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Investigating the Effects of Uncertainties Associated with the Unconventional Gas Development in the Netherlands

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Abstract. *The natural gas production in the Netherlands is estimated to decline significantly in the coming 25 years. This situation has led producers to consider alternatives such as unconventional gas resources which are successfully utilized in the US and debated all over the world. However, despite the substantial initial resource estimates, unconventional gas development in the Netherlands is believed to be highly challenging, especially due to the technical, economic and societal uncertainties such as geological characteristics, costs, prices and public acceptance. Hence, whether the unconventional gas production can significantly contribute to the gas supply or not in this deeply uncertain environment rises as an important question. In this study, this question is investigated by developing a system dynamics simulation model for the unconventional gas development, and using this model for the exploration of future possibilities based on a large number of scenarios. Also, the model is used to assess the effectiveness of price and supply regulation policies under uncertainty. In most of the scenarios, the production rate is observed to be very low, indicating a negligible contribution to the total gas supply. The model can be used to test several other policy alternatives, and the effects of uncertainties in the model structure itself can be investigated by developing different model structures.*

Keywords. *Unconventional gas, natural gas, uncertainty, exploratory modeling and analysis, system dynamics*

1 Introduction

Following the discovery of the Groningen gas field and many small on and offshore fields more than 50 years ago, the Dutch energy sector experienced a rapid transition. Households and industry took advantage of this abundant and convenient energy source, while exploration and production companies and the government benefited from the high revenues (Correljé, van der Linde, and Westerwoudt 2003). However, despite the effective government policies which encouraged the production from small fields and extended the lifecycle of Groningen field for future supply, the approaching depletion is expected to cause the current production of 85 bcm/year to drop down to approximately 15 bcm/year in 2035 (MEZ 2010). Still, the state-owned exploration and production company EBN has set its goal as 30 billion cubic meters (bcm) annual production in 2030 from conventional or unconventional small fields, although this is estimated to be only around 10 bcm (EBN 2011), (MEZ 2011).

Unconventional gas is the generic name given to the gas produced from more challenging reservoirs, with the most well-known types being shale gas, tight gas and coal bed methane (CBM). After the rapid production boost in the United States, unconventional gas has emerged as a promising but debatable solution to ensure the security of supply also in the Netherlands. However, the development in the Netherlands is surrounded by several uncertainties. (Eker and van Daalen 2012, forthcoming) identifies such uncertainties at the European level, which are present in the Dutch case, too. These uncertainties are mainly about the cost and price developments which determine economic viability, the attitude of investors and authorities, and public acceptance issues due to environmental risks.

Whether unconventional gas can make a significant contribution to cover the discrepancy between conventional gas production estimates and the 30/30 goal rises as an important question in the presence of uncertainties. This paper seeks an answer to this question by investigating how unconventional gas development may evolve under the influence of various uncertainties. Assessment of the effectiveness of selected policy alternatives which are implemented in other regions and cases is the secondary purpose of this paper.

In the remainder of this paper, first the methodology used in this study will be described. Then in section 3, the model and its underlying assumptions will be explained. In section 4, the results of simulation experiments will be discussed in terms of the development of production under the effects of uncertainties and in terms of the effectiveness of policies. The paper will end with conclusions in section 5.

2 Method: Exploratory System Dynamics Modeling and Analysis

Exploratory Modeling and Analysis (EMA) can be defined as “a research methodology that uses computational experiments to analyze complex and uncertain systems” (Bankes, Walker, and Kwakkel 2010). As a model-based decision support tool for decision making under deep uncertainty, EMA enables taking a huge number of uncertainties into account simultaneously, exploring a huge number of future world alternatives, and finding policy options which perform well in any of these future worlds (Bankes 1993), (Agusdinata 2008).

System dynamics (SD) is a modeling methodology used to analyze and understand the behavior of dynamic complex systems based on causal relations and feedback loops (Sterman 2000). With such attributes, SD models enable generating plausible scenarios, whereas EMA enables generating a huge number of such scenarios for uncertainty analysis. Hence, the combination of these two, called Exploratory System Dynamics Modeling and Analysis (ESDMA), provides the systematic exploration and analysis of a huge number of plausible behaviors over time, and testing the robustness of various policies according to these scenarios (Pruyt and Kwakkel 2011).

This study adopts the ESDMA methodology: SD is selected as the modeling methodology due to its appropriateness to represent the feedback-rich gas system with the fundamental relations between supply, demand and investments. However, uncertainties in the unconventional gas case are difficult to investigate using only SD. Therefore, EMA is chosen for uncertainty analysis due to its ability to generate a huge number of scenarios by setting various parameter values and function forms, and to analyze the results of these scenarios.

3 Model Description

Unconventional gas differs from conventional gas only in terms of production techniques and related socio-economic issues. Because of that, to investigate the development of unconventional gas, only the upstream of the gas industry, e.g. exploration and production, is included in the model. The upstream sector of the gas industry is modeled based on the field lifecycle which is composed of exploration, appraisal, development and production phases (Jahn, Cook, and Graham 2008), and in correspondence with the resource and reserve terminology of the Society of Petroleum Evaluation Engineers (2002). Fig. 1 shows this structure, which can also be used for representing the conventional gas lifecycle. *Prospective resources* are undiscovered but assumed to be technically and economically recoverable resources according to geological estimations. Once the presence of prospective resources is proven with exploration drilling activities, they are named as *contingent resources* if they are technically recoverable but uneconomic, and they can become *undeveloped reserves* immediately if they are also economically recoverable. Depending on fluctuations in price and cost, some reserves may become uneconomic to develop, or some contingent resources may become economically recoverable, hence *undeveloped reserves*. Although they are economically recoverable, undeveloped reserves are used for recovery only if they are prepared for production with the construction of production wells, and become *developed reserves*. The *production rate* is formulated as the minimum of *developed reserves*, *production capacity* which depends on the total number of production wells and the annual *demand for unconventional gas*.

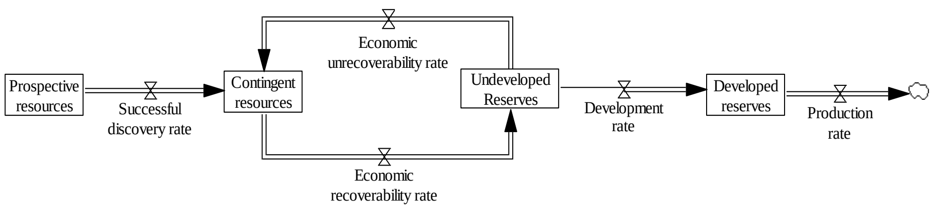

Fig. 1. The representation of the gas field lifecycle

There is no unique definition of economic recoverability since it depends on the individual investment decisions of firms. As an aggregate economic recoverability definition at the system level, in this model, undeveloped reserves are assumed to be at the breakeven level which makes potential revenues equal to development cost with current price and cost values, and continuously adjusted according to that.

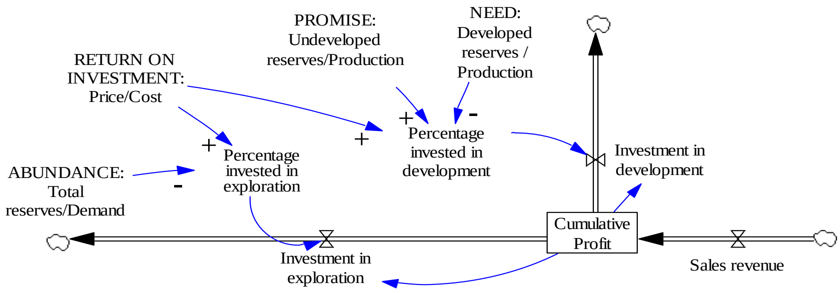

Fig. 2. Investments in the model

Certainly, the extent of new discoveries and the development rate depends on the investments made in these activities by the industry. In this model, these investments are assumed to be percentages of the cumulative profit obtained from the sales, and the percentages are assumed to be related to four factors as shown in Fig. 2. Firstly, following the existing SD models about natural gas (Naill 1974), (Chyong Chi, Nuttall, and Reiner 2009) the ratio of wellhead price to the unit cost of development is assumed to indicate the general profitability in the industry, which increases investments in both exploration and development. The ratio of total reserves to the demand indicates abundance and inhibits investments in exploration. Investment in development increases if undeveloped reserves are promising to maintain the production rate, which is represented by the ratio of undeveloped reserves to the production rate. Lastly, the ratio of developed reserves to the production rate indicates the availability of reserves to maintain the production, which in turn shows the need for developing more.

Demand is an important factor which affects investment decisions and production rate. In this model, the total of domestic and export demand is assumed to change with a steady fraction and also depending on the price changes. Since conventional gas production will be continuing as the primary source, the demand specifically for unconventional gas is formulated as the difference between the total demand and conventional production assuming that this deficit is desired to be covered first by the unconventional domestic production rather than imports.

In the existing gas or petroleum resource models (Naill 1974), (Chyong Chi, Nuttall, and Reiner 2009), (Richardson, Sterman, and Davidsen 1988) the relation between investments and exploration or development rates is modeled via the unit cost of exploration or development, i.e. the cost per cubic meter of gas. This structure, which links the investments directly to the discovery and development of reserves, is considered a powerful representation and could be an alternative model structure. However, in this study, the use of investments for land acquisition and well construction which leads to the discovery and development of reserves is preferred to be explicitly modeled. The development of unconventional gas requires drilling a higher number of wells due to low recovery amounts per well compared to conventional gas, and this leads to issues like large land requirements, large public opposition and long delays in the licensing procedure. The structure with wells enables including the uncertainties regarding these issues in the model more explicitly. Fig. 3 shows the core of this structure where exploration wells which result in discoveries are improved to become production wells or stimulate the construction of new wells.

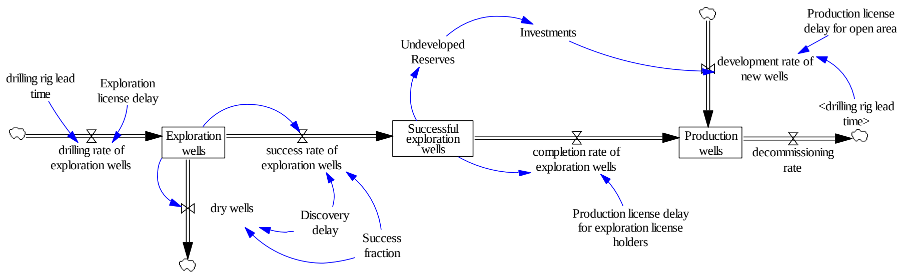

Fig. 3. The representation of well drilling in the model

Fig. 4 shows these model sectors described above, namely the reserves, investments, demand and wells, and via which variables they are connected. The entire list of model equations can be obtained from the authors.

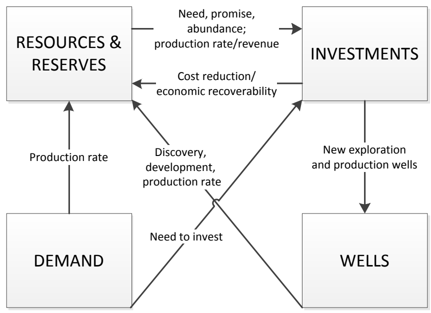

Fig. 4. Model sectors and their connections

4 Results

The model is quantified based on the data obtained from the Dutch conventional and the US unconventional gas production records. The uncertainty ranges of parameters and alternatives of graphical functions are given in Appendix I. The model is simulated for the time period 2011 until 2050, and 5000 experiments are conducted on the model, each for a different combination of uncertainty values and alternatives.

4.1 No Policy

In Fig. 5 where each line depicts an experiment result, it can be seen that the *production rate* slightly exceeds 20 bcm/year in only one case, and it is mostly below 2 bcm in 2030 as the density graph at the right shows. Given the increasing pattern of *developed reserves* and *UG demand* even under uncertainties, low production rates are attributed to low *production capacity* levels without any doubt. This means that the drilling rate of production wells was not adequate, and this is traced back to the decreasing investments in all cases as Fig. 6 shows, due to low *sales revenues* which do not allow further high investments.

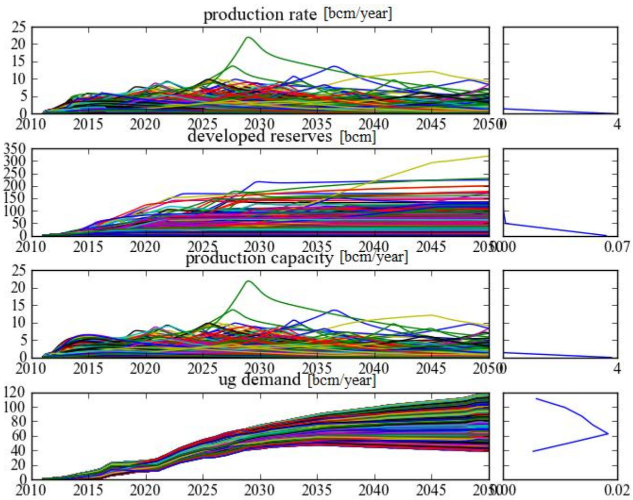

Fig. 5. Output ranges of production rate and related variables in the case of no policy

Although the analysis results demonstrated a very small contribution by unconventional gas to the gas supply, unconventional production rates can still be increased with effective policies. In that sense, knowing the subspaces of uncertainty which yield high production rates would be insightful for the generation of effective policy candidates. Fig. 7 shows the uncertainties which are involved in the cases where *production rate* resulted in values greater than 1 bcm/year in 2030 only with a portion of their entire range. These are determined with the implementation of the Patient Rule Induction Method (PRIM) (Bryant and Lempert 2010) on the output data of experiments, which resulted in three groups of cases. In Fig. 7, each color represents such a group that contains a fraction of cases of interest, together with the others, and each line shows the sub-range of the corresponding uncertainty that formed the cases in this group. For example, there was no case in which *average estimated ultimate recoverability per well* is smaller the mid value of its uncertainty range but the *production rate* in 2030 is greater than 1 bcm/year. In summary, high *production rates* are obtained in the case of high values of *wellhead price, initial well productivity, average EUR per well*, and *development acceptance fraction*, and low values of *production license delay for exploration license holders*.

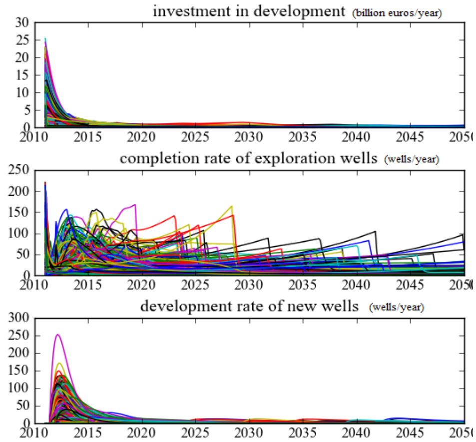

Fig. 6. Output ranges of production capacity drivers in the case of no policy

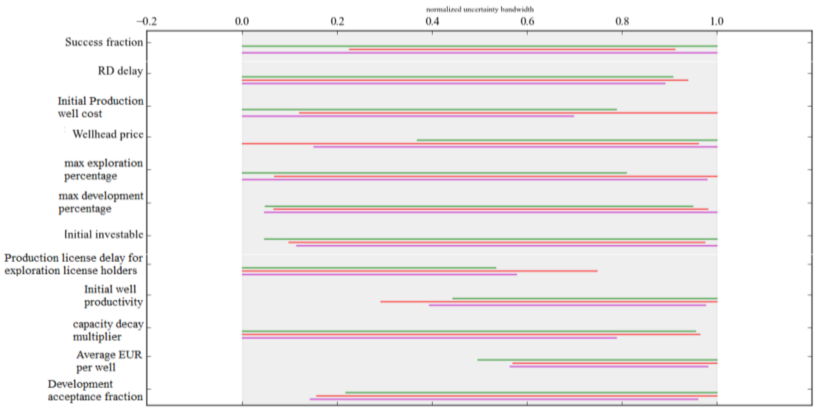

Fig. 7. Uncertainty ranges which yield production rates greater than 1 bcm/year in 2030

4.2 Policy Alternatives

Although *initial well productivity*, *average EUR per well, development acceptance fraction* and *production license delay for exploration license holders* are shown to be more influential on the *production rate* in the above analysis, wellhead price is a more common policy variable which can be stabilized at values higher than the uncertain market prices as currently done in Middle East and India (IEA 2009). It can be a solution to the decreasing investment rates discussed in the previous section by increasing the revenues and indicating higher rate of returns. Therefore, the effectiveness of price regulation in terms of increasing the *production rate* is tested in this study, by considering two pricing schemes: The first policy option, called *price regulation 1* imposes a constant wellhead price, 0.35 €/m^3 till 2050, whereas the second one, called *price regulation 2*, sets a dynamic scheme in which the price is initially 0.45 €/m^3, but gradually reduced to 0.28 €/m^3 in 15 years.

Regulating supply in order to preserve the reserves for future supply is another common policy similar to the “small fields” policy of the Dutch government and exemplified in (Naill 1974), too. Such a regulation which reduces the supply as the ratio of *developed reserves* to the *production rate* decreases is also tested in this study in terms of its impact on *production rate*.

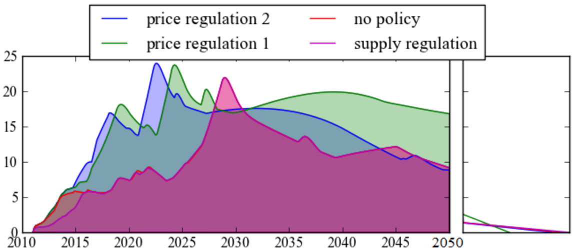

Fig. 8. Comparison of policies on the production rate

Fig. 8 shows the envelopes that *production rate* values are packed in, in other words, the range between the minimum and maximum values it may take. In that sense, *supply regulation* cannot be said to perform considerably different than no policy option, except the maximum production rate values created by it being lower than those in the case of no policy in the first five years. Both price regulation alternatives can generate higher *production rates* than no policy case, but in the first five years when the alternative 2 has a higher price, the maximum production rates that may be generated do not differ from those of alternative 1. More importantly, the majority of cases still result in production rates lower than 2 bcm/year in 2030, as can be seen in the density graph at right.

5 Conclusion

In this study, the development of unconventional gas production in the Netherlands under uncertainty has been analyzed. The system dynamics model built for this purpose is distinguished from the existing gas models in terms of detailing the exploration and production procedures with the inclusion of license application, land acquisition and well drilling activities. This model is used to generate numerous scenarios and to explore the future possibilities with these scenarios. The results imply that, without any policy intervention or with price and supply regulation policies, unconventional gas production is expected to remain much below the desired amount. However, different policy alternatives, especially regarding the uncertainties shown to be influential on production rate in Section 4.1, can be generated and tested in the same way. For example, *initial well productivity* and *average EUR per well* can be pushed to have high values by implementing technology improvement policies.

The analysis of results showed that what impedes the growth of the production rate is the unavailability of capital for investments. In the model, despite an initial capital consumed in the very first years, the only financial resource for investments is assumed to be the revenues collected from the sales of unconventional gas itself.

Following the insufficiency of revenues to finance further development, the investors are recommended to use external resources for a longer duration.

In this model the investment decisions about the development of reserves are assumed to be dependent on the availability of reserves with respect to the production rate and the ratio of development cost to the wellhead price. However, real decision making mechanism is more complex than that, and differs according to the individual preferences of firms. Therefore, the effects of such model structure uncertainties regarding the resources and decision making mechanisms of investments can be investigated with several different models in the future research.

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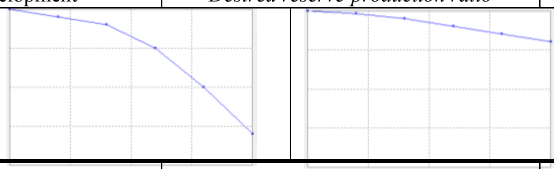
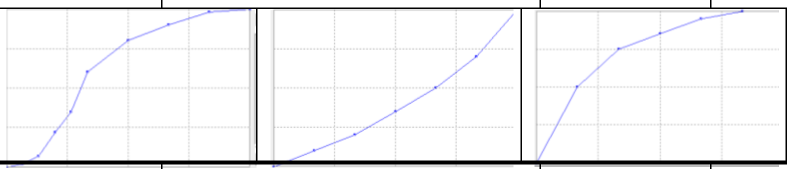
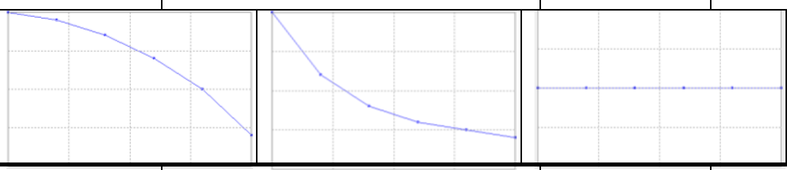
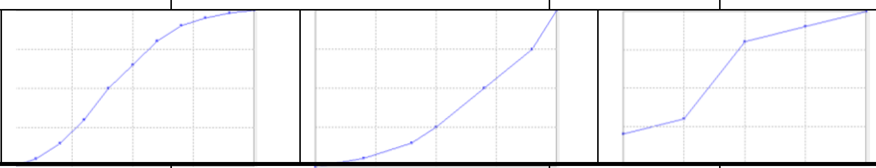
Appendix: Uncertainties in the model and their ranges

Uncertainty name	Range	References
Tight recovery factor	0.4 – 0.6	(Muntendam-Bos et al. 2009)
GIIP Tight	Triangular(147,185,228) [bcm]	
Shale recovery factor	0.05 – 0.2	
GIIP Shale	Triangular(48000,110000,230000)	
CBM recovery factor	0.25 – 0.28	
GIIP CBM	Triangular(977, 1417, 2029) [bcm]	
Success fraction	Triangular(0.4, 0.65, 0.7)	(EBN 2011)
Average discoveries per well	0.5 – 1 [bcm/well]	
Threshold tech. investment	0.01 – 1 [billion euro]	-
R&D delay	0.5 – 3 [years]	-
Initial production well cost	0.02 - 0.033 [billion euro/well]	(EBN 2011), (Geny 2010)
Steady demand change fraction	-0.01 - 0.01	(GTS 2011), (Energiezaak 2011)
Price elasticity of gas demand	0.3 – 0.5	-
Desired reserve demand ratio	20 – 50 [years]	-
Desired reserve production ratio	20 – 50 [years]	-
Wellhead price	0.2 – 0.3 [€/m^3]	(EBN 2011), (Geny 2010), (IEA 2009)
max exploration percentage	0.8 - 1	-
max development percentage	0.5 – 0.9	-
Initial investable	10 – 30 [billion euro]	-
Discovery delay	1 – 5 [years]	(Naill 1974), (EBN 2011)
drilling rig lead time	0.5 – 1 [years]	-
Exploration license delay	0.25 – 1.25 [years]	(NLOG 2007)
Prod. lic. delay for exp. lic. holders	0.25 – 0.75 [years]	
Prod. lic. delay for open area	0.5 – 1.25 [years]	
Initial well productivity	0.0075 - 0.025 [bcm/year/well]	(IEA 2009)
capacity decay multiplier	0.2 – 0.27 [1/year]	(IEA 2009)
Initial exploration well cost	0.013 - 0.022 [billion euro/well]	(EBN 2011), (Geny 2010)
Average EUR per well	0.01 - 0.2 [bcm/well]	(Muntendam-Bos et al. 2009), (IEA 2009)
Exploration acceptance fraction	0 - 0.75	-
Development acceptance frac.	0 – 0.6	-
area per well	40 – 320 [acre/well]	(Muntendam-Bos et al. 2009)
Land cost per km2	0.003 - 0.006 [€/km^2]	(NLOG 2007)

Uncertainty	Input	x axis range	y axis range
Effect of need on development	*Developed reserve-production ratio / Desired reserve-production ratio*	0 - 2	0 - 1
Alternatives			1
Effect of promise on development	*Undeveloped reserve-production ratio/Desired reserve-production ratio*	0 - 3	0 - 1
Alternatives			1
Effect of scarcity on exploration	*Reserve-demand ratio/Desired reserve-demand ratio*	0 - 2	0 - 1
Alternatives			1
Effect of ROI on investment	*Return on Investment*	0 - 2	0 - 1
Alternatives			
Conventional Production	*Time*	2011- 2050, 2011 - 2035	0 - 80
Alternatives			
Fraction invested in development technology	*Return on Investment*	0 – 1.5	0 – 1
Alternatives