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Novel Simplified Method for Coalbed Methane Feasibility Evaluation

Jose A. Gutiérrez, Raquel García, Erasmo Cadena

Department of Mining Engineering, University of León, Leon, Spain
Email: jagutbr@unileon.es

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Abstract

Coal during its carbonization process produces a gas. This gas, mainly formed by methane, can be used. This gas, coalbed methane (CBM), is usually mainly formed by methane and can be considered similar to natural gas as energy source. The evaluation of the techno-economic feasibility of the extraction of this gas depends on a large number of complex different factors. The work carried out covers the different aspects to simplify the first approach for CBM feasibility quantification considering a short number of indicators. A theoretical review and a state of the art description have been carried out, taking into account all the factors that can influence in the development of a CBM project. After that, technical feasibility has been used to evaluate total amount of gas that can be recovered. The last step was to evaluate economic feasibility to know how much gas could be economically profitable. Conclusions got have been used to develop a simple method for evaluating CBM economic feasibility considering just four easy known parameters of coal beds. These are: the rank, the thickness, the gas concentration, and the permeability.

Keywords

CBM, Feasibility Assessments, Coal, Natural Gas

1. Introduction

The gas contained in coal layers is an important energy resource capable of supporting the growing increase in energy demand. As unconventional deposits of natural gas, in addition to the coal layers, we can find natural gas in shales and low permeability sandstones. In this paper, we will focus only on the methane content of coal bed methane (CBM).

The first signs of the energy use of coal date back to 200 BC, according to Chinese records. In our days, and on a world scale, coal stands as the second type of fuel in order of consumption, although in our country its energy relevance has decreased in recent years. Due to the increase in coal consumption in Asia mainly, it is expected to become the first source of energy worldwide in the coming years.

The gas contained in the coal is a byproduct of the process of maturing it, as will be detailed later, which can be increased later due to different mechanisms. Initially, this gas was considered dangerous, so it was to reduce its concentration to increase safety in the mines. At present, this vision has changed and, far from diluting it, the maximum use of its energy potential is pursued.

The feasibility assessments for CBM exploitation cover a large number of complex of factors usually not available from the data sources of every coal basin. There is a need of performing a first approach of the economic feasibility of CBM exploitation with a simplified method.

This work is focused on the economic viability of the CBM production with the aim of knowing the possible development and factors influencing it. Several tables are proposed as a decision support system for CBM feasibility assessments.

The final use of these tables and factors will facilitate the first approach form of the economic feasibility of CBM extraction to carry out future detailed analysis of a coal basin.

2. Types of Methane Emissions from Coal

We have different origins of methane in coal layer, CBM (coal bed methane), which we can differentiate as follows:

- Methane from active mines, CMM (coal mine methane). It can also be obtained from ventilation air, VAM (ventilation air methane)
- Extraction of methane from abandoned mines, AMM (abandoned mine methane)
- Progress of surface surveys before the underground exploitation of coal. If the coal has not been extracted we would speak of methane in virgin carbon layer, VCBM (virgin coalbed methane).
- ECBM (enhanced coalbed methane), where the recovery of VCBM is stimulated by the injection of N_2 or CO_2. This method can be combined with the storage of CO_2.

The following **Table 1** shows the methane concentration most commonly obtained by each method and the gas flow in each case.

Table 1. Typical concentration of CBM systems [1].

CBM source	Methane concentration (%)	Gas flow (×1000 m^3/day)
VCBM	>95	1 - 18
CMM	35 - 75	6 - 195
VAM	0.08	4 - 140
AMM	35-90	11-86

3. Methane in Virgin Carbon Layers (VCBM)

The conventional exploitation of the VCBM is carried out by vertical drilling and hydraulic fracturing that helps to desorb the methane contained in the coal, although methods based on horizontal drilling are currently being successfully tested, thus recovering the VCBM more profitably.

The viability of a project of this type varies from 4 to 8 m^3 of CH_4/t of coal. The fundamental problems are the low permeability of coal, for which the layer is stimulated by various methods. This procedure requires a high number of surveys, which increases the operating costs.

Most coals have a porosity saturated in water. If a reduction of this pressure is caused by extracting the water by pumping, the methane of the micropores begins to desorb, which diffuses slowly through the fissures until reaching the sounding by which the depression has been caused.

The countries with the greatest potential for VCBM would be Russia, Canada, China, Australia and the United States. Even though the VCBM is a great source of clean energy, only the United States and Australia have well-established commercial productions [1].

4. Potential CBM of Coal Layers

For the methane in the coal layers to be an economically exploitable resource, the coal must present a series of characteristics that have been demonstrated after the experience acquired in the wells that are already in operation. It is useless to have a very powerful layer of coal if it has not produced the necessary gas or has not been able to store it.

Many times the exploration strategies are based on the location of the highest accumulated height, ignoring the interrelation between the geological and hydrogeological factors that affect the productivity of the MBC, methodological neglect that leads to great failures in the exploration.

The MBC productivity of a coal deposit is determined by six closely interrelated factors:

- Tectonic and structural framework.
- Depositional framework and coal distribution.
- Rank and quality of coal.
- Gas content.
- Hydrodynamics.
- Permeability.

The fairway is the synergy of several factors that originate the areas with the highest gas content. They are characterized by:

- Groundwater flow towards the center of the basin.
- Generation of secondary biogenic gas.
- High coal rank.
- High concentration of gas towards flow barriers, which would cause an upward flow to discharge areas.
- Conventional gas entrapment migrated or in solution.

5. Methodology for Determining Each Parameter

The objective of this chapter is to establish initial parameters of the reserve in order to know its production. CBM production depends on several parameters. In this section we will detail the methodology used to determine them.

A methodology for the initial estimation of CBM resources and reserves easily extrapolated has been developed. This methodology will serve to determine in what amount the parameters of the reserve should vary to obtain the return on investment. The calculations have been made in Anglo-Saxon units, due to their greater development in calculation methods and they have been converted to units of the international system later for a better compression. It will consist on the determination of:

- Coal saturation.
- Absolute permeability.
- Porosity, compressibility and pore volume
- Calculation of gas production.

5.1. Coal Saturation

Once the drilling point has been defined, the immediate analysis of the coal is taken and its rank determined. The analysis is corrected in ash, for an ash content of 15%, which is the estimated content in the layer. The analysis of ash-free dry coal, which will be used in later calculations, is also corrected.

Once this is done, the gas content of the target layer is extracted and expressed both in gross ton, tb, (15% ash) and per dry ton free of ash or pure ton (daf or tp).

Knowing the depth and the coal rank are known, we can estimate the maximum theoretical gas amount from the type adsorption isotherms of the Eddy diagram, Figure 1. By comparing the maximum capacity of adsorption with the gas content, we can know the degree of saturation of the coal.

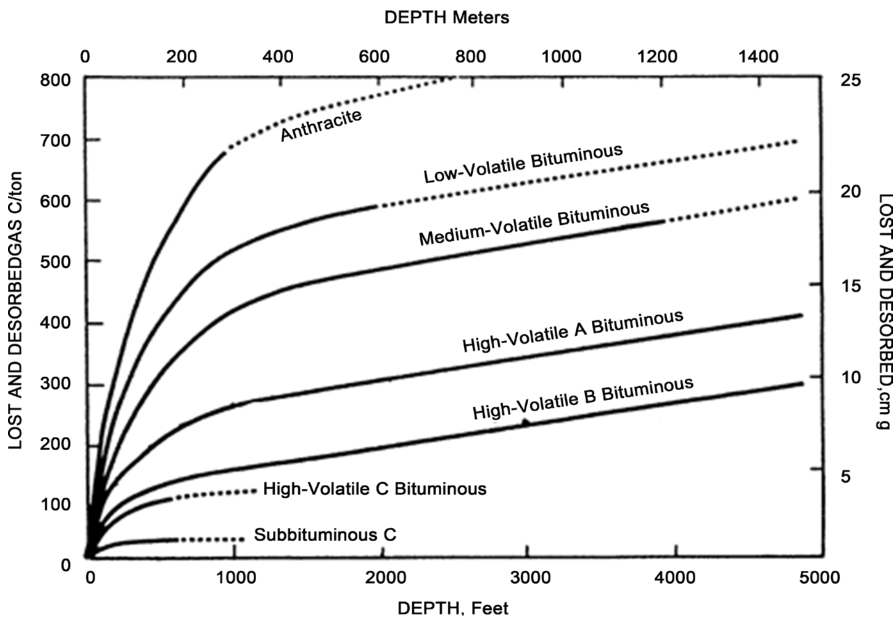

Figure 1. Eddy diagram for maximum gas adsorption [2].

5.2. Calculation of Maximum Desorbed or Recovered Gas

The next stage determines the calculation of the initial pressure of the matrix and of the fractures. The initial pressure of the fractures is established based on the depth, the initial pressure of the matrix is related to this. From the Eddy curve, a minimum desorption pressure is estimated, which will be the pressure of the fractures at which the coal will begin to desorb gas.

The final pressure of the well, and therefore of the fractures, is set at 75 psi as an operating parameter. Again entering the Eddy curve we can know the amount of gas not desorbed, and by difference with this, the percentage of gas recovered maximum.

5.3. Absolute Permeability

To determine the absolute permeability we will use the equation of Gray [3] that relates cleats and permeability:

$$K = \frac{\left(1.013 \times 10^{10}\right) \times b^3}{12 \times s} \tag{1}$$

Equation (1): Gray's Equation. Where:

- b: width of cleats (mm)
- s: spacing of cleats (mm)
- K: permeability (mD)

In order to determine the characteristics of the cleats, the following tables and graphs will be used, as well as articles about the spacing of cleats in the coal [4] [5] [6] and they are contrasted with data from other similar carbons and with results from various research articles on char properties. Table 2 shows cleats spacing depending on coal rank. Figure 2 shows cleats spacing regarding vitrinite reflectance and Figure 2.

In Figure 2 can be seen the importance of number of cleats and cleats aperture on the permeability of coal. Permeability and its evolution during CBM exploitation are crucial factors in the feasibility of a CBM exploitation. This permeability is mainly depending on cleat spacing, and aperture.

5.4. Porosity, Compressibility and Pore volume

The porosity will be estimated according to the range based on the analysis of the Gas Research Institute [7].

5.5. Well Spacing

Well spacing is manifested as a key factor for the economic viability of the reserve.

Table 2. Spacing of cleats depending on coal rank [5].

Coal rank	Cleats spacing (cm)
Sub-bituminous	2 - 15
Bituminous high in volatiles	0.36 - 2
Bituminous medium and low volatile	<1

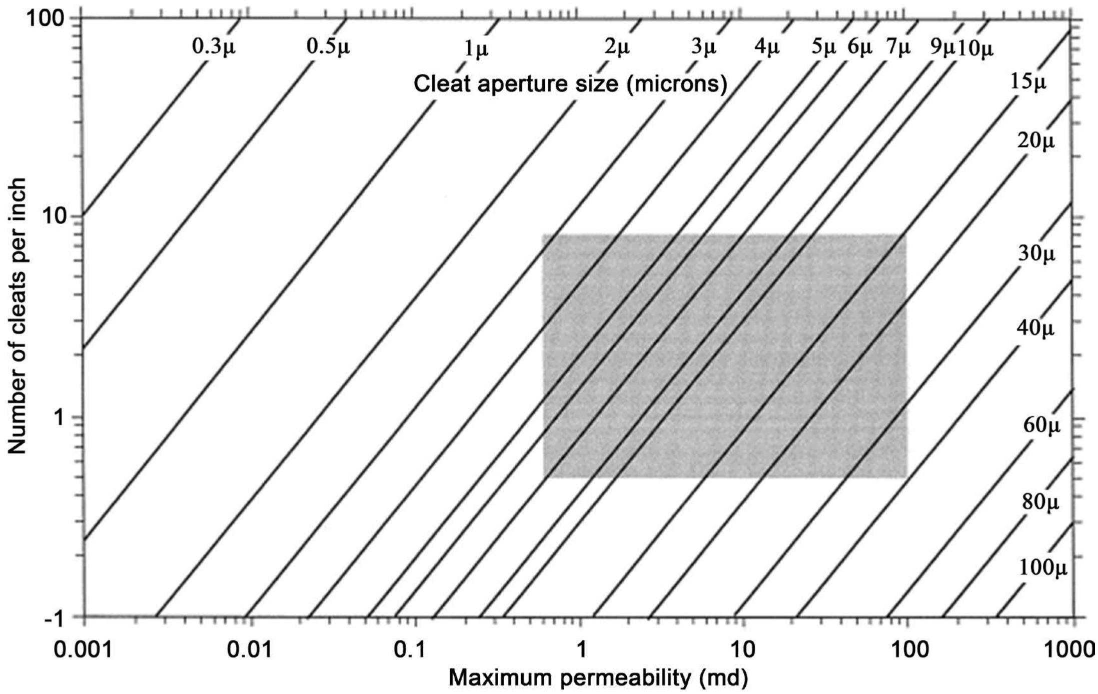

Figure 2. Relation permeability, cleats number and cleats spacing [4].

The well spacing is estimated according to the properties of the reserve, with permeability being the most important parameter. The upper and lower limits are set at 800 and 500 m, or 120 and 60 acres respectively, surfaces that are considered appropriate for CBM exploitation.

6. Estimation of Gas Production

The estimation of gas production over time is carried out by developing the curves defined by García Arenas for the Department of Petroleum and Natural Gas Engineering of West Virginia [8]. They describe a curve model from two dimensionless parameters, tD and qD, which thanks to their dimensionless condition are able to simulate the production of gas in any basin. **Figure 3** shows the typical CBM production curve in logarithmic scale. The equations used are Equations (2)-(4).

This method has been proven by specific simulation software for CBM, such as the CMG GEM, with good results.

$$q_D = \frac{q}{q_{peak}} \quad (2)$$

Equation (2) Adimensional peak flow [8]

$$t_D = \frac{t \cdot q_{peak}}{G_i} \quad (3)$$

Equation (3) Adimensional time factor [8]

where:

- q_D: dimensionless peak flow.

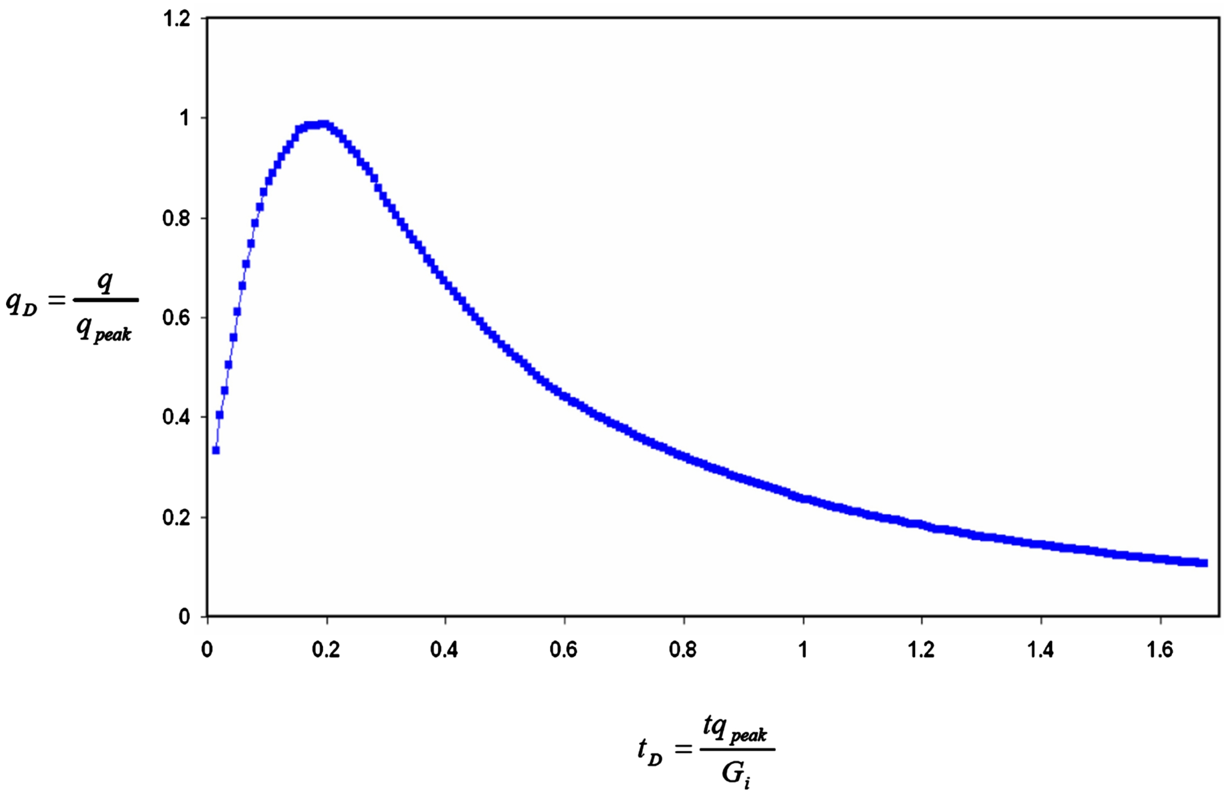

Figure 3. CBM production curve in logarithmic scale. In abscissas td, in ordinate qd [4].

- Q: actual flow.
- Q_{peak}: peak or maximum flow.
- t_D: dimensionless time factor.
- T: time in days.
- G_i: amount of gas in place.

G_i is determined multiplying coal quanty per coal gas contents. The greatest difficulty lies in the estimation of peak flow. It will come de-terminated by:

$$q_{peak} = qD \cdot k \cdot h \cdot \left(P_m - P_{wf}\right) \quad (4)$$

Equation (4) Peak flow [8]

where:

- k: permeability.
- h: height of coal layer.
- P_m: initial pressure of the matrix.
- P_{wf}: initial pressure in the fracture system.

We have all the data of previous stages except the q_{peak}, which is obtained through the following **Figure 4**.

7. Economic Feasibility

In this section we will study the economic viability of CBM wells, in order to be able to decide on their exploitation. Once described, the development costs of a well type CBM will be defined for the selected cases. Later, the paths for the

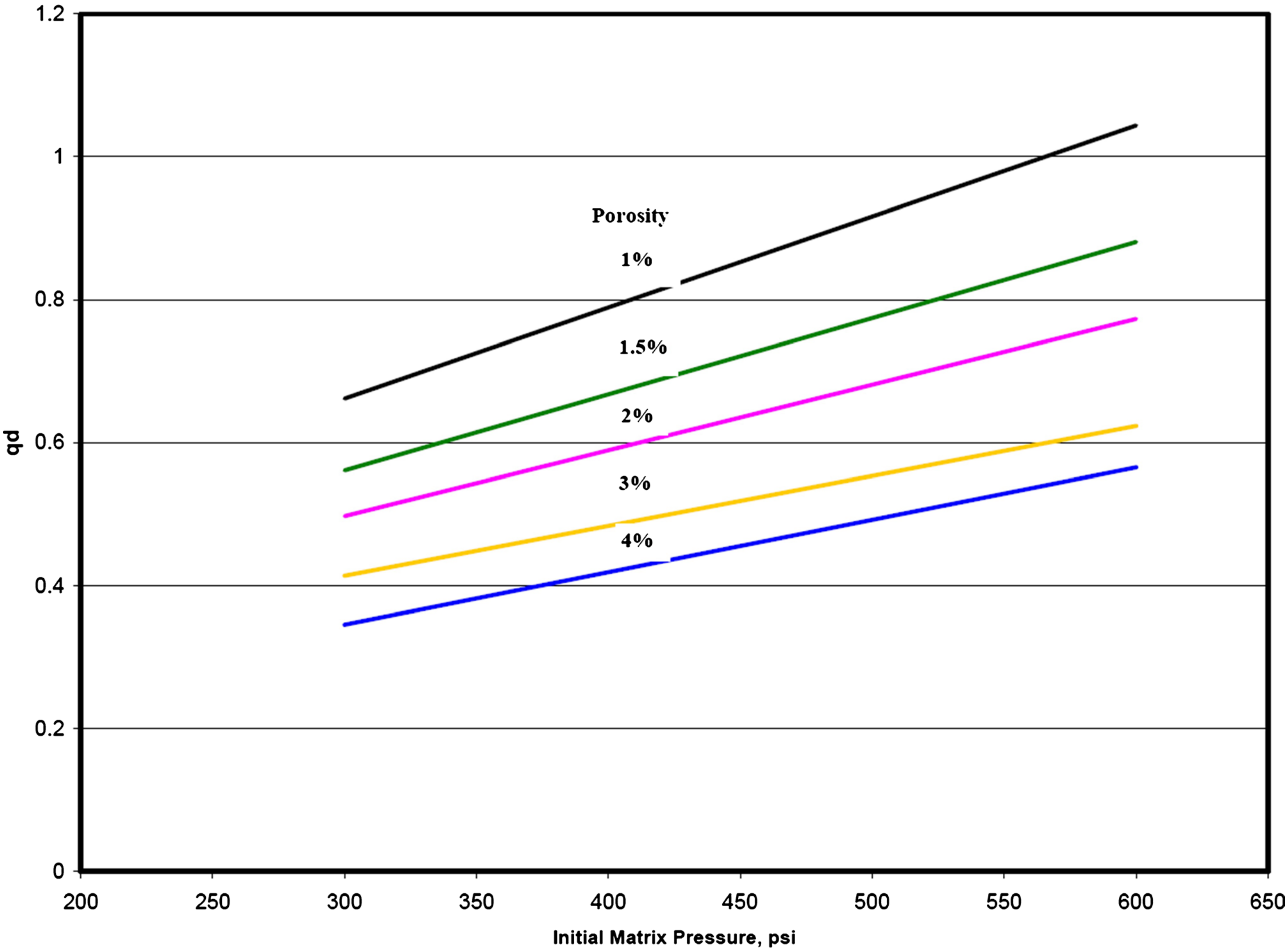

Figure 4. Dimensionless peak flow [8].

recovery of the investment will be defined.

The CBM extraction has been considered with own funds, without any other type of financing or state, banking, European subsidy, etc. The main risk factors in the development of a project of this type are: the capacity of the gas pipeline or the consumption to be obtained, the prices of natural gas, the sale price of the producer's gas and technological knowledge.

Three returns of investment will be defined, starting with the three of own funds. The first one will be an absolute return, for which the well covers the expenses generated by the gas generated, the second will be the one that gives us more profitability than an investment of 4% per year, and the third will also include the uncertainty of the investment that is considered at 8%. These returns will be calculated for four scenarios of variation in the price of natural gas.

As a last step, the development of a method has been reached so that, based on simple parameters of the gas deposit, it is possible to quickly determine the viability of the CBM extraction.

7.1. Costs of a CBM Well

In this section, we will define the annual costs of a CBM well. Up to 20 years.

The study conducted by the US.DOE [9] will be used as a basis. This is shown in Table 3.

From the reference of the drilling costs for 500 and 900 feet respectively, we can obtain the costs of our type drilling of 1000 m. The capital investment costs (CAPEX) for the well would be shown in Table 4

The drilling and development costs of the surface installation for a CBM well are set at 240,000 euros. Regarding the cost of operation and maintenance, the US.DOE found the following values, shown in Table 5.

As annual fixed costs we can determine the following, shown in Table 6.

The variable costs that we can associate correspond to the capture and storage

Table 3. Drilling costs CBM [9].

Depth (ft)	500	950	
Depth (m)	152	290	1.000
Dilling costs (€)	**60.000**	**74.000**	**146.515**
Intangibles	50.000	62.000	
Tangibles	10.000	12.000	
Well completion costs (€)	**22.500**	**27.750**	**54.943**
Intangibles	7.500	9.250	
Tangibles	15.000	18.500	

Table 4. CAPEX costs of a CBM well [9].

Concept	Costs (€)
Permits	12,000
Drilling and finishing well (1000 m)	160,000
Water collection	20,000
Water removal	1200
Electric energy	10,000
Gas collection	35,000
Total	238,200

Table 5. O & M costs of a CBM well [9].

Year	Costs (€)
1	37,500
2 - 4	20,000
<4	15,000

Table 6. Annual fixed costs of a CBM well [9].

Leasing	Management	Water treatment	Maintenance
15,000	9000	3000	10,000

of natural gas and its transportation. Capture and storage of NG is € 0.006/m^3 Transportation is estimated in € 0.003/Nm^3.

7.2. Revenue from Extraction of the CBM

The expected revenues will come in fully from the sales of the recovered gas. Although it is possible to obtain financing as described above, as well as the technology itself, these aids will depend on the body that develops the project, in this study are not going to take into account these income derived from the potential financing exposed.

Regarding the price of the CBM, for natural gas the price depends on the market. The market sets a calorific value of the gas at 34.48 MJ/m^3, which will be used in the conversion. Due to the variability of the price of gas, revenues may fluctuate significantly, so a sensitivity analysis of the feasibility of the project is carried out, with four possible scenarios based on this price variability of the gas. At first, the price of gas remained constant. The second would contemplate a gas price 25% lower than the current one. The third and fourth would be made considering an increase of 25% and 50% of the price of gas respectively, this is shown in Table 7.

8. Determination of Parameters for Viable Production

As described before, there are several parameters that condition the technical and economic viability of the development of a CBM project. Once analyzed the results on the technical and economic viability it is possible not only to know factors that affect the viable production, but also they can be quantified.

In this section we will quantify the minimum factors for viable production. It has been possible to develop a method to reduce the number of parameters and from it, to be able to determine the economic viability of the reserve. They are specified as:

- Geometry of the reserve. Surface area and height.
- Coal rank.
- Gas in situ or amount of gas.
- Permeability.

Based on these four parameters we should be able to know the possibility of extracting CBM.

The minimum amount of gas in situ was not found as relevant as initially

Table 7. Gas price scenarios.

	Price NG	€/MWh	€/m^3
Scenario 1	Reference	26.413	0.2527
Scenario 2	−25%	21.1304	0.2022
Scenario 3	+25%	33.01625	0.3159
Scenario 4	+50%	39.6195	0.3791

expected. The minimum quantity depends exclusively on the coal rank, varying from 12 m^3/t pure in anthracites to 5 m^3/t pure in high bituminous carbons in volatile type B. The rest of the minimum values of gas in situ can be seen in the following Table 8.

The rest of factors will depend on the profitability that you want to obtain in the project, so the data will be analyzed according to this objective. Thus, for a positive return (IRR > 0%) we will obtain the same minimum values as for a return greater than 4% or 8%. First let's analyze the minimum values for positive profitable production

8.1. Positive Profitable Production (IRR > 0%)

The average annual production (m^3) required for minimum economic profitability (IRR > 0%) depends on the operation time of the well and the gas prices. The following Table 9 shows the minimum annual average production values for minimum profitable production. We observe how this minimum annual average production decreases with the operating time. In addition, you can check the influence of the price of gas.

Depending on the gas price scenario, the amount of gas to drain annually will vary. This amount will depend on the permeability and the height of the layer. The following Table 10 gives the minimum height for several permeability values in each of the scenarios. It can be verified that, when the permeability is low, the minimum height required increases, while as the permeability increases, the minimum height of the layer is reduced very significantly.

8.2. Cost-Effective Production with Higher Profitability (IRR > 4%)

Considering that own funds can yield up to 4% in a fixed term, this percentage is set at least for viable production. With which the previous average annual

Table 8. Minimum gas concentration for profitability according to the range.

Coal Rank	Gas concentration (m^3/t pure)
Anthracite	12
Bituminous low volatile	8
Bituminous medium in volatile	7
Bituminous high in volatile type A	6
Bituminous high in volatile type B	5

Table 9. Average annual minimum production for positive profitability (m^3).

Years	Scenario 1	Scenario 2	Scenario 3	Scenario 4
10	325,000	410,000	260,000	215,000
20	270,000	340,000	215,000	180,000
30	250,000	315,000	200,000	170,000
50	245,000	305,000	195,000	160,000

minimum production would be modified, as shown in **Table 11**. The new values would be:

Depending on the gas price scenario, the amount to drain annually will vary. This amount will depend on the permeability and the height of the layer. The following **Table 12** details the minimum height for several permeability values in each of the scenarios.

Table 10. Minimum height for various permeability values.

IRR > 0%	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Permeability (mD)	Minimum height (m)	Minimum height (m)	Minimum height (m)	Minimum height (m)
1	45	55	35	30
2.5	9.5	12	7.5	6.5
5	4	5	3	2.6
7.5	2.6	3.2	2.2	1.8
>10	2.1	2.6	1.7	1.4

Table 11. Average annual minimum production for profitability greater than 4% (m^3).

Years	Scenario 1	Scenario 2	Scenario 3	Scenario 4
10	345,000	440,000	275,000	230,000
20	290,000	365,000	230,000	195,000
30	275,000	345,000	220,000	180,000
50	270,000	330,000	210,000	175,000

Table 12. Minimum height for various permeability values.

IRR > 4%	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Permeability (mD)	Minimum height (m)	Minimum height (m)	Minimum height (m)	Minimum height (m)
1	1	50	60	40
2.5	2.5	10	13	8.5
5	5	4.5	5.5	3.3
7.5	7.5	2.8	3.5	2.4
>10	> 10	2.3	2.9	1.8

8.3. Profitable Production Higher Profitability (IRR > 8%)

Considering that own funds can yield up to 4% in a fixed term and the uncertainty of the investment is set at 8% the minimum percentage to make the project attractive. With which the previous average annual minimum production would be modified. The new values would be shown in **Table 13** and **Table 14**.

Depending on the gas price scenario, the amount to drain annually will vary. This amount will depend on the permeability and the height of the layer. The

Table 13. Average annual minimum production for profitability greater than 8% (m^3).

Years	Scenario 1	Scenario 2	Scenario 3	Scenario 4
10	370.000	465.000	295.000	245.000
20	320.000	400.000	255.000	210.000
30	305.000	380.000	240.000	200.000
50	300.000	370.000	235.000	195.000

Table 14. Minimum height for various permeability values.

IRR > 4%	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Permeability (mD)	**Minimum height (m)**	**Minimum height (m)**	**Minimum height (m)**	**Minimum height (m)**
1	53	66	42	35
2.5	12	13	9	7.5
5	4.6	5.7	3.6	3
7.5	3.1	3.5	2.5	2.1
>10	2.5	3.1	2.0	1.7

following table details the minimum height for several permeability values in each of the scenarios. It can be verified that, when the permeability is low, the minimum height required increases, while as the permeability increases, the minimum height of the layer is reduced very significantly as shown in Table 14.

9. Minimum Basic Characteristics for Profitable Production

By developing the above, tables can be obtained that will determine the minimum values for viable production. Next, these tables will be exposed in which several parameters are evaluated:

- IRR.
- Price of natural gas.
- Coal rank.
- Gas in place (GIP).
- Gas in situ (GIS) or amount of gas.
- Height of the bad.
- Permeability.

The input data would be the expected return or IRR, price of gas (scenario) and the rank of coal. In the cells corresponding to the other four factors: GIP, GIS, height and permeability, the minimum values for profitable production are determined, so that to obtain positive profitability all of them must be overcome.

A group of 24 tables, named as Table 15, have been developed, one for each profitability and price scenario of the gas valued, for 30 and 10 years of production respectively. Once the production time is set, 10 or 30 years, the first thing to look for in the tables will be the minimum profitability required: 0%, 4% or 8%. Next, the gas price scenario will be assessed. The next step will be to determine

Table 15. Minimum conditions for profitability (Group of tables).

IRR	Price	Rank	GIP area min.	GIS min.	Height min.	Perm
30 years	€/m³		m³	m³/tp	m	mD
IRR > 0%	Scenario 1	Anthracite	346,759,920	12	45	1
IRR > 0%	Scenario 1	Anthracite	73,204,872	12	9.5	2.5
IRR > 0%	Scenario 1	Anthracite	30,823,104	12	4.0	5
IRR > 0%	Scenario 1	Anthracite	20,035,018	12	2.6	7.5
IRR > 0%	Scenario 1	Anthracite	16,182,130	12	2.1	10
IRR > 0%	Scenario 1	Bituminous low volatiles	231,173,280	8	45	1
IRR > 0%	Scenario 1	Bituminous low volatiles	48,803,248	8	9.5	2.5
IRR > 0%	Scenario 1	Bituminous low volatiles	20,548,736	8	4.0	5
IRR > 0%	Scenario 1	Bituminous low volatiles	13,356,678	8	2.6	7.5
IRR > 0%	Scenario 1	Bituminous low volatiles	10,788,086	8	2.1	10
IRR > 0%	Scenario 1	Bituminous medium volatiles	202,276,620	7	45	1
IRR > 0%	Scenario 1	Bituminous medium volatiles	42,702,842	7	9.5	2.5
IRR > 0%	Scenario 1	Bituminous medium volatiles	17,980,144	7	4.0	5
IRR > 0%	Scenario 1	Bituminous medium volatiles	11,687,094	7	2.6	7.5
IRR > 0%	Scenario 1	Bituminous medium volatiles	9,439,576	7	2.1	10
IRR > 0%	Scenario 1	Bituminous high volatiles A	173,379,960	6	45	1
IRR > 0%	Scenario 1	Bituminous high volatiles A	36,602,436	6	9.5	2.5
IRR > 0%	Scenario 1	Bituminous high volatiles A	15,411,552	6	4.0	5
IRR > 0%	Scenario 1	Bituminous high volatiles A	10,017,509	6	2.6	7.5
IRR > 0%	Scenario 1	Bituminous high volatiles A	8,091,065	6	2.1	10
IRR > 0%	Scenario 1	Bituminous high volatiles B	144,483,300	5	45	1
IRR > 0%	Scenario 1	Bituminous high volatiles B	30,502,030	5	9.5	2.5
IRR > 0%	Scenario 1	Bituminous high volatiles B	12,842,960	5	4.0	5
IRR > 0%	Scenario 1	Bituminous high volatiles B	8,347,924	5	2.6	7.5
IRR > 0%	Scenario 1	Bituminous high volatiles B	6,742,554	5	2.1	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 0%	Scenario 2	Anthracite	423,817,680	12	55	1
IRR > 0%	Scenario 2	Anthracite	92,469,312	12	12.0	2.5
IRR > 0%	Scenario 2	Anthracite	38,528,880	12	5.0	5
IRR > 0%	Scenario 2	Anthracite	24,658,483	12	3.2	7.5
IRR > 0%	Scenario 2	Anthracite	20,035,018	12	2.6	10
IRR > 0%	Scenario 2	Bituminous low volatiles	282,545,120	8	55	1
IRR > 0%	Scenario 2	Bituminous low volatiles	61,646,208	8	12.0	2.5
IRR > 0%	Scenario 2	Bituminous low volatiles	25,685,920	8	5.0	5

Continued

IRR > 0%	Scenario 2	Bituminous low volatiles	16,438,989	8	3.2	7.5
IRR > 0%	Scenario 2	Bituminous low volatiles	13,356,678	8	2.6	10
IRR > 0%	Scenario 2	Bituminous medium volatiles	247,226,980	7	55	1
IRR > 0%	Scenario 2	Bituminous medium volatiles	53,940,432	7	12.0	2.5
IRR > 0%	Scenario 2	Bituminous medium volatiles	22,475,180	7	5.0	5
IRR > 0%	Scenario 2	Bituminous medium volatiles	14,384,115	7	3.2	7.5
IRR > 0%	Scenario 2	Bituminous medium volatiles	11,687,094	7	2.6	10
IRR > 0%	Scenario 2	Bituminous high volatiles A	211,908,840	6	55	1
IRR > 0%	Scenario 2	Bituminous high volatiles A	46,234,656	6	12.0	2.5
IRR > 0%	Scenario 2	Bituminous high volatiles A	19,264,440	6	5.0	5
IRR > 0%	Scenario 2	Bituminous high volatiles A	12,329,242	6	3.2	7.5
IRR > 0%	Scenario 2	Bituminous high volatiles A	10,017,509	6	2.6	10
IRR > 0%	Scenario 2	Bituminous high volatiles B	176,590,700	5	55	1
IRR > 0%	Scenario 2	Bituminous high volatiles B	38,528,880	5	12.0	2.5
IRR > 0%	Scenario 2	Bituminous high volatiles B	16,053,700	5	5.0	5
IRR > 0%	Scenario 2	Bituminous high volatiles B	10,274,368	5	3.2	7.5
IRR > 0%	Scenario 2	Bituminous high volatiles B	8,347,924	5	2.6	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 0%	Scenario 3	Anthracite	269,702,160	12	35	1
IRR > 0%	Scenario 3	Anthracite	57,793,320	12	7.5	2.5
IRR > 0%	Scenario 3	Anthracite	23,117,328	12	3.0	5
IRR > 0%	Scenario 3	Anthracite	16,952,707	12	2.2	7.5
IRR > 0%	Scenario 3	Anthracite	13,099,819	12	1.7	10
IRR > 0%	Scenario 3	Bituminous low volatiles	179,801,440	8	35	1
IRR > 0%	Scenario 3	Bituminous low volatiles	38,528,880	8	7.5	2.5
IRR > 0%	Scenario 3	Bituminous low volatiles	15,411,552	8	3.0	5
IRR > 0%	Scenario 3	Bituminous low volatiles	11,301,805	8	2.2	7.5
IRR > 0%	Scenario 3	Bituminous low volatiles	8,733,213	8	1.7	10
IRR > 0%	Scenario 3	Bituminous medium volatiles	157,326,260	7	35	1
IRR > 0%	Scenario 3	Bituminous medium volatiles	33,712,770	7	7.5	2.5
IRR > 0%	Scenario 3	Bituminous medium volatiles	13,485,108	7	3.0	5
IRR > 0%	Scenario 3	Bituminous medium volatiles	9,889,079	7	2.2	7.5
IRR > 0%	Scenario 3	Bituminous medium volatiles	7,641,561	7	1.7	10
IRR > 0%	Scenario 3	Bituminous high volatiles A	134,851,080	6	35	1
IRR > 0%	Scenario 3	Bituminous high volatiles A	28,896,660	6	7.5	2.5
IRR > 0%	Scenario 3	Bituminous high volatiles A	11,558,664	6	3.0	5

Continued

IRR > 0%	Scenario 3	Bituminous high volatiles A	8,476,354	6	2.2	7.5
IRR > 0%	Scenario 3	Bituminous high volatiles A	6,549,910	6	1.7	10
IRR > 0%	Scenario 3	Bituminous high volatiles B	112,375,900	5	35	1
IRR > 0%	Scenario 3	Bituminous high volatiles B	24,080,550	5	7.5	2.5
IRR > 0%	Scenario 3	Bituminous high volatiles B	9,632,220	5	3.0	5
IRR > 0%	Scenario 3	Bituminous high volatiles B	7,063,628	5	2.2	7.5
IRR > 0%	Scenario 3	Bituminous high volatiles B	5,458,258	5	1.7	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 0%	Scenario 4	Anthracite	231,173,280	12	30	1
IRR > 0%	Scenario 4	Anthracite	50,087,544	12	6.5	2.5
IRR > 0%	Scenario 4	Anthracite	20,035,018	12	2.6	5
IRR > 0%	Scenario 4	Anthracite	13,870,397	12	1.8	7.5
IRR > 0%	Scenario 4	Anthracite	10,788,086	12	1.4	10
IRR > 0%	Scenario 4	Bituminous low volatiles	154,115,520	8	30	1
IRR > 0%	Scenario 4	Bituminous low volatiles	33,391,696	8	6.5	2.5
IRR > 0%	Scenario 4	Bituminous low volatiles	13,356,678	8	2.6	5
IRR > 0%	Scenario 4	Bituminous low volatiles	9,246,931	8	1.8	7.5
IRR > 0%	Scenario 4	Bituminous low volatiles	7,192,058	8	1.4	10
IRR > 0%	Scenario 4	Bituminous medium volatiles	134,851,080	7	30	1
IRR > 0%	Scenario 4	Bituminous medium volatiles	29,217,734	7	6.5	2.5
IRR > 0%	Scenario 4	Bituminous medium volatiles	11,687,094	7	2.6	5
IRR > 0%	Scenario 4	Bituminous medium volatiles	8,091,065	7	1.8	7.5
IRR > 0%	Scenario 4	Bituminous medium volatiles	6,293,050	7	1.4	10
IRR > 0%	Scenario 4	Bituminous high volatiles A	115,586,640	6	30	1
IRR > 0%	Scenario 4	Bituminous high volatiles A	25,043,772	6	6.5	2.5
IRR > 0%	Scenario 4	Bituminous high volatiles A	10,017,509	6	2.6	5
IRR > 0%	Scenario 4	Bituminous high volatiles A	6,935,198	6	1.8	7.5
IRR > 0%	Scenario 4	Bituminous high volatiles A	5,394,043	6	1.4	10
IRR > 0%	Scenario 4	Bituminous high volatiles B	96,322,200	5	30	1
IRR > 0%	Scenario 4	Bituminous high volatiles B	20,869,810	5	6.5	2.5
IRR > 0%	Scenario 4	Bituminous high volatiles B	8,347,924	5	2.6	5
IRR > 0%	Scenario 4	Bituminous high volatiles B	5,779,332	5	1.8	7.5
IRR > 0%	Scenario 4	Bituminous high volatiles B	4,495,036	5	1.4	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 4%	Scenario 1	Anthracite	385,288,800	12	50	1

Continued

IRR > 4%	Scenario 1	Anthracite	80,910,648	12	10.5	2.5
IRR > 4%	Scenario 1	Anthracite	34,675,992	12	4.5	5
IRR > 4%	Scenario 1	Anthracite	21,576,173	12	2.8	7.5
IRR > 4%	Scenario 1	Anthracite	17,723,285	12	2.3	10
IRR > 4%	Scenario 1	Bituminous low volatiles	256,859,200	8	50	1
IRR > 4%	Scenario 1	Bituminous low volatiles	53,940,432	8	10.5	2.5
IRR > 4%	Scenario 1	Bituminous low volatiles	23,117,328	8	4.5	5
IRR > 4%	Scenario 1	Bituminous low volatiles	14,384,115	8	2.8	7.5
IRR > 4%	Scenario 1	Bituminous low volatiles	11,815,523	8	2.3	10
IRR > 4%	Scenario 1	Bituminous medium volatiles	224,751,800	7	50	1
IRR > 4%	Scenario 1	Bituminous medium volatiles	47,197,878	7	10.5	2.5
IRR > 4%	Scenario 1	Bituminous medium volatiles	20,227,662	7	4.5	5
IRR > 4%	Scenario 1	Bituminous medium volatiles	12,586,101	7	2.8	7.5
IRR > 4%	Scenario 1	Bituminous medium volatiles	10,338,583	7	2.3	10
IRR > 4%	Scenario 1	Bituminous high volatiles A	192,644,400	6	50	1
IRR > 4%	Scenario 1	Bituminous high volatiles A	40,455,324	6	10.5	2.5
IRR > 4%	Scenario 1	Bituminous high volatiles A	17,337,996	6	4.5	5
IRR > 4%	Scenario 1	Bituminous high volatiles A	10,788,086	6	2.8	7.5
IRR > 4%	Scenario 1	Bituminous high volatiles A	8,861,642	6	2.3	10
IRR > 4%	Scenario 1	Bituminous high volatiles B	160,537,000	5	50	1
IRR > 4%	Scenario 1	Bituminous high volatiles B	33,712,770	5	10.5	2.5
IRR > 4%	Scenario 1	Bituminous high volatiles B	14,448,330	5	4.5	5
IRR > 4%	Scenario 1	Bituminous high volatiles B	8,990,072	5	2.8	7.5
IRR > 4%	Scenario 1	Bituminous high volatiles B	7,384,702	5	2.3	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 4%	Scenario 2	Anthracite	462,346,560	12	60	1
IRR > 4%	Scenario 2	Anthracite	100,175,088	12	13.0	2.5
IRR > 4%	Scenario 2	Anthracite	42,381,768	12	5.5	5
IRR > 4%	Scenario 2	Anthracite	26,970,216	12	3.5	7.5
IRR > 4%	Scenario 2	Anthracite	22,346,750	12	2.9	10
IRR > 4%	Scenario 2	Bituminous low volatiles	308,231,040	8	60	1
IRR > 4%	Scenario 2	Bituminous low volatiles	66,783,392	8	13.0	2.5
IRR > 4%	Scenario 2	Bituminous low volatiles	28,254,512	8	5.5	5
IRR > 4%	Scenario 2	Bituminous low volatiles	17,980,144	8	3.5	7.5
IRR > 4%	Scenario 2	Bituminous low volatiles	14,897,834	8	2.9	10
IRR > 4%	Scenario 2	Bituminous medium volatiles	269,702,160	7	60	1

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IRR > 4%	Scenario 2	Bituminous medium volatiles	58,435,468	7	13.0	2.5
IRR > 4%	Scenario 2	Bituminous medium volatiles	24,722,698	7	5.5	5
IRR > 4%	Scenario 2	Bituminous medium volatiles	15,732,626	7	3.5	7.5
IRR > 4%	Scenario 2	Bituminous medium volatiles	13,035,604	7	2.9	10
IRR > 4%	Scenario 2	Bituminous high volatiles A	231,173,280	6	60	1
IRR > 4%	Scenario 2	Bituminous high volatiles A	50,087,544	6	13.0	2.5
IRR > 4%	Scenario 2	Bituminous high volatiles A	21,190,884	6	5.5	5
IRR > 4%	Scenario 2	Bituminous high volatiles A	13,485,108	6	3.5	7.5
IRR > 4%	Scenario 2	Bituminous high volatiles A	11,173,375	6	2.9	10
IRR > 4%	Scenario 2	Bituminous high volatiles B	192,644,400	5	60	1
IRR > 4%	Scenario 2	Bituminous high volatiles B	41,739,620	5	13.0	2.5
IRR > 4%	Scenario 2	Bituminous high volatiles B	17,659,070	5	5.5	5
IRR > 4%	Scenario 2	Bituminous high volatiles B	11,237,590	5	3.5	7.5
IRR > 4%	Scenario 2	Bituminous high volatiles B	9,311,146	5	2.9	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 4%	Scenario 3	Anthracite	308,231,040	12	40	1
IRR > 4%	Scenario 3	Anthracite	65,499,096	12	8.5	2.5
IRR > 4%	Scenario 3	Anthracite	25,429,061	12	3.3	5
IRR > 4%	Scenario 3	Anthracite	18,493,862	12	2.4	7.5
IRR > 4%	Scenario 3	Anthracite	13,870,397	12	1.8	10
IRR > 4%	Scenario 3	Bituminous low volatiles	205,487,360	8	40	1
IRR > 4%	Scenario 3	Bituminous low volatiles	43,666,064	8	8.5	2.5
IRR > 4%	Scenario 3	Bituminous low volatiles	16,952,707	8	3.3	5
IRR > 4%	Scenario 3	Bituminous low volatiles	12,329,242	8	2.4	7.5
IRR > 4%	Scenario 3	Bituminous low volatiles	9,246,931	8	1.8	10
IRR > 4%	Scenario 3	Bituminous medium volatiles	179,801,440	7	40	1
IRR > 4%	Scenario 3	Bituminous medium volatiles	38,207,806	7	8.5	2.5
IRR > 4%	Scenario 3	Bituminous medium volatiles	14,833,619	7	3.3	5
IRR > 4%	Scenario 3	Bituminous medium volatiles	10,788,086	7	2.4	7.5
IRR > 4%	Scenario 3	Bituminous medium volatiles	8,091,065	7	1.8	10
IRR > 4%	Scenario 3	Bituminous high volatiles A	154,115,520	6	40	1
IRR > 4%	Scenario 3	Bituminous high volatiles A	32,749,548	6	8.5	2.5
IRR > 4%	Scenario 3	Bituminous high volatiles A	12,714,530	6	3.3	5
IRR > 4%	Scenario 3	Bituminous high volatiles A	9,246,931	6	2.4	7.5
IRR > 4%	Scenario 3	Bituminous high volatiles A	6,935,198	6	1.8	10
IRR > 4%	Scenario 3	Bituminous high volatiles B	128,429,600	5	40	1

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IRR > 4%	Scenario 3	Bituminous high volatiles B	27,291,290	5	8.5	2.5
IRR > 4%	Scenario 3	Bituminous high volatiles B	10,595,442	5	3.3	5
IRR > 4%	Scenario 3	Bituminous high volatiles B	7,705,776	5	2.4	7.5
IRR > 4%	Scenario 3	Bituminous high volatiles B	5,779,332	5	1.8	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 4%	Scenario 4	Anthracite	269,702,160	12	35	1
IRR > 4%	Scenario 4	Anthracite	53,940,432	12	7.0	2.5
IRR > 4%	Scenario 4	Anthracite	20,805,595	12	2.7	5
IRR > 4%	Scenario 4	Anthracite	15,411,552	12	2.0	7.5
IRR > 4%	Scenario 4	Anthracite	11,558,664	12	1.5	10
IRR > 4%	Scenario 4	Bituminous low volatiles	179,801,440	8	35	1
IRR > 4%	Scenario 4	Bituminous low volatiles	35,960,288	8	7.0	2.5
IRR > 4%	Scenario 4	Bituminous low volatiles	13,870,397	8	2.7	5
IRR > 4%	Scenario 4	Bituminous low volatiles	10,274,368	8	2.0	7.5
IRR > 4%	Scenario 4	Bituminous low volatiles	7,705,776	8	1.5	10
IRR > 4%	Scenario 4	Bituminous medium volatiles	157,326,260	7	35	1
IRR > 4%	Scenario 4	Bituminous medium volatiles	31,465,252	7	7.0	2.5
IRR > 4%	Scenario 4	Bituminous medium volatiles	12,136,597	7	2.7	5
IRR > 4%	Scenario 4	Bituminous medium volatiles	8,990,072	7	2.0	7.5
IRR > 4%	Scenario 4	Bituminous medium volatiles	6,742,554	7	1.5	10
IRR > 4%	Scenario 4	Bituminous high volatiles A	134,851,080	6	35	1
IRR > 4%	Scenario 4	Bituminous high volatiles A	26,970,216	6	7.0	2.5
IRR > 4%	Scenario 4	Bituminous high volatiles A	10,402,798	6	2.7	5
IRR > 4%	Scenario 4	Bituminous high volatiles A	7,705,776	6	2.0	7.5
IRR > 4%	Scenario 4	Bituminous high volatiles A	5,779,332	6	1.5	10
IRR > 4%	Scenario 4	Bituminous high volatiles B	112,375,900	5	35	1
IRR > 4%	Scenario 4	Bituminous high volatiles B	22,475,180	5	7.0	2.5
IRR > 4%	Scenario 4	Bituminous high volatiles B	8,668,998	5	2.7	5
IRR > 4%	Scenario 4	Bituminous high volatiles B	6,421,480	5	2.0	7,5
IRR > 4%	Scenario 4	Bituminous high volatiles B	4,816,110	5	1.5	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min,**	**Perm**
30 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 8%	Scenario 1	Anthracite	408,406,128	12	53	1
IRR > 8%	Scenario 1	Anthracite	92,469,312	12	12	2.5
IRR > 8%	Scenario 1	Anthracite	35,446,570	12	4,6	5
IRR > 8%	Scenario 1	Anthracite	23,887,906	12	3.1	7.5

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IRR > 8%	Scenario 1	Anthracite	19,264,440	12	2.5	10
IRR > 8%	Scenario 1	Bituminous low volatiles	272,270,752	8	53	1
IRR > 8%	Scenario 1	Bituminous low volatiles	61,646,208	8	12	2,5
IRR > 8%	Scenario 1	Bituminous low volatiles	23,631,046	8	4.6	5
IRR > 8%	Scenario 1	Bituminous low volatiles	15,925,270	8	3.1	7.5
IRR > 8%	Scenario 1	Bituminous low volatiles	12,842,960	8	2.5	10
IRR > 8%	Scenario 1	Bituminous medium volatiles	238,236,908	7	53	1
IRR > 8%	Scenario 1	Bituminous medium volatiles	53,940,432	7	12	2.5
IRR > 8%	Scenario 1	Bituminous medium volatiles	20,677,166	7	4.6	5
IRR > 8%	Scenario 1	Bituminous medium volatiles	13,934,612	7	3.1	7.5
IRR > 8%	Scenario 1	Bituminous medium volatiles	11,237,590	7	2.5	10
IRR > 8%	Scenario 1	Bituminous high volatiles A	204,203,064	6	53	1
IRR > 8%	Scenario 1	Bituminous high volatiles A	46,234,656	6	12	2.5
IRR > 8%	Scenario 1	Bituminous high volatiles A	17,723,285	6	4.6	5
IRR > 8%	Scenario 1	Bituminous high volatiles A	11,943,953	6	3.1	7.5
IRR > 8%	Scenario 1	Bituminous high volatiles A	9,632,220	6	2.5	10
IRR > 8%	Scenario 1	Bituminous high volatiles B	170,169,220	5	53	1
IRR > 8%	Scenario 1	Bituminous high volatiles B	38,528,880	5	12	2.5
IRR > 8%	Scenario 1	Bituminous high volatiles B	14,769,404	5	4.6	5
IRR > 8%	Scenario 1	Bituminous high volatiles B	9,953,294	5	3.1	7.5
IRR > 8%	Scenario 1	Bituminous high volatiles B	8,026,850	5	2.5	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 2	Anthracite	508,581,216	12	66	1
IRR > 8%	Scenario 2	Anthracite	100,175,088	12	13	2.5
IRR > 8%	Scenario 2	Anthracite	43,922,923	12	5.7	5
IRR > 8%	Scenario 2	Anthracite	26,970,216	12	3.5	7.5
IRR > 8%	Scenario 2	Anthracite	23,887,906	12	3.1	10
IRR > 8%	Scenario 2	Bituminous low volatiles	339,054,144	8	66	1
IRR > 8%	Scenario 2	Bituminous low volatiles	66,783,392	8	13	2.5
IRR > 8%	Scenario 2	Bituminous low volatiles	29,281,949	8	5.7	5
IRR > 8%	Scenario 2	Bituminous low volatiles	17,980,144	8	3.5	7.5
IRR > 8%	Scenario 2	Bituminous low volatiles	15,925,270	8	3.1	10
IRR > 8%	Scenario 2	Bituminous medium volatiles	296,672,376	7	66	1
IRR > 8%	Scenario 2	Bituminous medium volatiles	58,435,468	7	13	2.5
IRR > 8%	Scenario 2	Bituminous medium volatiles	25,621,705	7	5.7	5
IRR > 8%	Scenario 2	Bituminous medium volatiles	15,732,626	7	3.5	7.5

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IRR > 8%	Scenario 2	Bituminous medium volatiles	13,934,612	7	3.1	10
IRR > 8%	Scenario 2	Bituminous high volatiles A	254,290,608	6	66	1
IRR > 8%	Scenario 2	Bituminous high volatiles A	50,087,544	6	13	2.5
IRR > 8%	Scenario 2	Bituminous high volatiles A	21,961,462	6	5.7	5
IRR > 8%	Scenario 2	Bituminous high volatiles A	13,485,108	6	3.5	7.5
IRR > 8%	Scenario 2	Bituminous high volatiles A	11,943,953	6	3.1	10
IRR > 8%	Scenario 2	Bituminous high volatiles B	211,908,840	5	66	1
IRR > 8%	Scenario 2	Bituminous high volatiles B	41,739,620	5	13	2.5
IRR > 8%	Scenario 2	Bituminous high volatiles B	18,301,218	5	5.7	5
IRR > 8%	Scenario 2	Bituminous high volatiles B	11,237,590	5	3.5	7.5
IRR > 8%	Scenario 2	Bituminous high volatiles B	9,953,294	5	3.1	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 3	Anthracite	323,642,592	12	42	1
IRR > 8%	Scenario 3	Anthracite	69,351,984	12	9	2.5
IRR > 8%	Scenario 3	Anthracite	27,740,794	12	3.6	5
IRR > 8%	Scenario 3	Anthracite	19,264,440	12	2.5	7.5
IRR > 8%	Scenario 3	Anthracite	15,411,552	12	2.0	10
IRR > 8%	Scenario 3	Bituminous low volatiles	215,761,728	8	42	1
IRR > 8%	Scenario 3	Bituminous low volatiles	46,234,656	8	9	2.5
IRR > 8%	Scenario 3	Bituminous low volatiles	18,493,862	8	3.6	5
IRR > 8%	Scenario 3	Bituminous low volatiles	12,842,960	8	2.5	7.5
IRR > 8%	Scenario 3	Bituminous low volatiles	10,274,368	8	2.0	10
IRR > 8%	Scenario 3	Bituminous medium volatiles	188,791,512	7	42	1
IRR > 8%	Scenario 3	Bituminous medium volatiles	40,455,324	7	9	2.5
IRR > 8%	Scenario 3	Bituminous medium volatiles	16,182,130	7	3.6	5
IRR > 8%	Scenario 3	Bituminous medium volatiles	11,237,590	7	2.5	7.5
IRR > 8%	Scenario 3	Bituminous medium volatiles	8,990,072	7	2.0	10
IRR > 8%	Scenario 3	Bituminous high volatiles A	161,821,296	6	42	1
IRR > 8%	Scenario 3	Bituminous high volatiles A	34,675,992	6	9	2.5
IRR > 8%	Scenario 3	Bituminous high volatiles A	13,870,397	6	3.6	5
IRR > 8%	Scenario 3	Bituminous high volatiles A	9,632,220	6	2.5	7.5
IRR > 8%	Scenario 3	Bituminous high volatiles A	7,705,776	6	2.0	10
IRR > 8%	Scenario 3	Bituminous high volatiles B	134,851,080	5	42	1
IRR > 8%	Scenario 3	Bituminous high volatiles B	28,896,660	5	9	2.5
IRR > 8%	Scenario 3	Bituminous high volatiles B	11,558,664	5	3.6	5
IRR > 8%	Scenario 3	Bituminous high volatiles B	8,026,850	5	2.5	7.5

Continued

IRR > 8%	Scenario 3	Bituminous high volatiles B	6,421,480	5	2.0	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
30 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 4	Anthracite	269,702,160	12	35	1
IRR > 8%	Scenario 4	Anthracite	57,793,320	12	7.5	2.5
IRR > 8%	Scenario 4	Anthracite	23,117,328	12	3	5
IRR > 8%	Scenario 4	Anthracite	16,182,130	12	2.1	7.5
IRR > 8%	Scenario 4	Anthracite	13,099,819	12	1.7	10
IRR > 8%	Scenario 4	Bituminous low volatiles	179,801,440	8	35	1
IRR > 8%	Scenario 4	Bituminous low volatiles	38,528,880	8	7.5	2.5
IRR > 8%	Scenario 4	Bituminous low volatiles	15,411,552	8	3	5
IRR > 8%	Scenario 4	Bituminous low volatiles	10,788,086	8	2.1	7.5
IRR > 8%	Scenario 4	Bituminous low volatiles	8,733,213	8	1.7	10
IRR > 8%	Scenario 4	Bituminous medium volatiles	157,326,260	7	35	1
IRR > 8%	Scenario 4	Bituminous medium volatiles	33,712,770	7	7.5	2.5
IRR > 8%	Scenario 4	Bituminous medium volatiles	13,485,108	7	3	5
IRR > 8%	Scenario 4	Bituminous medium volatiles	9,439,576	7	2.1	7.5
IRR > 8%	Scenario 4	Bituminous medium volatiles	7,641,561	7	1.7	10
IRR > 8%	Scenario 4	Bituminous high volatiles A	134,851,080	6	35	1
IRR > 8%	Scenario 4	Bituminous high volatiles A	28,896,660	6	7.5	2.5
IRR > 8%	Scenario 4	Bituminous high volatiles A	11,558,664	6	3	5
IRR > 8%	Scenario 4	Bituminous high volatiles A	8,091,065	6	2.1	7.5
IRR > 8%	Scenario 4	Bituminous high volatiles A	6,549,910	6	1.7	10
IRR > 8%	Scenario 4	Bituminous high volatiles B	112,375,900	5	35	1
IRR > 8%	Scenario 4	Bituminous high volatiles B	24,080,550	5	7.5	2.5
IRR > 8%	Scenario 4	Bituminous high volatiles B	9,632,220	5	3	5
IRR > 8%	Scenario 4	Bituminous high volatiles B	6,742,554	5	2.1	7.5
IRR > 8%	Scenario 4	Bituminous high volatiles B	5,458,258	5	1.7	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 0%	Scenario 1	Anthracite	755,166,048	12	98	1
IRR > 0%	Scenario 1	Anthracite	161,821,296	12	21.0	2.5
IRR > 0%	Scenario 1	Anthracite	45,464,078	12	5.9	5
IRR > 0%	Scenario 1	Anthracite	24,658,483	12	3.2	7.5
IRR > 0%	Scenario 1	Anthracite	16,182,130	12	2.10	10
IRR > 0%	Scenario 1	Bituminous low volatiles	503,444,032	8	98	1
IRR > 0%	Scenario 1	Bituminous low volatiles	107,880,864	8	21.0	2.5

Continued

IRR > 0%	Scenario 1	Bituminous low volatiles	30,309,386	8	5.9	5
IRR > 0%	Scenario 1	Bituminous low volatiles	16,438,989	8	3.2	7.5
IRR > 0%	Scenario 1	Bituminous low volatiles	10,788,086	8	2.10	10
IRR > 0%	Scenario 1	Bituminous medium volatiles	440,513,528	7	98	1
IRR > 0%	Scenario 1	Bituminous medium volatiles	94,395,756	7	21.0	2.5
IRR > 0%	Scenario 1	Bituminous medium volatiles	26,520,712	7	5.9	5
IRR > 0%	Scenario 1	Bituminous medium volatiles	14,384,115	7	3.2	7.5
IRR > 0%	Scenario 1	Bituminous medium volatiles	9,439,576	7	2.10	10
IRR > 0%	Scenario 1	Bituminous high volatiles A	377,583,024	6	98	1
IRR > 0%	Scenario 1	Bituminous high volatiles A	80,910,648	6	21.0	2.5
IRR > 0%	Scenario 1	Bituminous high volatiles A	22,732,039	6	5.9	5
IRR > 0%	Scenario 1	Bituminous high volatiles A	12,329,242	6	3.2	7.5
IRR > 0%	Scenario 1	Bituminous high volatiles A	8,091,065	6	2.10	10
IRR > 0%	Scenario 1	Bituminous high volatiles B	314,652,520	5	98	1
IRR > 0%	Scenario 1	Bituminous high volatiles B	67,425,540	5	21.0	2.5
IRR > 0%	Scenario 1	Bituminous high volatiles B	18,943,366	5	5.9	5
IRR > 0%	Scenario 1	Bituminous high volatiles B	10,274,368	5	3.2	7.5
IRR > 0%	Scenario 1	Bituminous high volatiles B	6,742,554	5	2.10	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 0%	Scenario 2	Anthracite	1,001,750,880	12	130	1
IRR > 0%	Scenario 2	Anthracite	200,350,176	12	26.0	2.5
IRR > 0%	Scenario 2	Anthracite	57,793,320	12	7.5	5
IRR > 0%	Scenario 2	Anthracite	30,823,104	12	4.0	7.5
IRR > 0%	Scenario 2	Anthracite	20,189,133	12	2.62	10
IRR > 0%	Scenario 2	Bituminous low volatiles	667,833,920	8	130	1
IRR > 0%	Scenario 2	Bituminous low volatiles	133,566,784	8	26.0	2.5
IRR > 0%	Scenario 2	Bituminous low volatiles	38,528,880	8	7.5	5
IRR > 0%	Scenario 2	Bituminous low volatiles	20,548,736	8	4.0	7.5
IRR > 0%	Scenario 2	Bituminous low volatiles	13,459,422	8	2.62	10
IRR > 0%	Scenario 2	Bituminous medium volatiles	584,354,680	7	130	1
IRR > 0%	Scenario 2	Bituminous medium volatiles	116,870,936	7	26.0	2.5
IRR > 0%	Scenario 2	Bituminous medium volatiles	33,712,770	7	7.5	5
IRR > 0%	Scenario 2	Bituminous medium volatiles	17,980,144	7	4.0	7.5
IRR > 0%	Scenario 2	Bituminous medium volatiles	11,776,994	7	2.62	10
IRR > 0%	Scenario 2	Bituminous high volatiles A	500,875,440	6	130	1
IRR > 0%	Scenario 2	Bituminous high volatiles A	100,175,088	6	26.0	2.5

Continued

IRR > 0%	Scenario 2	Bituminous high volatiles A	28,896,660	6	7.5	5
IRR > 0%	Scenario 2	Bituminous high volatiles A	15,411,552	6	4.0	7.5
IRR > 0%	Scenario 2	Bituminous high volatiles A	10,094,567	6	2.62	10
IRR > 0%	Scenario 2	Bituminous high volatiles B	417,396,200	5	130	1
IRR > 0%	Scenario 2	Bituminous high volatiles B	83,479,240	5	26.0	2.5
IRR > 0%	Scenario 2	Bituminous high volatiles B	24,080,550	5	7.5	5
IRR > 0%	Scenario 2	Bituminous high volatiles B	12,842,960	5	4.0	7.5
IRR > 0%	Scenario 2	Bituminous high volatiles B	8,412,139	5	2.62	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 0%	Scenario 3	Anthracite	601,050,528	12	78	1
IRR > 0%	Scenario 3	Anthracite	130,998,192	12	17.0	2.5
IRR > 0%	Scenario 3	Anthracite	36,987,725	12	4.8	5
IRR > 0%	Scenario 3	Anthracite	19,264,440	12	2.5	7.5
IRR > 0%	Scenario 3	Anthracite	12,791,588	12	1.66	10
IRR > 0%	Scenario 3	Bituminous low volatiles	400,700,352	8	78	1
IRR > 0%	Scenario 3	Bituminous low volatiles	87,332,128	8	17.0	2.5
IRR > 0%	Scenario 3	Bituminous low volatiles	24,658,483	8	4.8	5
IRR > 0%	Scenario 3	Bituminous low volatiles	12,842,960	8	2.5	7.5
IRR > 0%	Scenario 3	Bituminous low volatiles	8,527,725	8	1.66	10
IRR > 0%	Scenario 3	Bituminous medium volatiles	350,612,808	7	78	1
IRR > 0%	Scenario 3	Bituminous medium volatiles	76,415,612	7	17.0	2.5
IRR > 0%	Scenario 3	Bituminous medium volatiles	21,576,173	7	4.8	5
IRR > 0%	Scenario 3	Bituminous medium volatiles	11,237,590	7	2.5	7.5
IRR > 0%	Scenario 3	Bituminous medium volatiles	7,461,760	7	1.66	10
IRR > 0%	Scenario 3	Bituminous high volatiles A	300,525,264	6	78	1
IRR > 0%	Scenario 3	Bituminous high volatiles A	65,499,096	6	17.0	2.5
IRR > 0%	Scenario 3	Bituminous high volatiles A	18,493,862	6	4.8	5
IRR > 0%	Scenario 3	Bituminous high volatiles A	9,632,220	6	2.5	7.5
IRR > 0%	Scenario 3	Bituminous high volatiles A	6,395,794	6	1.66	10
IRR > 0%	Scenario 3	Bituminous high volatiles B	250,437,720	5	78	1
IRR > 0%	Scenario 3	Bituminous high volatiles B	54,582,580	5	17.0	2.5
IRR > 0%	Scenario 3	Bituminous high volatiles B	15,411,552	5	4.8	5
IRR > 0%	Scenario 3	Bituminous high volatiles B	8,026,850	5	2.5	7.5
IRR > 0%	Scenario 3	Bituminous high volatiles B	5,329,828	5	1.66	10

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IRR	Price	Rank	GIP area min	GIS min.	Height min.	Perm
10 years	€/m³		m³	m³/tp	m	mD
IRR > 0%	Scenario 4	Anthracite	516,286,992	12	67	1
IRR > 0%	Scenario 4	Anthracite	107,880,864	12	14.0	2.5
IRR > 0%	Scenario 4	Anthracite	31,593,682	12	4.1	5
IRR > 0%	Scenario 4	Anthracite	16,952,707	12	2.2	7.5
IRR > 0%	Scenario 4	Anthracite	10,865,144	12	1.41	10
IRR > 0%	Scenario 4	Bituminous low volatiles	344,191,328	8	67	1
IRR > 0%	Scenario 4	Bituminous low volatiles	71,920,576	8	14.0	2.5
IRR > 0%	Scenario 4	Bituminous low volatiles	21,062,454	8	4.1	5
IRR > 0%	Scenario 4	Bituminous low volatiles	11,301,805	8	2.2	7.5
IRR > 0%	Scenario 4	Bituminous low volatiles	7,243,429	8	1.41	10
IRR > 0%	Scenario 4	Bituminous medium volatiles	301,167,412	7	67	1
IRR > 0%	Scenario 4	Bituminous medium volatiles	62,930,504	7	14.0	2.5
IRR > 0%	Scenario 4	Bituminous medium volatiles	18,429,648	7	4.1	5
IRR > 0%	Scenario 4	Bituminous medium volatiles	9,889,079	7	2.2	7.5
IRR > 0%	Scenario 4	Bituminous medium volatiles	6,338,001	7	1.41	10
IRR > 0%	Scenario 4	Bituminous high volatiles A	258,143,496	6	67	1
IRR > 0%	Scenario 4	Bituminous high volatiles A	53,940,432	6	14.0	2.5
IRR > 0%	Scenario 4	Bituminous high volatiles A	15,796,841	6	4.1	5
IRR > 0%	Scenario 4	Bituminous high volatiles A	8,476,354	6	2.2	7.5
IRR > 0%	Scenario 4	Bituminous high volatiles A	5,432,572	6	1.41	10
IRR > 0%	Scenario 4	Bituminous high volatiles B	215,119,580	5	67	1
IRR > 0%	Scenario 4	Bituminous high volatiles B	44,950,360	5	14.0	2.5
IRR > 0%	Scenario 4	Bituminous high volatiles B	13,164,034	5	4.1	5
IRR > 0%	Scenario 4	Bituminous high volatiles B	7,063,628	5	2.2	7.5
IRR > 0%	Scenario 4	Bituminous high volatiles B	4,527,143	5	1.41	10
IRR	Price	Rank	GIP area min	GIS min.	Height min.	Perm
10 years	€/m³		m³	m³/tp	m	mD
IRR > 4%	Scenario 1	Anthracite	847,635,360	12	110	1
IRR > 4%	Scenario 1	Anthracite	177,232,848	12	23.0	2.5
IRR > 4%	Scenario 1	Anthracite	50,087,544	12	6.5	5
IRR > 4%	Scenario 1	Anthracite	26,970,216	12	3.5	7.5
IRR > 4%	Scenario 1	Anthracite	17,723,285	12	2.30	10
IRR > 4%	Scenario 1	Bituminous low volatiles	565,090,240	8	110	1
IRR > 4%	Scenario 1	Bituminous low volatiles	118,155,232	8	23.0	2.5
IRR > 4%	Scenario 1	Bituminous low volatiles	33,391,696	8	6.5	5

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IRR > 4%	Scenario 1	Bituminous low volatiles	17,980,144	8	3.5	7.5
IRR > 4%	Scenario 1	Bituminous low volatiles	11,815,523	8	2.30	10
IRR > 4%	Scenario 1	Bituminous medium volatiles	494,453,960	7	110	1
IRR > 4%	Scenario 1	Bituminous medium volatiles	103,385,828	7	23.0	2.5
IRR > 4%	Scenario 1	Bituminous medium volatiles	29,217,734	7	6.5	5
IRR > 4%	Scenario 1	Bituminous medium volatiles	15,732,626	7	3.5	7.5
IRR > 4%	Scenario 1	Bituminous medium volatiles	10,338,583	7	2.30	10
IRR > 4%	Scenario 1	Bituminous high volatiles A	423,817,680	6	110	1
IRR > 4%	Scenario 1	Bituminous high volatiles A	88,616,424	6	23.0	2.5
IRR > 4%	Scenario 1	Bituminous high volatiles A	25,043,772	6	6.5	5
IRR > 4%	Scenario 1	Bituminous high volatiles A	13,485,108	6	3.5	7.5
IRR > 4%	Scenario 1	Bituminous high volatiles A	8,861,642	6	2.30	10
IRR > 4%	Scenario 1	Bituminous high volatiles B	353,181,400	5	110	1
IRR > 4%	Scenario 1	Bituminous high volatiles B	73,847,020	5	23.0	2.5
IRR > 4%	Scenario 1	Bituminous high volatiles B	20,869,810	5	6.5	5
IRR > 4%	Scenario 1	Bituminous high volatiles B	11,237,590	5	3.5	7.5
IRR > 4%	Scenario 1	Bituminous high volatiles B	7,384,702	5	2.30	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 4%	Scenario 2	Anthracite	1,078,808,640	12	140	1
IRR > 4%	Scenario 2	Anthracite	223,467,504	12	29.0	2.5
IRR > 4%	Scenario 2	Anthracite	63,187,363	12	8.2	5
IRR > 4%	Scenario 2	Anthracite	33,905,414	12	4.4	7.5
IRR > 4%	Scenario 2	Anthracite	22,346,750	12	2.90	10
IRR > 4%	Scenario 2	Bituminous low volatiles	719,205,760	8	140	1
IRR > 4%	Scenario 2	Bituminous low volatiles	148,978,336	8	29.0	2.5
IRR > 4%	Scenario 2	Bituminous low volatiles	42,124,909	8	8.2	5
IRR > 4%	Scenario 2	Bituminous low volatiles	22,603,610	8	4.4	7.5
IRR > 4%	Scenario 2	Bituminous low volatiles	14,897,834	8	2.90	10
IRR > 4%	Scenario 2	Bituminous medium volatiles	629,305,040	7	140	1
IRR > 4%	Scenario 2	Bituminous medium volatiles	130,356,044	7	29.0	2.5
IRR > 4%	Scenario 2	Bituminous medium volatiles	36,859,295	7	8.2	5
IRR > 4%	Scenario 2	Bituminous medium volatiles	19,778,158	7	4.4	7.5
IRR > 4%	Scenario 2	Bituminous medium volatiles	13,035,604	7	2.90	10
IRR > 4%	Scenario 2	Bituminous high volatiles A	539,404,320	6	140	1
IRR > 4%	Scenario 2	Bituminous high volatiles A	111,733,752	6	29.0	2.5
IRR > 4%	Scenario 2	Bituminous high volatiles A	31,593,682	6	8.2	5

Continued

IRR > 4%	Scenario 2	Bituminous high volatiles A	16,952,707	6	4.4	7.5
IRR > 4%	Scenario 2	Bituminous high volatiles A	11,173,375	6	2.90	10
IRR > 4%	Scenario 2	Bituminous high volatiles B	449,503,600	5	140	1
IRR > 4%	Scenario 2	Bituminous high volatiles B	93,111,460	5	29.0	2.5
IRR > 4%	Scenario 2	Bituminous high volatiles B	26,328,068	5	8.2	5
IRR > 4%	Scenario 2	Bituminous high volatiles B	14,127,256	5	4.4	7.5
IRR > 4%	Scenario 2	Bituminous high volatiles B	9,311,146	5	2.90	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 4%	Scenario 3	Anthracite	662,696,736	12	86	1
IRR > 4%	Scenario 3	Anthracite	138,703,968	12	18.0	2.5
IRR > 4%	Scenario 3	Anthracite	40,070,035	12	5.2	5
IRR > 4%	Scenario 3	Anthracite	21,576,173	12	2.8	7.5
IRR > 4%	Scenario 3	Anthracite	14,101,570	12	1.83	10
IRR > 4%	Scenario 3	Bituminous low volatiles	441,797,824	8	86	1
IRR > 4%	Scenario 3	Bituminous low volatiles	92,469,312	8	18.0	2.5
IRR > 4%	Scenario 3	Bituminous low volatiles	26,713,357	8	5.2	5
IRR > 4%	Scenario 3	Bituminous low volatiles	14,384,115	8	2.8	7.5
IRR > 4%	Scenario 3	Bituminous low volatiles	9,401,047	8	1.83	10
IRR > 4%	Scenario 3	Bituminous medium volatiles	386,573,096	7	86	1
IRR > 4%	Scenario 3	Bituminous medium volatiles	80,910,648	7	18.0	2.5
IRR > 4%	Scenario 3	Bituminous medium volatiles	23,374,187	7	5.2	5
IRR > 4%	Scenario 3	Bituminous medium volatiles	12,586,101	7	2.8	7.5
IRR > 4%	Scenario 3	Bituminous medium volatiles	8,225,916	7	1.83	10
IRR > 4%	Scenario 3	Bituminous high volatiles A	331,348,368	6	86	1
IRR > 4%	Scenario 3	Bituminous high volatiles A	69,351,984	6	18.0	2.5
IRR > 4%	Scenario 3	Bituminous high volatiles A	20,035,018	6	5.2	5
IRR > 4%	Scenario 3	Bituminous high volatiles A	10,788,086	6	2.8	7.5
IRR > 4%	Scenario 3	Bituminous high volatiles A	7,050,785	6	1.83	10
IRR > 4%	Scenario 3	Bituminous high volatiles B	276,123,640	5	86	1
IRR > 4%	Scenario 3	Bituminous high volatiles B	57,793,320	5	18.0	2.5
IRR > 4%	Scenario 3	Bituminous high volatiles B	16,695,848	5	5.2	5
IRR > 4%	Scenario 3	Bituminous high volatiles B	8,990,072	5	2.8	7.5
IRR > 4%	Scenario 3	Bituminous high volatiles B	5,875,654	5	1.83	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m³**		**m³**	**m³/tp**	**m**	**mD**
IRR > 4%	Scenario 4	Anthracite	547,110,096	12	71	1

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IRR > 4%	Scenario 4	Anthracite	115,586,640	12	15.0	2.5
IRR > 4%	Scenario 4	Anthracite	33,134,837	12	4.3	5
IRR > 4%	Scenario 4	Anthracite	17,723,285	12	2.3	7.5
IRR > 4%	Scenario 4	Anthracite	11,558,664	12	1.50	10
IRR > 4%	Scenario 4	Bituminous low volatiles	364,740,064	8	71	1
IRR > 4%	Scenario 4	Bituminous low volatiles	77,057,760	8	15.0	2.5
IRR > 4%	Scenario 4	Bituminous low volatiles	22,089,891	8	4.3	5
IRR > 4%	Scenario 4	Bituminous low volatiles	11,815,523	8	2.3	7.5
IRR > 4%	Scenario 4	Bituminous low volatiles	7,705,776	8	1.50	10
IRR > 4%	Scenario 4	Bituminous medium volatiles	319,147,556	7	71	1
IRR > 4%	Scenario 4	Bituminous medium volatiles	67,425,540	7	15.0	2.5
IRR > 4%	Scenario 4	Bituminous medium volatiles	19,328,655	7	4.3	5
IRR > 4%	Scenario 4	Bituminous medium volatiles	10,338,583	7	2.3	7.5
IRR > 4%	Scenario 4	Bituminous medium volatiles	6,742,554	7	1.50	10
IRR > 4%	Scenario 4	Bituminous high volatiles A	273,555,048	6	71	1
IRR > 4%	Scenario 4	Bituminous high volatiles A	57,793,320	6	15.0	2.5
IRR > 4%	Scenario 4	Bituminous high volatiles A	16,567,418	6	4.3	5
IRR > 4%	Scenario 4	Bituminous high volatiles A	8,861,642	6	2.3	7.5
IRR > 4%	Scenario 4	Bituminous high volatiles A	5,779,332	6	1.50	10
IRR > 4%	Scenario 4	Bituminous high volatiles B	227,962,540	5	71	1
IRR > 4%	Scenario 4	Bituminous high volatiles B	48,161,100	5	15.0	2.5
IRR > 4%	Scenario 4	Bituminous high volatiles B	13,806,182	5	4.3	5
IRR > 4%	Scenario 4	Bituminous high volatiles B	7,384,702	5	2.3	7.5
IRR > 4%	Scenario 4	Bituminous high volatiles B	4,816,110	5	1.50	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 1	Anthracite	924,693,120	12	120	1
IRR > 8%	Scenario 1	Anthracite	192,644,400	12	25	2,5
IRR > 8%	Scenario 1	Anthracite	55,481,587	12	7.2	5
IRR > 8%	Scenario 1	Anthracite	30,052,526	12	3.9	7.5
IRR > 8%	Scenario 1	Anthracite	19,495,613	12	2.53	10
IRR > 8%	Scenario 1	Bituminous low volatiles	616,462,080	8	120	1
IRR > 8%	Scenario 1	Bituminous low volatiles	128,429,600	8	25	2.5
IRR > 8%	Scenario 1	Bituminous low volatiles	36,987,725	8	7.2	5
IRR > 8%	Scenario 1	Bituminous low volatiles	20,035,018	8	3.9	7.5
IRR > 8%	Scenario 1	Bituminous low volatiles	12,997,076	8	2.53	10
IRR > 8%	Scenario 1	Bituminous medium volatiles	539,404,320	7	120	1

Continued

IRR > 8%	Scenario 1	Bituminous medium volatiles	112,375,900	7	25	2.5
IRR > 8%	Scenario 1	Bituminous medium volatiles	32,364,259	7	7.2	5
IRR > 8%	Scenario 1	Bituminous medium volatiles	17,530,640	7	3.9	7.5
IRR > 8%	Scenario 1	Bituminous medium volatiles	11,372,441	7	2.53	10
IRR > 8%	Scenario 1	Bituminous high volatiles A	462,346,560	6	120	1
IRR > 8%	Scenario 1	Bituminous high volatiles A	96,322,200	6	25	2.5
IRR > 8%	Scenario 1	Bituminous high volatiles A	27,740,794	6	7.2	5
IRR > 8%	Scenario 1	Bituminous high volatiles A	15,026,263	6	3.9	7.5
IRR > 8%	Scenario 1	Bituminous high volatiles A	9,747,807	6	2.53	10
IRR > 8%	Scenario 1	Bituminous high volatiles B	385,288,800	5	120	1
IRR > 8%	Scenario 1	Bituminous high volatiles B	80,268,500	5	25	2.5
IRR > 8%	Scenario 1	Bituminous high volatiles B	23,117,328	5	7.2	5
IRR > 8%	Scenario 1	Bituminous high volatiles B	12,521,886	5	3.9	7.5
IRR > 8%	Scenario 1	Bituminous high volatiles B	8,123,172	5	2.53	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min.**	**Height min.**	**Perm**
10 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 2	Anthracite	1,155,866,400	12	150	1
IRR > 8%	Scenario 2	Anthracite	238,879,056	12	31	2.5
IRR > 8%	Scenario 2	Anthracite	69,351,984	12	9.0	5
IRR > 8%	Scenario 2	Anthracite	36,987,725	12	4.8	7.5
IRR > 8%	Scenario 2	Anthracite	24,273,194	12	3.15	10
IRR > 8%	Scenario 2	Bituminous low volatiles	770,577,600	8	150	1
IRR > 8%	Scenario 2	Bituminous low volatiles	159,252,704	8	31	2.5
IRR > 8%	Scenario 2	Bituminous low volatiles	46,234,656	8	9.0	5
IRR > 8%	Scenario 2	Bituminous low volatiles	24,658,483	8	4.8	7.5
IRR > 8%	Scenario 2	Bituminous low volatiles	16,182,130	8	3.15	10
IRR > 8%	Scenario 2	Bituminous medium volatiles	674,255,400	7	150	1
IRR > 8%	Scenario 2	Bituminous medium volatiles	139,346,116	7	31	2.5
IRR > 8%	Scenario 2	Bituminous medium volatiles	40,455,324	7	9.0	5
IRR > 8%	Scenario 2	Bituminous medium volatiles	21,576,173	7	4.8	7.5
IRR > 8%	Scenario 2	Bituminous medium volatiles	14,159,363	7	3.15	10
IRR > 8%	Scenario 2	Bituminous high volatiles A	577,933,200	6	150	1
IRR > 8%	Scenario 2	Bituminous high volatiles A	119,439,528	6	31	2.5
IRR > 8%	Scenario 2	Bituminous high volatiles A	34,675,992	6	9.0	5
IRR > 8%	Scenario 2	Bituminous high volatiles A	18,493,862	6	4.8	7.5
IRR > 8%	Scenario 2	Bituminous high volatiles A	12,136,597	6	3.15	10
IRR > 8%	Scenario 2	Bituminous high volatiles B	481,611,000	5	150	1

Continued

IRR > 8%	Scenario 2	Bituminous high volatiles B	99,532,940	5	31	2.5
IRR > 8%	Scenario 2	Bituminous high volatiles B	28,896,660	5	9.0	5
IRR > 8%	Scenario 2	Bituminous high volatiles B	15,411,552	5	4.8	7.5
IRR > 8%	Scenario 2	Bituminous high volatiles B	10,113,831	5	3.15	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min,**	**Height min,**	**Perm**
10 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 3	Anthracite	724,342,944	12	94	1
IRR > 8%	Scenario 3	Anthracite	154,115,520	12	20	2.5
IRR > 8%	Scenario 3	Anthracite	43,922,923	12	5.7	5
IRR > 8%	Scenario 3	Anthracite	23,117,328	12	3.0	7.5
IRR > 8%	Scenario 3	Anthracite	15,411,552	12	2.00	10
IRR > 8%	Scenario 3	Bituminous low volatiles	482,895,296	8	94	1
IRR > 8%	Scenario 3	Bituminous low volatiles	102,743,680	8	20	2.5
IRR > 8%	Scenario 3	Bituminous low volatiles	29,281,949	8	5.7	5
IRR > 8%	Scenario 3	Bituminous low volatiles	15,411,552	8	3.0	7.5
IRR > 8%	Scenario 3	Bituminous low volatiles	10,274,368	8	2.00	10
IRR > 8%	Scenario 3	Bituminous medium volatiles	422,533,384	7	94	1
IRR > 8%	Scenario 3	Bituminous medium volatiles	89,900,720	7	20	2.5
IRR > 8%	Scenario 3	Bituminous medium volatiles	25,621,705	7	5.7	5
IRR > 8%	Scenario 3	Bituminous medium volatiles	13,485,108	7	3.0	7.5
IRR > 8%	Scenario 3	Bituminous medium volatiles	8,990,072	7	2.00	10
IRR > 8%	Scenario 3	Bituminous high volatiles A	362,171,472	6	94	1
IRR > 8%	Scenario 3	Bituminous high volatiles A	77,057,760	6	20	2.5
IRR > 8%	Scenario 3	Bituminous high volatiles A	21,961,462	6	5.7	5
IRR > 8%	Scenario 3	Bituminous high volatiles A	11,558,664	6	3.0	7.5
IRR > 8%	Scenario 3	Bituminous high volatiles A	7,705,776	6	2.00	10
IRR > 8%	Scenario 3	Bituminous high volatiles B	301,809,560	5	94	1
IRR > 8%	Scenario 3	Bituminous high volatiles B	64,214,800	5	20	2.5
IRR > 8%	Scenario 3	Bituminous high volatiles B	18,301,218	5	5.7	5
IRR > 8%	Scenario 3	Bituminous high volatiles B	9,632,220	5	3.0	7.5
IRR > 8%	Scenario 3	Bituminous high volatiles B	6,421,480	5	2.00	10
IRR	**Price**	**Rank**	**GIP area min**	**GIS min,**	**Height min,**	**Perm**
10 years	**€/m^3**		**m^3**	**m^3/tp**	**m**	**mD**
IRR > 8%	Scenario 4	Anthracite	601,050,528	12	78	1
IRR > 8%	Scenario 4	Anthracite	130,998,192	12	17.0	2.5
IRR > 8%	Scenario 4	Anthracite	36,987,725	12	4.8	5
IRR > 8%	Scenario 4	Anthracite	19,264,440	12	2.5	7.5

Continued

IRR > 8%	Scenario 4	Anthracite	12,791,588	12	1.66	10
IRR > 8%	Scenario 4	Bituminous low volatiles	400,700,352	8	78	1
IRR > 8%	Scenario 4	Bituminous low volatiles	87,332,128	8	17.0	2.5
IRR > 8%	Scenario 4	Bituminous low volatiles	24,658,483	8	4.8	5
IRR > 8%	Scenario 4	Bituminous low volatiles	12,842,960	8	2.5	7.5
IRR > 8%	Scenario 4	Bituminous low volatiles	8,527,725	8	1.66	10
IRR > 8%	Scenario 4	Bituminous medium volatiles	350,612,808	7	78	1
IRR > 8%	Scenario 4	Bituminous medium volatiles	76,415,612	7	17.0	2.5
IRR > 8%	Scenario 4	Bituminous medium volatiles	21,576,173	7	4.8	5
IRR > 8%	Scenario 4	Bituminous medium volatiles	11,237,590	7	2.5	7.5
IRR > 8%	Scenario 4	Bituminous medium volatiles	7,461,760	7	1.66	10
IRR > 8%	Scenario 4	Bituminous high volatiles A	300,525,264	6	78	1
IRR > 8%	Scenario 4	Bituminous high volatiles A	65,499,096	6	17.0	2.5
IRR > 8%	Scenario 4	Bituminous high volatiles A	18,493,862	6	4.8	5
IRR > 8%	Scenario 4	Bituminous high volatiles A	9,632,220	6	2.5	7.5
IRR > 8%	Scenario 4	Bituminous high volatiles A	6,395,794	6	1.66	10
IRR > 8%	Scenario 4	Bituminous high volatiles B	250,437,720	5	78	1
IRR > 8%	Scenario 4	Bituminous high volatiles B	54,582,580	5	17.0	2.5
IRR > 8%	Scenario 4	Bituminous high volatiles B	15,411,552	5	4.8	5
IRR > 8%	Scenario 4	Bituminous high volatiles B	8,026,850	5	2.5	7.5
IRR > 8%	Scenario 4	Bituminous high volatiles B	5,329,828	5	1.66	10

the rank of the coal in our reserve.

Subsequently, we must verify that the permeability, height and gas and GIP values of the area affected by the well are greater than or equal to those defined in the corresponding table. The minimum GIP divided by the height will give a layer surface. This surface corrected with the dip will give us a surface area to drain, which will determine the minimum spacing of the wells.

As a remark it should be added that these tables are used to determine profitability for vertical drilling and without multilayer drilling. Summary tables for project viability are shown below.

10. Conclusions

The economic viability was calculated with three different profitability objectives for positive evaluation. The first one only contemplates the recovery of the investment (IRR > 0%), while the second and third raise the possibility of obtaining more return than an investment of 4% and 8%. For these projections, four possible scenarios were considered of natural gas price in the wholesale market:

the current price (scenario 1), price reduction by 25% (scenario 2), price increase by 25% (scenario 3) and price increase 50% (scenario 4).

For the estimation of the economic viability, in a first stage, the annual production of each well was determined and, after this, it was the annual investment and operation costs. Next, revenues were defined for each of the proposed scenarios and profitability was analyzed for each case.

Recovering the results and the methodology followed, we obtained the possibility of carrying out a sensitivity analysis of the technical parameters of the reserve to economic profitability, which resulted in the development of user-friendly tables, through which we can determine the economic viability of any CBM reservation. These tables are based on the quantification of the following factors:

- IRR.
- Price of natural gas.
- Coal rank.
- Gas in place (GIP).
- Gas *in situ* (GIS) or amount of gas.
- Height.
- Permeability.

For the use of these tables, the IRR and the gas price scenarios are data to be chosen by the designer, therefore subjective. The minimum gas quantity is only a function of the coal rank. Height and permeability are intimately linked. When the permeability is higher, the height needed to obtain profitability of well is reduced. The GIP is a function of GIS, height and spacing. From the above, it is clear that the tables will help to design the well spacing.

Applying these tables to the autonomous community of Castilla y León, it will be possible to know the amount of extractable gas in a profitable manner for 10 or 30 years of production. It will be carried out for gas prices corresponding to scenario 1, with returns of 0%, 4% and 8%.

Regarding the main geological and geomorphological factors and their relationship with the economic viability of CBM farms, the following conclusions can be drawn:

- The amount of gas or gas *in situ* minimum required for viable production is dependent on the rank of coal. This is because for a final downhole pressure each coal can store a given adsorbed gas.
- If the permeability is considered independent of the rank, the key factor to develop a project of this type regarding permeability is the height. Thus a layer with low height but high permeability can be exploitable in a cost-effective manner. The same statement can be established in the opposite direction, since height is usually a more familiar property in coal deposits. It can be inferred that for a given height, the CBM exploitation goes to depend very directly on the permeability obtained in drilling tests.
- The greater the depth, the greater the cost of drilling, but the greater will be the gas adsorbed due to the pressure. The optimum depth to carry out a pro-

ject of this type will vary between 500 and 1500 m. Above 1500 m drilling costs increase, as well as the technical complexity of it.

- Regarding the variation in operating time, permeability becomes a key factor once it is shortened. A CBM farm will be more sensitive to exploitation times the lower its permeability. Permeabilities above 15 - 20 mD present low sensitivity to the reduction of production times.
- The permeability, confirmed as a key factor, will depend exponentially on the width of the cleats network, while it will depend on the spacing in a linear manner, so the width of the cleats will be a crucial factor in the development of the project.
- The expected production time will define very clearly the spacing of the wells. The greater the period of exploitation, the greater the spacing of the wells may be, a circumstance that will increase profitability due to the fact that the highest cost of a well of this type is drilling. The annual fixed operating and maintenance costs for more than 10 years are shown as low in the economic set of the operation, of the order of € 50,000/well per year. The spacing will be in the range of 500 and 800 m.

Regarding purely economic factors, the viability of a project of this type will depend more on the evolution of gas prices than on the required profitability. This high sensitivity to gas prices justifies the realization of the production analysis for the 4 different scenarios proposed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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