FORECASTING ALGERIA'S NATURAL GAS PRODUCTION USING A BASIC AND GENERALIZED HUBBERT MODEL

Hicham **BENAMIROUCHE**[*]
Oum Elkheir **MOUSSI**[**]

Recieved : 24/05/2017/ **Accepted** 27/02/2018 /**Published online** : 14/03/2018

ABSTRACT

This paper aims to evaluate a long-term physical availability of natural gas in Algeria using the peak production approach. This leads to estimate two models. The first is the basic Hubbert model, while, the second is second is the Generalized Hubbert model, which accounted for disruptions in gas production by using a series of Hubbert curves in combination with a polynomial smoothing function to improve the first model. Our findings show that is more reliable to present the peak as a short plateau from 2005 to 2008, with respective volume of 107.5 to 109.5 Billion cubic meter (bcm). About 2000 bcm will be produced in the upcoming years, with 90% depletion by 2035. The results of forecasts' accuracy indicate that the second model provide a high accuracy forecast.

KEYWORDS: Hubbert Curve, Generalized Hubbert Model, Natural gas production, Algeria.

JEL CLASSIFICATION: C53, Q35, Q47.

[*] Research Center of Applied Economics for Development. CREAD. E.mail: hbenamirouche@yahoo.fr / h.benamirouche@cread.dz

[**] Higher National School of Statistics and Applied Economics. ENSSEA

PRÉVISION DE LA PRODUCTION GAZIÈRE DE L'ALGÉRIE PAR LE MODÈLE GÉNÉRALISÉ DE HUBBERT

RÉSUMÉ

Cet article a pour objectif d'évaluer la disponibilité du gaz naturel en Algérie à long terme en s'appuyant sur l'approche pic de production. Cela a conduis à l'estimation de deux modèles. Le premier est le modèle de base de Hubbert, tandis que le deuxième est le modèle généralisé de Hubbert, qui tient compte des ruptures de production gazières par la combinaison d'une série de modèles de Hubbert avec des fonctions d'intervention pour améliorer le modèle de base. Les résultats montrent qu'il est plus réaliste de présenter le pic comme un court plateau de production, allant de 2005 à 2008, avec un volume de 107.5 à 109.5 milliards de mètres cube (Gm^3), respectivement. Environ, 2000 Gm^3 restantes pour les années avenir, avec un épuisement de 90% du total de réserves à l'horizon 2035. Les résultats de validation et de comparaison des modèles montrent que le deuxième modèle fournit des prévisions avec une haute précision.

MOTS CLÉS Hubbert Curve, Generalized Hubbert Model, Natural gas production, Algeria.

JEL CLASSIFICATION: C53, Q35, Q47.

تقدير إنتاج الغاز الطبيعي في الجزائر باستعمال النموذج الأصلي و النموذج العام لهوبرت

ملخص

يهدف هذا المقال إلى تقييم وفرة الغاز الطبيعي في الجزائر على المدى البعيد، و ذلك بالاعتماد على طريقة ذروة الإنتاج، حيث تم تقدير نموذجين لتوقع تطور إنتاج الغز. النموذج الأول هو النموذج الأصلي لهوبرت، بينما النموذج الثاني فهو النموذج العم لهوبرت، و الذي يأخد بعين الاعتبار فترات اضطراب الإنتاج وذلك باستعمال منحنيات هوبرت مع دوال التمهيد من أجل تحسين جودة النموذج الأصلي. أظهرت النتائج أنه من الأفضل صياغة ذروة إنتاج كفترة قصيرة ممتدة من 2005 إلى 2008، حيث تنحصر كمية الإنتاج بين 107.5 إلى 109.5 على التوالي. كما أنه يتبقى حوالي 2000 مليار متر مكعب كاحتياطات قابلة للاستخراج مع تسجيل استنفاذ 90 بالمائة من إجمالي الاحتياطات بحلول 2035. تشير نتائج جودة التوقع أن النموذج الثاني يقدم تقديرات عالية الدقة.

كلمات مفتاحية: منحنى هوبرت، النموذج العام لهوبرت، إنتاج الغاز الطبيعي، الجزائر.

تصنيف جال: C53, Q35, Q47

1- INTRODUCTION

In Algeria, oil and natural gas are considered as a vector for socioeconomic development. However, the ratio Reserves to the production of each resource (56 years for gas vs 18 years for oil; (see BP Statistical Review of World Energy (2014)) gives natural gas the priority to cover the energy needs of the country in a long term.

Natural gas represents around 41% of primary energy production, 97% of electricity production sources, 65% of energy's total consumption, 56% of hydrocarbon export volume and, 30% of foreign exchange earnings from hydrocarbon (See National energy balance 2014: Algeria's Energy Ministry, Edition 2015).

Since 2005, natural gas production volume has been stagnating and fluctuated around 106 bcm (without Reinjected volume). Campbell (2009) has given the peak gas of Algeria in 2011, and Mohr (2010) has differentiated three cases, in which peak gas could be registered between 2015 and 2020 with peak volume from 110 to 129 bcm. Guseo et al. (2015) show a decreasing trend in conventional Algerian natural gas production. The authors estimated the ultimate recoverable reserves of Algeria at 3000 bcm in the end of 2012.

Thus, predict the evolution of natural gas production is becoming increasingly necessary to establish the future energy policy of the country regarding the continued increase in domestic gas consumption and to honor the gas export contracts. In fact, during the last decade since 2005, Algeria's natural gas demand grew at 5,3%/year while the marketed production decreased by 0,5%, resulting in contraction of total gas export volume of 3.5%/year.

Various techniques have been employed to model and forecast oil and gas production. Jakobsson, et al. (2014) had summarized the modeling approaches into two broad classes; Top down models that forecast aggregate production through some form of extrapolation of aggregate variables (curve fitting, system dynamic simulation and economic model). The second is the Bottom-up models that represent the supply chain of the upstream oil industry, and forecast aggregate production as the sum of production from smaller units.

But, two techniques have received considerable development efforts and application (Kaufmann et Cleveland, 2001). The first one is based on fitting discoveries and production data models, the so-called Hubbert curve. The work of the petroleum geologist Hubbert (1956, 1962) was relatively successful in estimating US oil production in the lower 48 states. The Hubbert curve is identical to the continuous form of the logistic equation. Rehrl and Friedrich (2006) have explained the behavior of oil discovery by combinations of two effects: (i) increasing information with exploration and cumulative discoveries, (ii) decreasing recovery rate with exploitation and cumulative discoveries.

Several authors had used Hubbert model (or its variants) to forecast world oil and gas production (Alfattah and Startzman 2000, Bartlett 2000, Campbel and Laherrere 1998, Guseo et al 2007, Imam et al 2004, Laherrere 2007, Magio and Cacciola 2009, Mohr and Evans 2010, Wang et al 2011). In addition, other studies had been based on this technique to forecast production in specific countries such as Former Soviet Union (Laherrere 2002), United States (Reynold and Zhao 2007), Brazil (Saraiva et al 2014, Szklo, et al. 2007), Peru (Chavez-Rodriguez 2015), OPEC (Ebrahimi and Ghasabani 2015, Nashawi, et al. 2010), Iran (Kiani, et al. 2009).

However, the Hubbert approach has some limitations (Laherrere 1997, 2000, Bardi 2005, Brandt 2007, Guseo et al 2007, Magio and Cacciola 2009). It assumes that oil production is only time-dependent and does not take into account the effect of possible technological and/or economic factors. In addition, it provides a forecast with only one peak in oil production, which seems valid when applied, but only in a small number of cases, i.e., oil production in the US Lower 48 states (already proven) or countries with a large number of oil fields and basins, such as the Former Soviet Union.

The second technique, has received considerable development efforts, is the economic model for the depletion of an exhaustible resource, the so-called Hotteling model (Hotelling 1931). The economic models use the economic factors such as prices, costs to explain the evolution of production or supply (Fattouh 2007).

Various authors showed that economic variables could improve the fit of the Hubbert curve: Kaufmann (1991), Cleveland and Kaufmann (1991), Kaufmann and Clevelan (2001), Reynolds (1999), Reynolds and Baek (2012), Smith (2012).

For Algeria's case, it could be hypothesized that gas discovery and production could follow a Hubbert model, then, it is time-dependent. However, the production history in Algeria is marked by some State interventions (1974, 1980), accidents (2006, 2013) and, demand shock (2009), which can result in disruptions, and therefore the basic curve of Hubbert could generate a poorly fitting model to the data. In fact, Moussi (2012) estimated the peak gas of Algeria to be occurring in 2004 using this basic Hubbert Approach, while the historical data show that it was occurring in 2008.

Alternatively, new approaches could be following. Research in growth and diffusion contexts allows considering interventions, which may heavily affect normal production evolution. In fact, Guseo, et al. (2007) examined joint effects of economic and strategic or technological interventions using a Generalized Bass Model (GBM) developed by Bass et al (1994), in which authors have specified an intervention function. Later, Guseo et al (2015) developed an extended version, namely, Generalized Bass Model Bemmaor Modified Model (GBMBMM). The model incorporates and expands the basic nature of GBM by introducing latent heterogeneity effects based on relevant contributions by Bemmaor (1994) and Bemmaor and Lee (2002). Based on Algeria's marketed gas production, Guseo et al (2015) estimated the recoverable reserves at 3000 bcm. However, until the end of 2014, Algeria's cumulative gas production has reached 2966 bcm (including flared and shrinked production), which suggests that Guseo et al (2015) underestimated the ultimate recoverable gas reserves of Algeria. For this, the Generalized Hubbert Model (Mohr and Evans, 2010) can be employed in our case. It accounted for disruptions in gas production by using a series of Hubbert curves in combination with a polynomial smoothing function for improving the basic Hubbert curve.

Given the few scientific empirical literature about the Algeria's Natural gas production, our study aims to estimate and forecast natural gas production in Algeria uses a basic Hubbert curve, and then proposing a Generalized Hubbert Model, developed by Mohr and Evans (2010).

The rest of the paper is organized as follows. Section two provides a brief review of natural gas production in Algeria. Section three presents methodology and Data. Section four reports the empirical results and discussion. Conclusion and policy implications are given in the final section.

2- NATURAL GAS PRODUCTION IN ALGERIA

The first discoveries of natural gas in Algeria were carried out in 1954 in the basin of Ahnet and In Salah (1956). However, these two discoveries have not been exploited for commercial and economic reasons.

Algeria's largest natural gas field "Hassi R'Mel" was discovered in November 1956, with initial proved reserves of 3000 bcm. It holds more than half of Algeria's total proved natural gas reserves. Table 01 shows the most important discoveries in Algeria.

Table 01: **The most important natural gas discoveries in Algeria**

Basins	1st year of discovery	Initial Reserves (bcm)	1st year of production
Ahnet	1954	100	2004
In Salah	1956	107	2004
Hassi R'Mel	1956	3040	1960/1964
Tin Fouyé Tabankort	1960	260	1963/1999
Gassi Touil	1961	195.3	-
Alrar	1961	317	1965
Rhourde Nouss	1962	464	1988
Tiggentourine (Illizi)	1960	9	2006
Ohant (Illizi)	1960	-	1961/2003

Source: Using Mekhalfi. A (2014) and Verdu, Jean Yves (1996)

Based on the exploration efforts and the political events, we can distinguish four (04) periods of the discoveries' history. The first started in 1910 to 1950, which consisted to look for hydrocarbons on the basis of surface indices, without achieving great results. The second started in 1950 to 1970. It was characterized by the discovery of the most important fields basing on the introduction of seismic and drilling at greater depths. However, the number of discoveries was dropped rapidly following the departure of many oil companies in the aftermath of the independence in 1962. The third period, between 1970 and 1985, was characterized by a significant decline in the number of exploration drill following the nationalization policy. The efforts were concentrated to develop the discovered fields. The last period is marked by a profound modification of the legislation through the implementation of the law 86-14, which consists of the production's sharing with foreign partners. This allowed to attract more investments in drilling and exploration of new areas, and to introduce more new technologies. The results were satisfactory in term of the reserves' renewal.

Thus, natural gas production in Algeria started effectively in 1960 from the field of Hassi R'Mel, with a lower volume of 0,2 bcm, destined only to the domestic market. Since, gross production increased strongly, especially during second half of the 1990s following robust policy actions early that decade to bolster the gas sector (Aissaoui, 2013, 2016). However, this trend was reversing during the last decade since 2008. In fact, gross production dropped from 201.2 bcm in 2008 to 179,5 bcm in 2013 before slightly increasing to 183,8 in 2015. The key components of gross production (Re-injected and Marketed) have trended downward to 77,1 bcm and 84,5 bcm in 2015, after peaked to 95 bcm in 2009, and 89,2 bcm in 2005, respectively. Table 02 depicts the natural gas production components for each first year of different decades.

Table 02: **Natural gas production components by one year of decade**

Unit (bcm)	1970	1980	1990	2000	2008	2015
Gross Production	9,9	43,4	126,6	163,0	201,2	183,8
Reinjected	1,8	14,3	64,2	67,4	92,9	77,1
Flared	3,4	9,7	4,5	6,7	5,0	3,5
Shrinkage	0,7	1,3	6,2	5,5	16,8	18,7
Marketed	3,9	18,0	51,6	83,2	86,5	84,5

Source: Different National Energy Balance: Algeria's Energy Ministry

Aissaoui (2013) indicated: *"lower gross production and lower volumes of gas re-injected suggest that there may not have been enough raw gas to maintain the recycling process at its optimum capacity. This in turn suggests that, notwithstanding additional volumes during the last decade from Ohanet, In Salah (dry gas) and In Amenas, production has at best plateaued, probably as a result of mature fields, chief among them Hassi R'Mel, depleting faster than commonly assumed"*.

After 60 years of its discovery (1956), the giant field Hassi R'Mel has reached its maturity's stage. This field has been overexploited because of several reasons, such the failure of the Sonatrach-Repsol partnership in 2007 for the development of the integrated project in Gassi Touil, and the halt of gas production in Tiguentourine plant following the terrorist attack in 2013.

However, Attar (2016) indicated that Algeria still has a significant production capacity of the existing fields, and its production will increase through the development of current fields in the southwest Sahara which are expected plateau production can exceed 16 bcm additional in the medium term. (See table 03)

Table 03 : **Gas Fields Being Developed or Contemplated for Development**

	Sponsors	Estimated 2P resereves (bcm)	Expected Plateau production (bcm/year)	First production initially planned	Starting date at the time writing
Program in partnership					
In Salah Southern Fields	Sonatrach, BP, Statoil	65,0	(a)	2014	2016
Touat (Adrar)	Sonatrach, Engie	68,5	4,6	2016	2018
Reggane North	Sonatrach, Repsol, DEA, Edison	47,9	2,9	2017	2018
Timimoun	Sonatrach, Total, Cepsa	25,5	1,6	2016	2018
Isarene (Ain Tsila)	Sonatrach, Petrocletic, Enel	59,2	3,6	2017	2018
Sonatrach's own program					
Tinhert	Sonatrach	110,0	7,0	2015	2018
Ahnet (b)	Sonatrach	61,5	4,0	2015	-
Hassi Mouina	Sonatrach	-	1,4	-	-
Hassi Ba Hamou	Sonatrach	-	1,8	-	-
Menzel Ledjmet (Periphery)	Sonatrach	-	4,4	-	-
Bourarhat North	Sonatrach	-	-	-	-
Gassi Touil (Periphery)	Sonatrach	-	-	-	-
Erg Issaouane	Sonatrach	-	-	-	-
Tisselit North	Sonatrach	-	-	-	-

(a) Dry gas fields developed to maintain the planned plateau production of 9 bcm at In Salah, strated in Feb 2016

(b) Following Total's exit from Ahnet, Partex Oil & Gas, which hold a 2% stake in the venture, remains a virtual partner

Source: Aissaoui (2016) using Companies' Annual Reports and Official Web-posting

Aissaoui (2016) argued that *"most of these projects are tight, dry or, in the case of the southwestern formations, have high CO_2 content, therefore too costly to be able to offset the notable shortfall in government revenues"*.

The evolution of gas production reflects many uncertainties in terms of plateau and decline, which deserves to be studied through the analysis of its historical evolution and the estimation of its future trajectory.

3- METHODOLOGY AND DATA

3.1- Model Description

We aim to forecast the gas production in Algeria through the evaluation of the physical availability in the long term. We use the peak production approach, which offers long-term scenarios without investment constraints (Geopolitical, Economics,…).

This approach uses the Ultimate Recoverable Reserves (URR) and not the proven reserves. This allows for the influence of the following factors on the reserves' growth (Brocorens, 2009):

- Technology: improving the recovery rate of hydrocarbons in place within fields;
- Geological: addition of others fields identified later;
- Revaluation: successive corrections to initial evaluations of reserves.

In the peak production model, the evolution of production is represented by a Hubbert curve, and the URR include the gas already extracted, the remaining 2P reserves and, the estimate of future discoveries (Brocorens, 2009).

We are basing in this work on Hubbert's approach. For this, we follow, in a first time, the basic Hubbert model (Hubbert, 1962). Next, we describe an application of diffusive growth models, which is the Generalized Hubbert Model (Mohr and Evans, 2010).

3.1.1. Basic Hubbert model (HM)

K.Hubbert (1956) extrapolated the hydrocarbon production of the US and the world with a bell shape curve. He only presented some graphical methods (See Michel, B, 2010). The main idea of the Hubbert curve is that the rate of discoveries/production for a given set of fields would grow exponentially up to a maximum value, after which it would decrease until reserves were exhausted, following a bell-shaped curve (See Saraiva, et al. 2014).

In a later study, Hubbert (1962) gave a more detailed methodology. He proposed to model the cumulative discoveries of hydrocarbons with a simple logistic curve, which is discovered by Verhulst in 1838:

$$Q_D(t) = \frac{Q_\infty}{1 + ae^{-bt}} \dots \dots . (1)$$

Where Q_D and Q_∞ represent, respectively, the accumulated production up to time t, which tends to Q_∞ the ultimate reserves URR. a and b are estimated parameters.

Laherrere (2000) indicated that in practice it is more convenient to use the derivative of the logistic curve to model how annual production starts and ends at zero with a peak in between. It is in effect the Hubbert curve, although there are variants such as the Gauss curve, the Cauchy curve, the sine wave and even the parabola.

Equation (1) was reviewed by several authors (Kaufmann, 1991, Moroney and Berg 1999, Laherrere 2000, Rehrl and Freidrich 2006, Szklo, et al. 2007, Saraiva, et al. 2014) to the following representation:

$$P_t = \frac{2P_m}{1 + Cosh[b(t - t_m)]} \dots \dots \dots . (2)$$

Where :

$$b = \frac{4P_m}{Q_\infty} \dots \dots \dots . (3)$$

Where P_t is the production in period t; P_m is the production peak, which occurs in t_m; *b* and *c* are parameters.

Laherrere (2000) argued that a simple Hubbert curve may be ideally applied only in the following cases:

- Where there is a large population of fields, such that the sum of a large number of asymmetrical distributions becomes symmetrical (normal) under the Central Limit Theorem of statistics;
- Where exploration follows a natural pattern unimpeded by political events or significant economic factors;
- Where a single geological domain having a natural distribution of fields is considered, political boundaries should be avoided.

3.1.2. Generalized Hubbert Model (GHM)

In the presence of disruptions, the basic Hubbert curve tends to generate a poorly fitting model to the data. Mohr and Evans (2010) proposed the Generalized Hubbert model (GHM), which accounted for disruptions by using a series of Hubbert curves in combination with a polynomial smoothing function for improving the basic Hubbert curve.

Then, according to Mohr and Evans (2010):

$$\frac{dQ_t}{dt} = bQ_t\left(1 - \frac{Q_t}{Q_\infty}\right)X_t \ldots\ldots\ldots\ldots\ldots (4)$$

Where b is the rate constant, and X_t is the intervention function used to insert disruption.

Based on the specification in equation (2) and the equation (4), we can obtain the following function to estimate:

$$\frac{dQ_t}{dt} = \frac{b.Q_m.X_t/2}{1 + Cosh\left[b\left(\int_0^t X(\tau)d\tau - t_m\right)\right]} \ldots\ldots\ldots\ldots\ldots (5)$$

Where Q_m is the Ultimate Recoverable Reserves (URR).

Guseo, et al. (2007) modeled the intervention function as a summation of disruptions, $i \in \{1,2,\ldots.n\}$:

$$X_t = 1 + f_1(t) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + f_i(t) \ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

With each disruption could have an exponential form, i.e:

$$f_i(t) = c_i \exp\left(b_i(t - t_{di})\right) H(t - t_{di}) \ldots\ldots\ldots\ldots (7)$$

Where

t_{di}, b_i, and c_i are the commencing year, the rate constant and the amplitude of the i-th disruption, respectively.

$H(t - t_{di})$is the unit step function, commencing in year t_{di}, and is defined as :

$$H(t-t_{di}) = \begin{cases} 0\ , & t-t_{di} < 0 \\ 0{,}5, & t-t_{di} = 0 \\ 1, & t-t_{di} > 0 \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

The specification of Guseo, et al. (2007) meant that the disruption, f, increased with the time given the sign of b_i. Usually, it is negative producing mean reverting effect, then;any disruption must eventually dissipate over time. In fact, Mohr and Evans (2010) modified the function$f_i(t)$. Mathematically, it's given by:

$$f_i(t) = \begin{cases} 0 & si\, t < t_{di} \\ \dfrac{c_i(t-t_{di})}{t_{ri}} & si\, t_{di} \le t < t_{di} + t_{ri} \\ c_i exp[b_i(t-t_{di}-t_{ri})] & si\, t_{di} + t_{ri} \le t \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Where

t_{di} is the commencing year of disruption,c_i controls how far production decreased, t_{ri} controls how long production was decreasing, and b_i controls how quickly production recovered.

3.2- Accuracy of the results

The accuracy of the forecasts is measured using local and general index. The local accuracy is based on the mean absolute error (MAE), the root mean square error (RSME) and the mean absolute percentage error (MAPE) (See Diana Emang, et al. 2010). We use only the MAPE in the case of local accuracy index because the two other indexes are poor measures of forecasting errors. The following equation isthe formula used in computing the MAPE:

$$MAPE = \frac{\sum_{i=1}^{N} \left| \frac{Q_i - \hat{Q}_i}{Q_i} \right|}{N} * 100\% \ldots\ldots\ldots\ldots (10)$$

Where Q_i and $\hat{Q}_i$ are the actual observed values and the predicted values, respectively. *N* is the number of the predicted values.

The accuracy of the forecast is evaluated based on the estimation of error, thus the smaller the value of MAPE, the better the forecast is.

This criterion is expressed in easy generic percentage terms. Lewis (1982) established the criterion of MAPE for model evaluation (See Table 04).

Table 04 : **Typical MAPE Values for Model Evaluation**

MAPE %	**Evaluation**
MAPE ≤ 10%	High accuracy forecasting
10% < MAPE ≤ 20%	Good forecasting
20% < MAPE ≤ 50%	Reasonable forecasting
MAPE > 50%	Inaccurate forecasting

Source: Lewis (1982)

Following Guseo et al (2007 and Guseo et al (2015), the global accuracy can be evaluated in two steps. As the first step, the squared multiple partial coefficient is computed with the following index:

$$\tilde{R}^2 = (R^2_{GHM} - R^2_{HM})/(1 - R^2_{HM}) \dots\dots..(11)$$

In order to evaluate the significance of the extension Generalized Hubbert Model with respect to the Basic Hubbert Model, we calculate the F-ratio as follow:

$$F = [\tilde{R}^2(N-\gamma)]/[(1-\tilde{R}^2)\theta] \dots\dots\dots(12)$$

Where; N is the number of observations γ is the number of parameters in Generalized Hubbert Model and, θ is the number of parameters in this model not considered in basic model.

F is a Fisher-Snedecor distribution, $F \sim F_{\theta,(N-\gamma)}$, with the common threshold 4 as an approximate robust criterion (For more details see Guseo et al (2015)).

Furthermore, we can compute the Bayesian Information Criterion (BIC) to identify the best model since the Generalized model is an extension of the Basic Hubbert model.

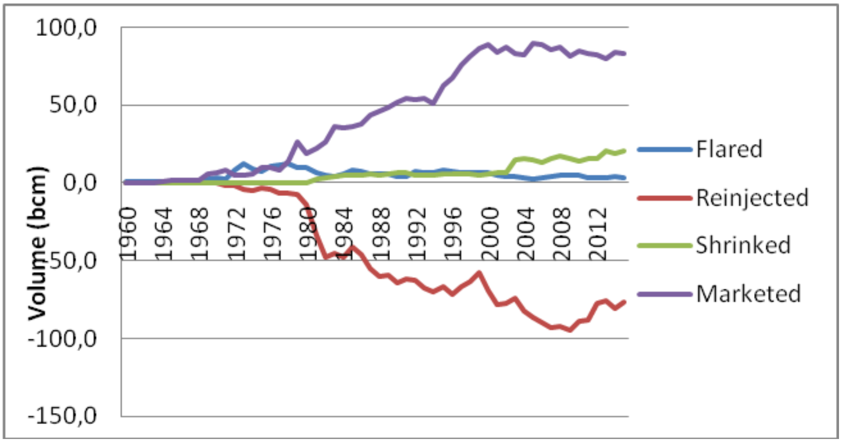
$$BIC = N.\ln\left(\frac{RSS}{N}\right) + k.\ln(N) \ldots\ldots\ldots\ldots (13)$$

Where RSS represents the Residual Sum of Squares for the fitted model and k is the number of parameters. A lower value for BIC is expected for the best fitted model.

3.3- Data

Algeria's gross gas production has increased significantly since the 80s to 2005, where it began to stagnate and peaked in 2008 (203 bcm). Its main components, marketed and reinjected production, had relatively the same evolution. The first one had peaked in 2005 (89 bcm), while the second in 2009 (95 bcm) which reflected the continuous efforts to increase the pressure within the field, especially the older one (See figure 01).

Figure 01 : **Algeria's Natural Gas production components**

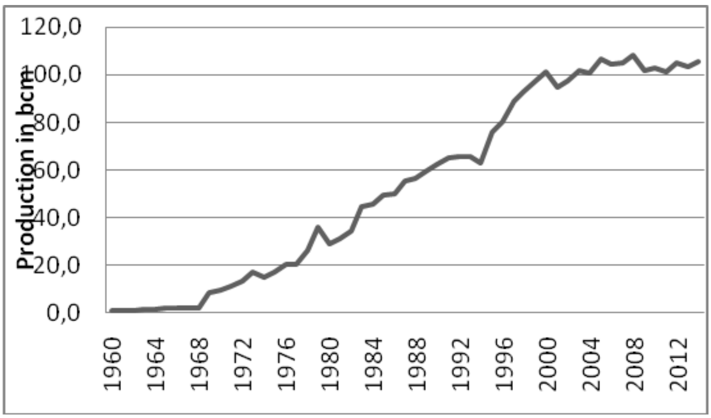


Source: Aissaoui (2001 et 2013) and the authors using OPEC Statistical Bulletins

To estimate the ultimate reserves and peak gas, we use cumulative production data because the technical evaluation of reserves is not very reliable since the resources have been over estimated to dismiss the risks of their exploitation, to improve the investment attractiveness and then, to strengthen the sales position, especially via long-term contracts. This cumulative production represents the sum of marketed, flared and, Shrinked production (Or the gross production minus the reinjected).

In fact, figure 02 reports the evolution of this volume, in which we cannot differentiate any second cycle of production until 2014, but the phase 2005-2014 gives an idea about a probable production plateau stage.

Figure 02 : **Annual Production (bcm)**



Source: Calculating using Aissaoui (2001 and 2013) and OPEC (2016).

The evolution of Algeria's natural gas production in figure (02) leads to hypothesize that cumulative production could have the form of a logistic curve.The gas production has not been affected by geopolitical factors, such the quota policy as the case of oil, nor by a major economic factors, and less by the investment policy, since the great discoveries were carried out between the half of 50s and the early of 60s, and the development of the giant Hassi R'Mel was made in the 70s.

In addition, the medium and small others fields contribute to stabilize the production and later to compensate for the decline of

Hassi R'Mel. This could give, mathematically, a symmetrical shape to the production curve.

However, this figure presents some temporary declines of production, which happened in/or after the year of the institutional, technological and economic interventions, and could be considered as disruptions. Table 05 describes these interventions.

Table 05: **Disruptions of natural gas production**

Year	Event caused Disruption	Decline (%)
1974	OPEC Embargo	12.1
1980	Cancellation of agreement: with El Paso Natural Gas, and Valhyd Program	19.1
2006	Accident in Skikda's LNG Plant	1.8
2009	Financial and Economic Crisis	5.9
2013	Accident in Tiguintourine's natural gas Plant	1.8

Source: Udapted using OPEC Annual Statistical Bulletin (2014).

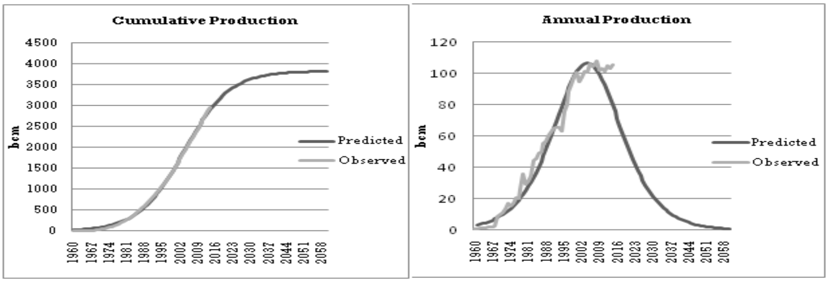
In Algeria's case, the embargo imposed by OPEC members in 1973, and the cancellation of: *(i)* the contract with American company El Paso Natural Gas, which focuses on the export of natural gas to US at a fixed price, not indexed on oil price, which is considered disadvantageous for Algeria's policymakers and, *(ii)* the plan Valhyd at the end 70s, could be considered as two institutional factors that result in disruptions in gas production. The accidents in gas production installations (Skikda LNG Plant 2004, terrorist attack in Tiguentourine 2013) are two additional technical factors that halted gas production in both sites. Finally, the financial and economic crisis of 2008, as an economic factor, had negatively affected the production of oil & gas through the fall in demand.

4- Results and Discussion

4.1- Basic Hubbert model

Based on equation (1), figure03 displays the results for the cumulative and annual natural gas production, respectively.

Figure 03: **Predicted Gas Production with basic Hubbert model**



The logistic curve of cumulative predicted values is very close to the curve of observed value, and the annual production curve appears symmetric. Based on the Hubbert curve, the Algeria peak gas occurred in 2005, with an approximate volume of 106 bcm. The future cumulative production could reach 3829,62 bcm, which reflects the URR of natural gas.

The estimated equation will be written as follows:

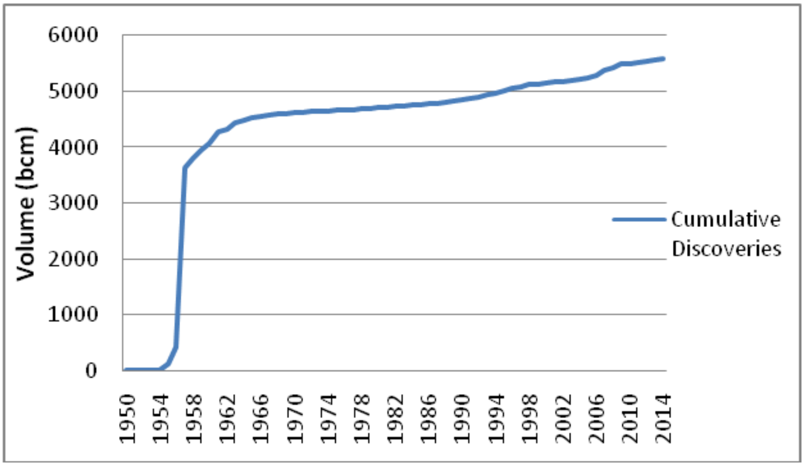
$$\frac{dQ_t}{dt} = \frac{3829{,}62}{1 + 146{,}14e^{-0{,}11t}} \dots\dots\dots\dots\dots (14)$$

If we consider the cumulative production's volume at the end of 2015 was equal to 2955 bcm, then only 863 bcm remained to be produced in the upcoming years, and 90% depletion by 2025.

It appears that the Hubbert curve can well adjust the evolution of Algeria's gas production. This could be justified through three factors.

The first one is relative to the cycle of discoveries because the production curve reflects in some degree the discoveries curve (Laherrere, 2000). Indeed, the existence of several cycles of discoveries can lead to several production cycles. However, we mentioned above that most of discoveries in Algeria were carried out between the mid-50s and the mid-60s. The following figure 04 shows the evolution of cumulative discoveries of natural gas in Algeria.

Figure 04 : **Cumulative natural gas discoveries**



Source: Established using Laherrere (2007) and Algeria's Energy Balance (2016)

The figure shows that about 80% of the gas discoverieswere carried out between 1956 and 1965, of which the giant Hassi R'Mel (1956) accounted for 50% of the total. The discoveries in the 90s were not very significant like the first ones.

The development of fields began in Hassi R'Mel, where the gross production was around 100 bcm in the early of the 80s. While, the development of other fields has delayed. They contributed to increase the gross production in the 90s, and to offset the decline of Hassi R'Mel during the last decade. As the result, the evolution of the Algeria's gas production is based mainly on the discoveries realized between the 50s and 60s, and thus have only one cycle over the period 1950-2016.

The second factor is the structure of the gas production, which is mainly dominated by Hassi R'Mel (currently 50% and much more during the first years of production). The development of this giant field gives the general shape of the gas production curve. Its decline during this last decade has required an increasing reinjected volume to stabilize its pressure. Then, the other fields contribute only, during this decade, to offset for its decline. This allowed to not have a second production cycle, and to give a symmetrical production curve.

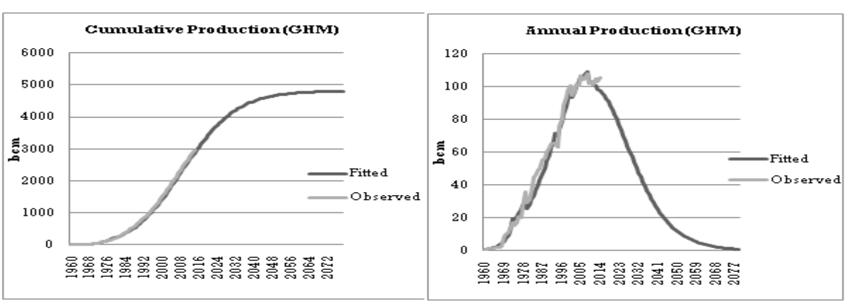
The third factor is the absence of significant economic or political factors that can largely affect gas production. Indeed, the natural gas production does not interfere with the constraint of production quotas like the case of oil. In addition, the low wellhead costs (0.60 $/MMBtu, Aissaoui, 2016) compared to sales prices, lead to develop the majority of gas fields. In this context, the giant Hassi R'Mel was developed mainly after the nationalizations according the technical and economic conditions of the time, without significant disruptions. As the result, the evaluation of the long-term natural gas availability in Algeria through "the peak production" approach cannot be affected by these factors.

However, the estimated Hubbert curve predicts a peak gas to be occurred in 2005, while the observation shows that until 2015, the peak occurred in 2008. This gap could be due to some disruptions, as transitory declines, without affecting the symmetrical shape. These disruptions are caused by some events explained in the section 3.3. It becomes interesting to consider them for improving the quality of the Hubbert curve adjustment.

4.2- Generalized Hubbert Model

Based on the equation (05) and the specification in (6) and (9), the results of a Generalized Hubbert Model for Algeria's Cumulative and annual natural gas production, have been summarized in figure (05).

Figure 05: **Predicted Gas Production with Generalized Hubbert model (GHM)**



The cumulative production curve is very close to the logistic curve, and the annual production is well described by the derived curve with disruptions. The annual production curve appears symmetric, and the estimated disruptions are very close to those observed. For an URR of 4897 bcm, the generalized Hubbert model projects a peak of 109,59 bcm to occur in 2008, with 90% depletion by 2035. About 2000 bcm will be produced in the upcoming years.

The estimated equation will be written as follows:

$$\frac{dQ_t}{dt} = \frac{4897,17}{1 + Cosh[0.10(t - 48,23)]} \dots\dots\dots\dots\dots\dots (15)$$

Based on the results obtained from the basic Hubbert model and the Generalized Hubbert model, we can deduce that it is more reliable to present the peak gas as a plateau from 2005 to 2008.[88]

In addition, taking the disruptions into account shifts the peak year a few years (3-7 years according to the IEA WEO 2008). The WEO(2008) suggested completing the peak production model with another short-term forecasting model to consider the economic, political and technological factors, which constitute the investment constraints. However, for the case of Algeria's gas production, we proposed to include the transitory events caused by these factors through an extension of the Hubbert model as specified by Mohr and Evans (2010). This remains possible only in the similar cases, which are well adjusted by the Hubbert curve based on the three reasons mentioned in the previous section.

Our findings about the remaining reserves at the end of 2015 (2000 bcm) differ from those reported by BP (British Petroleum) and APICORP (The Arab Petroleum Investments Corporation), which are 4500 bcm. Our estimates are, in our opinion, more reliable for three reasons. Firstly, we have used the volume effectively produced (gross minis the reinjected production, or the sum of the marketed, shrinked and, flared production) and not only the marketed production.

[88] Bréchet and Van Brusselen (2007) mentioned that for several experts the peak may take the form of a corrugated plateau.

Secondly, the Hubbert approach can well adjust the case of the Algeria's natural gas production. Finally, our findings are close to the last estimates announced by the Algerian government in the end of 2015, in which about 2700 bcm are the remaining gas reserves in Algeria.

The Generalized Hubbert model overcomes some limitations of the basic Hubbert model by specifying an intervention function, and provides some interest results. However, it cannot predict any future disruptions. In addition, improving operating techno-economic terms or the shale gas's exploitation could generate a second cycle of production. Then, the Generalized Hubbert Model will be unable to produce a good forecast. Probably, its combination with the Multi-Hubbert model might be a good alternative.

The gas curve shape could be affected following a future shale gas's exploitation. Indeed, Algeria ranks third globally after China and Argentina in technically recoverable shale gas reserves with 19800 bcm (and 27000 bcm according to other sources).

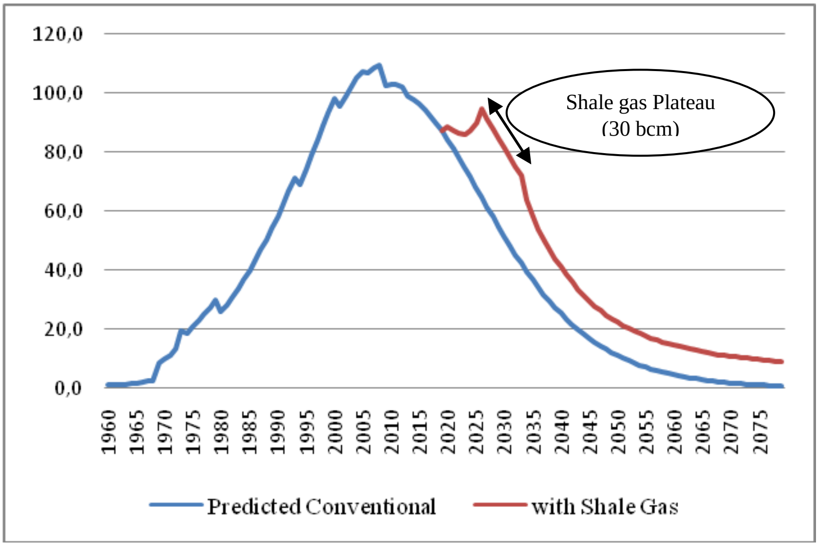
The US experience showed that the effective recovery rate is situated between 6.5 to 10%and not 15 to 25% expected before[89]. Then, we can assume that the volume to be effectively recovered in our case could situate between 1287 to 2700 bcm.

In parallel, to ensure the profitability, several experts argued that is necessary to realize a large number of drills, in which the exploitation of any well does not generally exceed (05) years. Following a fast production's growth during the first two years, the decline will be hyperbolic during two years (during which the production declines by 80-83%) and followed by an exponential form.

[89] It is difficult to extrapolate the US experience to the rest of the world's countries; the geology and the logistic are very different, and especially the legislation. In the US, the landowners are also owners of the subsoil. Then, they benefit a lot from the gas production's revenues. Therefore, they accept the pollution, thousands of water and sand trucks (22000 tons of sand by well in Louisiana) …..,etc. in other countries, the legislation is very different, the landowners cannot benefit from production's revenues, therefore they oppose this production. The Energy Information Administration (EIA) studies were very optimistic, but Poland that had to produce a huge volume was, finally, an example of big failure.

The commercial exploitation of shale gas in Algeria is planned for 2022, and the intensification of investment efforts allows reaching 30 bcm by 2025-2027 (CDER, 2014). Since Algeria has achieved only a few drills without starting an effective exploitation, it becomes difficult to estimate the shale gas production curve in the absence of reliable data. In fact, based on the previews assumptions, we can simulate the additional volumes of shale gas and, thus give a second scenario about a long-term evolution of Algeria's natural gas production.

Figure 06 : **Natural gas production with shale gas (bcm)**



The figure 06 shows that the exploitation of shale gas in Algeria could generate a second gas production cycle from 2022, with a second peak to occur in 2026 with 94.84 bcm, which is smaller than the first one of 2008. The shale gas production could plateaued between 2026 to 2033 with about 30 bcm. This allows maintaining the gas production above 70 bcm until 2033.

However, beyond the environmental risks, this exploitation is complicated regarding its technical and economic conditions. Indeed, the necessary infrastructures and technologies are mainly imported.

In addition to the drilling costs, the cost of completion operations and that of water resources are particularly high.

4.3- Accuracy of forecasts

The accuracy of the forecasts is evaluated based on local and global index reported in section 3.2. Table 06 reports the results of forecasts' accuracy.

Table 06: **Forecasts' accuracy**

Parameters	**Basic Hubbert Model (HM)**	**Generaliozed Hubbert Model (GHM)**
MAPE	19.4%	6.2%
R^2	0.9842	0.9895
$\tilde{R}^2$ w. r to HM	-	0.33
F	-	25.11
BIC	227.1	164.9

According to the table 05, the results indicate that the Mean Absolute Prediction Error (MAPE) attains lower values for the Generalized Hubbert Model than for the Basic Hubbert Model. Then, the Generalized Hubbert Model provides a high accuracy forecast (MAPE≤ 10%), while the Basic Hubbert Model provides a good forecast (10% <MAPE≤ 20%).

Using the global accuracy index, the squared partial correlation coefficient, $\tilde{R}^2$ equal to 0.33 (F = 25.11), and the BIC value is the minimum for the Generalized Hubbert Model. Therefore, this model provides a better fit to the historical gas production in Algeria and it can be used to forecast the gas production trajectory.

5- CONCLUSION AND POLICY IMPLICATIONS

Natural gas is becoming gradually the main energy in Algeria. It represents around 41% of primary energy production, 65% of energy's total consumption and, about 40% of total hydrocarbon export volume.

In a context marked by the continued increase of domestic gas consumption and the need for foreign exchange earnings to finance, economy, projecting future gas production is a key element in the energy planning and policy making of the country.

In this study, two models have been employed to estimate and forecast natural gas production of Algeria; Basic Hubbert Model and Generalized Hubbert Model. By and large, Algeria's natural gas production deviates from a basic Hubbert pattern, but can be well modeled through Generalized Hubbert approach.

Based on reliable data of the aggregate production of natural gas between the years 1960-2015, the main findings of our study are as follows:

- Algeria's natural gas aggregate production pattern presents only one cycle during this period, and cumulative production follows perfectly a logistic curve;
- The physical availability of Algeria's natural gas in the long term is well evaluated through the peak production approach using the Hubbert model;
- Generalized Hubbert model provides a better estimate and forecast compared with the basic Hubbert curve;
- Generalized Hubbert model projects a peak production of 109.59 bcm/year occured in 2008, but it is more reliable to present this peak gas as a plateau from 2005 to 2008;
- Projections show that production has reached the end plateau phase, a probable decline could be registered in the short term, in the absence of significant discoveries;
- About 2000 bcm constitute the remaining Ultimate Recoverable Reservescould be produced in the future years, and 90% depletion by 2035;

The results of this study provide policymakers a good understanding of Algeria's natural gas production pattern, and suggest some policy implications and recommendations. In fact, to ensure the renewal of reserves, this requires intensifying investment in upstream gas. It needs to create an attractive situationfor foreign companies,which are selective about investments at a time of low energy prices.

In parallel, acting in technological dimension in order to improve the field's recovery rate and to carry out secondary/tertiary recovery projects for mature gas fields. At least, accord more respect for rules in the cycling field of Hassi R'Mel (in which the reinjection reached 50% of gross production) because this field represents more than 50% of remaining recoverable reserves, and limiting the GOR (Gas Oil ration) to less than 2000 cubic meters / one cubic meter of condensates for the oil field.

Given the huge shale gas's reserves (19800 bcm), their exploitation could be a good way to maintain the total gas production more than 70 bcm, at least, until 2030. This allows satisfying the domestic gas consumption and still ensuring the gas exports (with less important volumes). But the shale gas's exploitation requires a specific technical and economic conditions in addition of changing legislation to better regulate this activity, which presents a high economic and environmental risks.

ACKNOWLEDGEMENTS

The Authors wish to thank M. Jean Laherrere for its comments and feedback, and M. Ali Aissaoui for the data that provided us.

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