm/day, later drop to 0,000006-0,000011 Mcm/day) [71], [72]. But still - the hydrocarbon flow is not sufficient for commercial and profitable exploitation.

By the end of March 2015, 70 exploration wells had been drilled in Poland for shale hydrocarbons, but none of them started production. Polish shale formations are different than US shale geological formations [73]. Previously it was assumed Poland, like the US, has one continuous broad shale belt. However, as it turns out Poland might have many areas where commercial extraction of shale gas and other hydrocarbons will be possible. Scale of exploration in Poland is much smaller than in the US [52]. So far, wells drilled in Poland amount to a small fraction of those drilled in the US. To estimate the amount of shale gas in Poland at least 20 and upwards of 100 pilot wells need to be initiated during the next two years. Though not regarded as a commercial phase [74] it would go a long way to ending any thought that the shale gas revolution has passed by Poland. Some would agree it only just begun.

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