Analytical Study of Iran Nonrenewable Energy Resources Using Hubbert Theory

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ABSTRACT: This study concentrates on the analysis of the oil and natural gas reserves of Iran, which hold a crucial role in the global energy market. A common method for the analysis and prediction of the production rates of nonrenewable reserves is used, namely, the Hubbert peak theory. The corresponding curves shed light on the energy policy and future guidelines of the region. Interestingly, Iran ranks fourth and second in the world’s oil and natural gas reserves, and the analysis covers more than 50 years, which makes it beneficial in different ways. Regional production rates, the maximum amount of production, and the approximate year in which this would happen, plus the time span until all reserves entirely run out, are extracted in this assessment. Besides, the effect of local consumption on production is examined in detail. Comparisons with other key countries are given. Oil producers, Iraq and Saudi Arabia, and natural gas producers, Russia and Qatar, are considered, and the reasons behind each selection are explained. In addition, global energy policies related to pollution reduction and the effects of the downstream industries are discussed. Moreover, the impact of the international sanctions on Iran production is reviewed. Furthermore, a prediction on outlook of the future of Iran oil and natural gas production is made. Finally, the energy outlook, including the main primary energy resources for these five countries, is briefly reviewed.

INTRODUCTION

Fossil fuels are one of the main targets of any energy-based studies. The reason is that, although fossil fuel consumption has decreased in the last 20 years, it remains one of the most widely used fuels globally. Crude oil, the most highly used fuel globally, holds more than 33% of the net energy consumption. However, it has had a reduction of 7% in usage since 1999. With more than 24%, natural gas is the third most consumed fuel. In contrast to oil and coal, it experienced an increase in the past few years. Except for oil, coal, and natural gas, the remaining energy consumption of the world is obtained from nuclear power, renewable energy, etc., which sum up to less than 10% of the net consumption. The main reasons for the high usage of oil and natural gas are low prices and relatively easy availability.1

Nonrenewable resource analysis contains extraction methods, price evaluation, exportation and regional policies, production rate predictions, and proven reserve capacity. Hubbert’s peak theory is a robust numerical method for analyzing the production rate of a region. This theory was first introduced in 1956 by King Hubbert for 48 states of the United States oil and uranium reserves (excluding Alaska and Hawaii). Then, it was generalized for utilization in other countries. It is commonly known as the first numerical method for the prediction of nonrenewable energy production peaks, in particular, for oil. This theory states that for each region, the production rate curve has a bell shape. Each curve identifies peak production and production duration depending on

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specific regional parameters. The strength of the method can be reflected in the fact that the regular discovery of new reserves and developments in new extraction technologies would not affect the curve’s general trend. However, Hubbert curves generally show more sensitivity to unexpected changes. On one hand, a sudden change in the regional circumstances may cause a deviation from the Hubbert prediction curve, for instance, a change in energy production policies. On the other hand, the new path of the production rate will also follow a new Hubbert curve with updated parameters. Thus, with careful considerations, some methods can be used for predicting production rate under sudden changes.

Figure 1 shows the prediction of the oil production rate for the U.S. The line with circle symbols shows the data from the U.S. oil production history between 1900 and 2020. The solid curve is the Hubbert prediction, which had already been plotted by King Hubbert in 1956, as mentioned before. This curve predicted the production rate path until 2008. The prediction was accurate, and it could correctly estimate the amount and time of maximum production. The maximum production is indicated in Figure 1 with two dotted lines, horizontal and vertical, showing the amount of maximum production and the exact predicted time, respectively. In 2008, which is highlighted in Figure 1 with a vertical dotted line, the production rate no longer followed the Hubbert curve and started a rising trend. This happened due to the U.S. policy change in oil production, when it moved toward selling oil reserves. This increase shows that regional development can affect the Hubbert curve, and the analysis needs to be revised, for particular circumstances.

This study aims to analyze I. R. Iran crude oil and natural gas reserves. The assessment mainly employs the Hubbert peak theory. With the 9% share of oil reserves and more than 16% of natural gas reserves, Iran is an influential country in the world energy outlook and thus is a good target for such a study. This can easily be understood from Figure 2a,b. Figure 2a shows the proportion of the first ten countries with proven oil reserves, and Figure 2b is the same for the natural gas reserves. As shown in Figure 2, Iran ranks as fourth and second in the world’s oil and natural gas reserves, respectively. When compared with other countries’ proportions, it can be said that Iran oil reserves are the first of the three most crucial countries in the Middle East. In natural gas, Iran is positioned in the world’s top three most important countries. Thus, the analysis seems to be vital for planning a reliable energy policy for the near and distant future.

There are some studies about Iran reserves, which used the Hubbert peak theory. Different research groups had plotted Hubbert curves for oil production of Iran and other OPEC (Organization of Petroleum Exporting Countries) countries with different goals. For instance, Behdad Kiani and his co-workers (2009) examined Hubbert theory on Iran; they studied it in civil industry affairs and social matters of oil production and summarized the reasons for the importance of oil production in Iran. Mohsen Ebrahimi and his co-worker implemented Hubbert theory for all OPEC countries, using the Multicyclic Hubbert Model. This model will be explained later. However, these works are limited to the information until 2015. Moreover, although the Hubbert curve is plotted in these papers, different Hubbert predictions are not discussed, and in-depth analysis of the application of this theory for Iran’s reserves is almost absent in the literature. Furthermore, to the best of the authors’ knowledge, such an analysis for the natural gas of I. R. Iran has never been performed.

The present research considers the oil data for 55 years from 1965 until 2020 and natural gas for 50 years from 1970 until 2020 and evaluates different parameter changes. The data is analyzed based on the energy and reserves considerations and makes comparisons with some of the rivals. A better approach for production and exportation can be achieved by comparing Iran’s production rate with that of rival countries. Iran’s
particular circumstances, such as the effects of war, sanctions, and domestic development, are considered. Diverse policies considering natural gas production prediction are analyzed. Moreover, the presentation of these observations from Iran’s particular political situation can promote the achievement of a better energy plan in the future. Moreover, a brief energy outlook is presented for Iran and other countries in this study, which would help one understand the global shape of the primary energy usage in future and the specific position of oil and natural gas reserves in this regard. Besides using a conventional approach for basic evaluations in this study in the longest analyzed time span and a somewhat new methodology, the innovative aspects and most important contributions can be summarized as follows. Both production and consumption are considered to estimate the exportation. Key countries in oil and gas industries are compared, and a numerical analysis of their future position is performed. Moreover, some advisory tips in energy policy and data analysis in the primary energy outlook are recommended.

The rest of this exposition is organized as follows. In section 2, the main problem is defined, and the reason for choosing every subject is described. In section 3, the paper’s evaluation method mentioned earlier, the Hubbert theory equation, is illustrated, followed by some explanation of its benefits and limitations. In section 4, the oil and natural gas production rates of Iran and other chosen countries are analyzed; results and discussions are given. Finally, the concluding remarks and future outlooks are summarized in the last section.

## SCOPE AND OBJECTIVES

The main topic to be addressed here is the prediction of the oil and natural gas curves in the near and distant future for Iran and some other countries. Considering the ranks of oil and natural gas in global energy consumption and Iran’s position in total proven reserves, it is helpful to analyze Iran’s production, consumption, and exportation and compare it with similar countries. It is shown that despite Iran’s high rank in the global oil and natural gas reserves, its production remains relatively low due to the international sanctions.

When using Hubbert theory for Iran, regional circumstances need to be considered. Some examples of these regional circumstances for Iran are the following: (I) Iran’s high rank in crude oil and natural gas reserves of the world; (II) the specific political situation in selling and exporting; (III) OPEC and GECF (Gas Exporting Countries Forum, also known as Gas OPEC) membership and its effects on political energy decisions; (IV) neighborhood of the primary production and selling rivals; and (V) the amount of crude oil selling instead of products from refinery and other downstream industries.

Figure 3 is a timeline that summarizes all critical years, which affect oil or natural gas production in each of the considered countries. Highlighting these years sheds light on the understanding of the reason behind production changes.

Iran is the main target of this study. However, in the oil-producing groups, these countries are chosen: Saudi Arabia and Iraq. There is a particular reason for each specific selection. Saudi Arabia is chosen due to its high proven reserves. This country is ranked second in oil proven reserves, first in crude oil exportation, and second in oil production and refinery product exportation. Having a regular production rate that confirms the Hubbert theory’s prediction is another reason for choosing this country. Iraq is chosen due to its production rate similarity with the Iran production rate. Its fluctuations in the early years of production can be compared to those of Iran, mainly because the total proven reserves are approximately the same in both countries. Some results due to the current production rate in Iraq are notable too. Moreover, all these countries are located in west Asia and are also OPEC members.

For the natural gas study, the following countries are chosen: the Russia Federation and Qatar. Russia is chosen due to its first rank in the natural gas proven reserves, and it also has had a crucial position in natural gas trading worldwide for many years. In addition, some of its fluctuation in production due to trading problems is notable for further analysis. Qatar is chosen due to its third rank in gas proven reserves and first rank in liquid natural gas (LNG) exportation. Another reason for evaluating Qatar production is its similarity to Iran in natural gas production, while the countries’ policies may differ.
METHODOLOGY

The Hubbert theory method is used for examination in this study and is explained in detail here. The relation between the year of maximum production rate, \( t_m \), the total proven reserves, \( Q_\infty \), and the cumulative production per year, \( Q_c(t) \), reads as follows:\(^8\)

\[
Q_c(t) = \frac{Q_\infty}{1 + e^{-y(t-t_m)}}
\]

(1)

In this equation, \( a \) and \( b \) are constant parameters and are defined for each particular region. The prediction of Hubbert theory for the peak production can be formalized as follows:\(^8\)

\[
Q_c(t_p) = \frac{Q_\infty}{2}
\]

(2)

where \( t_p \) is the year of peak production rate. It is a result of the analysis and has the following relation with \( t_m \)

\[
t_p = -\frac{1}{b} \ln \left( \frac{1}{a} \right) + t_m
\]

(3)

The Hubbert curve, which shows the production rate, can be achieved from the time derivation of eq 1, and the result would become a bell-shaped curve. When the constants in eq 1 change, both the peak production and the peak time would change correspondingly. These constants are determined by regional circumstances such as production technology, local consumption rate, energy policy, etc. However, routine changes of these parameters would not affect the constants and are already considered in the original shape of the curve. Hence, the constants may change in cases where specific developments happen through sudden and unexpected events. Thus, only in cases where such changes occur in a region, the corresponding Hubbert curve shall be computed again with different constants in eq 1.\(^1\) This analysis can extract vital information such as the amount of peak oil production, the exact year of this peak, the change in production rate, and the ending time of the reserves in each region. Moreover, this information can be analyzed further to be used for energy and economic policies.\(^1\)\(^1\)\(^3\)

Evaluating certain circumstances in the oil production of Iran with Hubbert theory can present an updated method. For predicting regions with dramatic fluctuations in their production, two procedures can be taken. One divides the fluctuating production history into shorter regular durations, and the second is the Multicyclic Hubbert Method. Considering different advantages and disadvantages of the two methods, the first one is used in this paper; however, both will be explained briefly.\(^4\)

In the first method, the irregular production region is divided into some regular durations, and the Hubbert curve is plotted for each part separately, using the Hubbert theory. In this paper, the production decline intervals are ignored to achieve a more accurate production rate path by eliminating the out-of-order data. This method was suggested before, but not used with details of any countries.\(^5\)

For estimating the constants of eq 1, cumulative production data is calculated, and the nonlinear least-squares optimization method is used. To get a brief view about how this optimization is done, the following description is given:\(^6\)

Assume the \( m \) point of data given in pairs of \((x_i, y_i)\), \( i = 1, \ldots, m \) which are optimized with an equation of \( y = f(x_i, c_1, \ldots, c_n) \), where \( c_i \) are parameters in the equation that should be found in the optimizing data. The first condition for this assumption is \( m \geq n \). For example, in Hubbert eq 1, the parameters that should be estimated are \( a \) and \( b \). In nonlinear least-squares optimization it is said that the best answer possible \( c \) is when SSE (sum of square errors) has its minimum value. SSE is described as in previous references\(^1\)

\[
SSE = \sum_{i=1}^{m} r_i^2
\]

(4)

Here, \( r_i \), named the residual error, is defined as follows:

\[
r_i = y_i - f(x_i, c_1, \ldots, c_n)
\]

(5)

For finding the minimum value of an equation, the gradient of its parameters should be zero. Because \( n \) parameters are in this equation, the partial derivation of each parameter should be set equal to zero.

\[
\frac{\partial SSE}{\partial c_j} = 2 \sum_i \frac{\partial r_i}{\partial c_j} = 0 \quad (j = 1, \ldots, n)
\]

(6)

In every optimization problem, the accuracy of optimization is important. There are some statistical data known as Goodness of Fit that can be used for evaluation of this accuracy. One of them is SSE: the lower the SSE, the higher the accuracy.\(^1\) The second one is the coefficient of determination known as \( R^2 \). This coefficient is defined by the mean value and the SSE of the data. The mean value of data is described as follows:\(^7\)

\[
\bar{y} = \frac{1}{m} \sum_{i=1}^{m} y_i
\]

(7)

TSS (total sum of squares) is the sum of deviations from the mean value square, which is defined as\(^7\)

\[
TSS = \sum_{i=1}^{m} (y_i - \bar{y})^2
\]

(8)

So, \( R^2 \) will be defined as follows:\(^7\)

\[
R^2 = 1 - \frac{SSE}{TSS}
\]

(9)

The closer this value is to unity, the higher the accuracy of the optimization. In a linear optimization where the answer is the mean-line, the \( R^2 \) is exactly equal to zero; further details can be seen in other references.\(^1\)\(^7\) In this paper, it will be shown that most of the time, to obtain a good optimization for the Hubbert equation, at least 15 data points are needed. This amount of data could achieve 99% accuracy with due attention to the estimated Goodness of Fit.\(^7\)

Another method for predicting irregular production is the Multicyclic Hubbert Method. This method has one equation consisting of many Hubbert equations with different regional parameters to show all ascents and descents in production rate. This method has been used several times for evaluating Iran’s production rate and those of some other OPEC countries. The equation of this theory directly gives the Hubbert curve and is based on the time derivative of eq 1.\(^1\)\(^4\)\(^8\)

The Multicyclic Hubbert Method equation is as follows:\(^1\)

\[
\frac{dQ_c}{dt} = \sum_{i} \frac{2Q_i}{1 + a_i \cosh(b_i(t - t_m))}
\]

(10)
In eq 10, \( a \), and \( b \) are constants. These constants are achieved in the same way the eq 1 constants have achieved. Other parameters are the same as eq 1 for each cycle of Hubbert curve. Note that, in this equation, the irregular production is divided in a different manner called the Cycle Hubbert. Each cycle is the production rate between two declines for a region that the production is regular in that cycle. For this method, instead of total proven reserves in eq 1, another equation is used: \(^{14}\)

\[
U_i = \int \frac{dQ_{ci}}{dt} = \frac{Q_{sci}}{b} \ln(1 + \sqrt{1 - a_i^2}) - \ln(a_i) - \frac{1}{2} \ln(1 - a_i^2)
\]

In eq 11, each \( U_i \) is the area under the production rate curve for each cycle. For instance, in Figure 1, two cycles should be modeled. The first \( U \) is the area under the production rate curve before 2008, and the second one is the area afterward. Thus, with this evaluation, the production data will be divided into regular cycles, and each cycle has its constants. Due to the low accuracy, this method is not used in this paper.\(^ {14,19} \)

Besides, this method does not show the duration of production for each analysis separately. Moreover, the first method, which was introduced above is more recent and state of the art for use in the fluctuating production rate circumstances.

## RESULTS AND DISCUSSION

**Iran Oil Production: Predictions, and Policies.** Iran total proven oil reserves are 155.6 thousand million barrels, about 9% of world oil reserves, and it stands fourth in rank after Venezuela, Saudi Arabia, and Canada.\(^ \text{1} \) The oil production rate data and Hubbert’s predictions from 1965 until 2020 are plotted in Figure 4 for Iran. The circle symbol presents the history of Iran oil production rate. As is clear in the circle symbols, it does not follow a regular path due to exceptional regional and political circumstances.

As indicated in Figure 4, three declines are visible in Iran oil production rate in 1978, 2011, and 2017. Accordingly, three Hubbert curves are plotted, one for each period of regular production rate. These time spans are given in Table 1 for each particular curve. For the first period between 1965 and 1978, the \( \alpha_{\text{iran}} \) curve is plotted. The \( \beta_{\text{iran}} \) refers to the Hubbert curve, in which the data of 1978–2011 is used and analyzed. At last, the 2011–2020 data is covered by the \( \gamma_{\text{iran}} \) Hubbert curve. For this approach, regional parameters are calculated for each of the mentioned time intervals separately. The method was explained in the Methodology section. So, the constants of eq 4, which determines Iran’s mentioned Hubbert curves, are stated in Table 1. In addition, Table 2 is provided for summarizing the oil production parameters and predicted statistics of these three Hubbert curves. This table includes information about maximum production history and predictions for peak production rate. These peak production data is shown in Figure 4, each of them with two lines, a horizontal and a vertical one. Inequality between the maximum production and peak prediction data can be seen in Table 2. These differences demonstrate that the production declines are not related to the Hubbert curve path on its ascending side. Thus, this might have happened due to sudden changes in the regional circumstances of Iran.

Iran had rapid growth at the beginning of its production in 1965. The \( \alpha_{\text{iran}} \) curve is presented with a black dashed line in Figure 4. Due to the low amount of proven reserves and the rapid production in those years, this curve shows a high slope. Consequently, its peak shows a high production rate; however, the time for the end of production is predicted rather early with this curve. After a drop in 1978 and increase again in 1980, the new \( \beta_{\text{iran}} \) curve is computed, which in many ways behaves differently than the \( \alpha_{\text{iran}} \) curve. The \( \beta_{\text{iran}} \) curve, which is drawn with a green dash-dotted line, has a lower slope and predicts the production peak around 2022. This can be attributed to the increase in total proven reserves and the slowdown in the production rate. The \( \gamma_{\text{iran}} \) curve plotted with a red solid line is rather similar to that of \( \beta_{\text{iran}} \). Their difference is a 15-year delay in the prediction of the production peak. The reason for this delay can be explained by the insufficiency in prediction between 2011 and 2013. Besides, both \( \beta_{\text{iran}} \) and \( \gamma_{\text{iran}} \) curves are flatter compared to \( \alpha_{\text{iran}} \) and show smoother production rates. This shape lowers the difference between the maximum production and the average rate of production. As also mentioned in the Methodology section explaining the optimization method, for a better prediction of Iran oil production after 2011, more years need to pass. Still, the production path and the approximate maximum production can be understood from the \( \gamma_{\text{iran}} \) curve, and a general perspective can be gained.

Considering the historical and political views of Iranian circumstances, the \( \alpha_{\text{iran}} \), \( \beta_{\text{iran}} \), and \( \gamma_{\text{iran}} \) curves can be analyzed in more detail. Each noticeable decline in the production rate
causes a change in predictions, and these changes are covered by each particular computation. Analyzing Figures 3 and 4 together would shed light on the possible reasons behind these increases, decreases, and fluctuations. The year 1978, which indicates Iran’s Islamic revolution, is shown with a vertical line in Figure 4. As is clear in this figure, the Iran oil production rate has gone through a dramatic drop this year and afterward. During the time interval of 1980 to 1988, which coincides with the Iran–Iraq war, the oil production rate experienced many fluctuations. This period is indicated with two vertical lines in Figure 4. The next important year is 2011 that was the beginning of the sanctions for Iran’s oil, illustrated in both Figures 3 and 4. The sanctions caused a slight decrease in the oil production rate for two years. After the beginning of the Iran nuclear deal process, the oil production rate rose again. In 2015, in which the JCPOA (Joint Comprehensive Plan of Actions, or Iran nuclear deal) was signed, Iran was at its highest production rate. However, in the year 2018 that indicates the USA’s withdrawal from the JCPOA, the oil production rate declined dramatically again, and it has had a downward trend until now. This is shown with a vertical line in Figure 4 indicating the corresponding year. Finally, the production decline after 2017 is not mentioned here, because the data after this year is not directly considered in the Hubbert curve calculations, similar to what is done for 1978–1980 and 2011–2013. Therefore, its effect can be calculated after a new ascent in production. However, considering the three Hubbert curve calculations and the overall oil policy of Iran, it would be rather straightforward to predict the image of the near-future. The lack of oil production between 2017 until the year the exports resumed will probably move the curve’s peak to later years, and the slope would not be expected to change to a great extent. Evidently, the delay in the peak year will be affected by the number of declining production years and the difference in curve slopes. To explain in more detail, when a sudden change in the region circumstances interrupts the Hubbert curve, two scenarios become possible for the previous prediction in coming years. In the first one, when changes are from outside of a region, they usually have negative effects and cause a decline in production. Thus, if the country does not collaborate in these changes, regular production would be continued after the problem is solved. Examples of this group are sanctions against Iran, which happened in 2011 and 2018. However, in cases in which changes are from inside a region, there would be direct effects on the overall production rate policies. This second scenario has examples in the present investigation as well, such as the new U.S. energy policy in 2008 and the Islamic Revolution of Iran 1979. This is perhaps the only imperfection of the Hubbert theory, where the changes in predictions would be more than shifting in time.

Furthermore, in addition to the discussion, which was given above on the effects of different events on the Iran oil production rate, other factors could be considered too. For instance, the local consumption rate may play a major role in energy reserves production. Figure 5 compares local consumption and production rates of oil in Iran. The green line with circle symbols corresponds to the production rate, and the red line with star symbols shows the local consumption rate, respectively. The solid black curve is the $\gamma_{iran}$ Hubbert prediction already introduced in Figure 4, repeated here for more clarity. As is clear in Figure 5, the local consumption rate has had a minor impact on the production rate path. This factor has experienced almost a constant increase throughout this 55-year duration. This can be attributed to the increase in population and fuel burners like vehicles, heating systems, etc. The total amount of oil production has been 74 000 Mbr in these years when the local consumption has been 21 600 Mbr, which makes about 29% of it. Thus, it is fair to conclude that the overall trend of oil production rate is probably much less related to the local consumption in Iran, and the external events explored above are much more influential. However, the increase in the local consumption could be related to an increase of refinery capacity to some extent as well. As mentioned before, the refinery capacity of Iran has increased to about 7.4% in recent years. However, this percentage had been less than 1% for ten years before 2017. Thus, even because of the increase in refinery capacity, a sharper increase in the local consumption rate is sensible in the last three years or so, but the impact on the overall production rate remains limited. Nevertheless, this figure may go through more even changes in the coming years.

The given information about the oil production rate can show the positive and negative outcomes of this industry for Iran. On one hand, if in the time that all rivals are reducing oil production Iran is still ascending, it would retain more time for setting policies based on the oil economy. On the other hand, due to developments in the energy industry and the necessity of countries (especially the countries committed to the Paris Agreement\textsuperscript{5}) to use renewable energies, crude oil costumers might eventually decrease and oil price may experience a drop. Besides, due to Iran’s membership in OPEC, a certain amount of oil can be produced each year. Thus, a sudden growth in oil sales may not easily be attainable.\textsuperscript{20}

Assuming Iran’s current situation, including the sanctions and other factors, the oil produced can be expected to be used in power plants and refineries. Although Iran has tried to decrease its economic dependence on oil, the country’s annual budget is still based on crude oil sales. That is perhaps the main reason sanctions could potentially cause enormous economic problems. However, If Iran manages to further continue its downstream industry developments, it can benefit from the added value of the oil instead. Otherwise, high inflation rates would probably be the most natural expectation.

![Figure 5. Comparison between production rate and local consumption of oil in Iran. green $\gamma_{iran}$: Iran oil’s production rate; red $\gamma_{iran}$: Iran oil’s local consumption; $\gamma_{iran}$: Hubbert prediction curve.](image-url)
Comparing the price of crude oil with its products illustrates the advantages of this policy. It is estimated that refining oil adds approximately 250% to its value, which is quite considerable.\textsuperscript{21} It should be mentioned that this policy has been already practiced by Iran, which has about 2.4% of world refinery capacity now. It has been said before that this amount has been increased by 7.4% in the past years.\textsuperscript{1} However, the internal usage of oil may be limited, due to some international commitments such as the Paris Agreement (refer to www.unfccc.int). According to this agreement, a reduction in CO\textsubscript{2} production is guaranteed until 2020; besides, Iran has a 2% share in total world CO\textsubscript{2} emission, which can be categorized as a rather high percentage compared to other industrial countries. This commitment would affect the oil production rate and may eventually decrease it. The Iran agreement incorporates a reduction of about 4–12% of the CO\textsubscript{2} emission by 2020. However, this agreement is only valid in a normal situation, when Iran is not sanctioned; otherwise, Iran has no commitment.\textsuperscript{22,23}

Using crude oil in downstream industries and selling or using its products for the country’s development could lead to achievements in economic growth. Iran’s current trade policy focuses on selling gasoline instead of crude oil, which is a beneficial policy for downstream industry. This policy has affected the statistical data of the oil industry. Iran had 9.2% growth in refinery throughput in recent years, which led to a 2.7% share in the world’s refinery production. This is a considerable share for Iran compared to developed countries in this field; more details can be found in other references.\textsuperscript{1,24}

**Comparison with Two Main Rivals in Oil Production.**

Figures 6 and 7 show the oil production rates for Saudi Arabia and Iraq, respectively. Saudi Arabia stands second in rank of oil reserves with 297.6 thousand million barrels, and Iraq with 145 thousand million barrels holds the fifth-highest rank in the world.\textsuperscript{1} These two countries, along with Iran, are the three primary oil producers and sellers in west Asia.

As is clear in Figure 6, the oil production of Saudi Arabia is divided into two regular time spans, first from 1965 until 1981 and then from 1981 until now; the corresponding Hubbert curves are named $\alpha_{\text{Saudi}}$ curve and $\beta_{\text{Saudi}}$ curve, respectively. Saudi Arabia is a suitable example of a region with sustainable production. Except for a decline in 1981, Saudi Arabia has had about 55 years of production on a regular path, shown by circle symbols. The $\alpha_{\text{Saudi}}$ Hubbert curve, which is presented by a black dashed line, was not valid from 1981 because of a decline in production rate in that year. In this year, Saudi Arabia has undergone a political miscalculation in the energy policy; the year is shown with a vertical dotted line in Figure 6. Saudi Arabia experienced a significant decline in this year, due to ignoring the OPEC policies and the world energy market system.

After 1981, the oil production rate of Saudi Arabia follows the $\beta_{\text{Saudi}}$ curve with a solid green line in Figure 6.\textsuperscript{25} As a result of this regular production rate, Saudi Arabia will pass its peak production in 2023, which is indeed not too far in the future. As shown in Figure 6, even in recent years, Saudi Arabia’s production rate slope became lower, which shows that the production rate would probably decrease soon. The effects of the Saudi Aramco explosion and the oil production crisis in the Coronavirus pandemic with the severe price decline are not apparent in the production rate yet. However, because Saudi Arabia is normally experiencing a descent in the slope of the production rate near the Hubbert curve’s peak, an uncommon decline in its production rate would not affect the general shape of the Hubbert curve or the peak production much, and only a delay in peak production for a few years would be anticipated.

On the opposite side, Iraq had a more vacillatory production rate than Iran before 2003. Iraq’s production history experienced three declines in 1980, 1991, and 1998. Thus, it has four time intervals with a regular production rate. However, due to the sparse data in the last time spans, the third and forth durations are diagnosed with one Hubbert curve to achieve a more accurate prediction. Therefore, three Hubbert curves are calculated for these three time spans: 1965–1980, 1980–1991, and 1991–2020. The curves are named $\alpha_{\text{Iraq}}$, $\beta_{\text{Iraq}}$, and $\gamma_{\text{Iraq}}$ respectively.

The fluctuating production rate of Iraq was predictable because of the several wars the country experienced, with Iran and Kuwait, and internal wars. The years 1980 and 1988, which indicate the start and finish of the Iraq–Iran war, are shown in Figure 7 with two vertical lines. This war caused a significant decline in the oil production rate. Then, the Iraq–Kuwait war, known as the Gulf War, starts in 1990 and ends in
1991 and is indicated in the figure with two other vertical lines. This war also caused a decrease in the Iraq oil production rate. In addition, the production rate slightly decreased due to internal wars in 1998. However, since the year 2003, which is the beginning of the Iraq invasion, the production rate has increased dramatically. This year is also illustrated in Figure 7 with a vertical dotted line.

The $\alpha_{Iraq}$ Hubbert curve, which was valid before Iraq–Iran war, is presented with a red dashed line. Then, after a sudden decline in 1980 the $\beta_{Iran}$ curve, shown with a green dash–dotted line, is computed. However, the data did not follow the regular path either because of the Gulf war. Therefore, the $\gamma_{Iraq}$ curve is plotted for the third regular duration. This curve covers a long-term steady and rapid production rate and is presented with a solid blue line. If Iraq continues the current production path, it would pass its peak production in the early 2032, near the year Iran also would pass (2037) and far from Saudi Arabia (2023). This can be attributed to differences between the production rate slope and the regional amounts of oil reserves.

Figure 8 shows the interaction of the newest Hubbert prediction for Iran, Iraq, and Saudi Arabia. The figure contains $\gamma_{Iran}$, $\beta_{Saudi}$ and $\gamma_{Iraq}$ curves. As seen from the dash-dotted line, Saudi Arabia probably soon, maybe around 2023, will pass its peak production, and Iran and Iraq have yet to reach it, although they cannot reach the level of Saudi Arabia’s peak production rate. The Iran Hubbert curve is shown with a solid line, and a dashed line presents the Iraq Hubbert curve. Iraq’s proven reserves are fewer than those of Iran, so it should reach peak production sooner, which is visible in the predicted curves. However, this cannot be related to the reserves only; the high slope of the production rate also has its effects. It worth noting that the fluctuations in the production before 2003, illustrated in Figure 6, are significant; plus, the mean value of production in Iraq is lower than that in Iran. Therefore, Iraq could have reached peak production after Iran, and its reserves would remain intact. However, Iraq’s conditions for production are currently facilitated; thus, the occurrence of an earlier peak production could be anticipated.

From the integral of the Hubbert curve or the cumulative oil production, it can be estimated that Iran will reach its final 30% of production around 2051. This year is 2039 and 2033 for Iraq and Saudi Arabia, respectively. This arrangement points to the important effects of the countries’ production slopes and history. Due to the lower mean value of production in Iran than in Iraq, there exists a gap of about 12 years between the years these two countries would reach their last 30% of reserves. By analysis of the curves of Iran, Iraq, and Saudi Arabia together, Iran is revealed to exceed the other two countries in production rate and would probably take its place in the oil market in the near future. In such a forecast, Saudi Arabia and Iraq would be eliminated as primary oil producers, and Iran would yet have about 30 years to remain on top of the production list.

**Iran’s Natural Gas Production: Predictions and Policies.** Iran’s total proven natural gas reserves are 32.0 trillion cubic meters, about 16.1% of the world natural gas reserves, and stand in second place after the Russian Federation. The natural gas production rate data and the Hubbert prediction from 1970 until 2020 are plotted in Figure 8 for Iran. The natural gas production is shown with circle symbols and the corresponding Hubbert curve computation is shown with a solid red line. According to the curve, the peak production happens around 2042, and the maximum production will be 753.8 Bcm/year. This amount is about three times the current production rate of Iran. It is worth noting that, unlike oil production, the natural gas production in Iran has been very regular, and the circle symbols collapse well on the Hubbert prediction curve, as is clear in Figure 9. The reason for this difference between natural gas and oil production behavior can be attributed to the dissimilar policies.

Assuming the pollution and the heating value, natural gas can be considered the most efficient fossil fuel. Iran uses natural gas as one of the main fuels in power plants in recent years. Furthermore, residential usage such as gas cookers, home heating, and hot tap water are mostly secured with the natural gas. On the contrary, while oil can be exported easily, and it does not need any special preparation operation, the exportation of natural gas is not simple and the transmission of natural gas involves different circumstances. Even for a short-distance transmission, special pipelines and equipment are
required to keep the natural gas high pressure and deliver it with the most negligible loss and the highest possible efficiency. For higher distances, the exportation of the natural gas is usually done in the LNG form that needs an initial operation. Considering these conditions for exportation, it is observed that data reports for the natural gas exportation are usually available for inter-regional exportations.1 Thus, the natural gas production curve is mainly affected by internal consumption, and international affairs barely affect it.

Figure 10 is a comparison between the local consumption rate and the production rate of natural gas in Iran. The green line with circle symbols shows the production rate of natural gas and the local consumption rate is indicated by a red line with star symbols.1 The solid black line is the Hubbert prediction for natural gas production rate; red −+: Iran natural gas’s production rate; green −−: Hubbert prediction for Iran natural gas production.

Iran holds a robust position in natural gas production and the associated industries. Iran has rich natural gas proven reserves, which can be used for regional and international purposes. The B.P. reports reveal that natural gas consumption has grown in recent years in the world.1 The main reason is perhaps its low price and of course the cleaner combustion. Natural gas has the least CO2 emission among all other types of fossil fuels, which make it an attractive choice for differing usage. Iran may reduce its environmental pollution problems by developing its production and transportation technology of natural gas. Evidently, substituting the industrial and residential fuel consumption from oil-based fuels to natural gas could increase these benefits. Eventually, due to the high-quality chemical properties of the natural gas, downstream industries would be developed with a similar policy as well.26

Iran could have a good investment in natural gas exportation, in particular, in the LNG form. This policy might be beneficial if Iran is not sanctioned for natural gas exportation. With these kinds of policies, Iran’s natural gas production rate would increase by a significant amount. Hubbert prediction showed that Iran has at least 30 years to end its natural gas reserves so that many of these policies could be set for a longer period.

Another opportunity that Iran has is its rich reserves in both the north and south of the country. Many natural gas producers are forced to barter gas for other countries because of the vast territory and difficulty in gas transportation. They spend part of their profit from natural gas exports to import natural gas from neighbors for some of their areas and instead supply their internal gas consumption. However, Iran has the advantage of possessing gas reserves close to different borders and does not have such a problem.

Similar to oil production, Iran can sell electricity production of its gas power plants to its neighbors, as long as the downstream industry develops and, in time, leads to the usage of natural gas as the main consumed fuel. This plan could be a substitute alternative in a situation where the natural gas exportation is under sanctions.

Comparison with Two Main Rivals in Natural Gas Production. Figures 11 and 12 show the natural gas production rates of Russia Federation and Qatar. Russian Federation holds the first rank in natural gas proven reserves with 38.0 trillion cubic meters, containing 19.1% of world reserves.1 Its production rate is presented from 1970 until 2020 with circle symbols in Figure 11. A Hubbert curve is plotted with the solid green line for this production period. The curve shows that the peak production has happened already in 2009.

It is noticeable that the production rates around this year are close to each other and almost cause a plateau to form, which shows that the prediction could probably be more reliable.
Figure 12. Qatar natural gas production history and Hubbert predictions. −−−: Natural gas production rate history; blue −−−: Hubbert prediction for Qatar natural gas production.

As shown in Figure 11, Russia has started natural gas production earlier than Qatar and Iran. In 1970, when Iran and Qatar production started from zero, Russia approximately had about 200 Bcm/year of production rate. Until 1985, Russia natural gas production included all CIS countries known as the Soviet Union. The year 1985 and 1991, which indicate the start and end of the Soviet Union’s dissolution, are shown with two vertical lines in Figure 11. This dissolution causes a decline in the natural gas production rate due to a decrease in natural gas proven reserves of the new Russia. However, Russia still has the highest amount of reserves compared to other countries. Thus, Russia did not face any problem increasing its production rate even after the dissolution of the Soviet Union. The year 2014 that indicates the Russo—Ukrainian war is also shown with a vertical line in Figure 11. As apparent in the figure, this year could be counted as the main reason for the recent fluctuation in Russia’s oil production rate. The war led to U.S. and European Union sanctions against Russia. However, due to the extensive need of the European countries for natural gas for their industrial and domestic use, these sanctions did not cause a considerable decline in Russia’s production rate.

As mentioned before, Russia probably passed its peak production in 2009. This is perhaps not simply due to possession of the greatest reserves across the globe, but instead, it is more likely because of Russia’s position at the top rank in natural gas exportation. In addition, Russia is in the neighborhood of the leading natural gas customers, Europe and East Asia. The natural gas pipeline transportation from Russia to Europe, named the Nord Stream, is the longest underwater transportation worldwide. Russian gas exportation accommodates more than 26% of the world natural gas trade, including ground and underwater pipelines and LNG exports. Qatar holds the third rank in natural gas proven reserves with 24.7 trillion cubic meters, containing 12.4% of the world reserves. The natural gas production rate is shown from 1970 until 2020 with circle symbols in Figure 12. Consequently, one Hubbert curve is computed for this production with the solid blue line. As appeared in Figure 12, this country’s production started to increase significantly from 2000. Beyond that year, Qatar’s natural gas production rate became similar to that of Iran. Qatar’s Hubbert curve predicted the peak production year in 2036, and its amount about 800 Bcm/year, about four times of the current production rate.

From 2017 until 2021, Qatar’s production rate declined due to political problems with the Arab League. These two years are indicated in Figure 10 with two vertical lines. The production rate shows a plateau between these years, which is predicted to become ascendant again when Qatar’s regional problems were solved.

After Russia, Qatar has the greatest amount of exportation. Qatar holds the first rank in LNG production in recent years and sold 22.1% of the world’s LNG in 2019. East Asia and Europe are the main customers of Qatar. Due to the possibility of exportation to longer distances, natural gas in the LNG form has a broader market worldwide. Figure 13 is a comparison of the three primary gas producers in the world. Since Russia has the longest history in natural gas production, its Hubbert curve is far behind the other two countries. The Russian Hubbert curve is shown with a green dash–dotted line. Russia’s Hubbert curve slope is lower than that of Qatar and Iran, but its production duration is higher than the rest to feed the natural gas demand in more years. According to this curve, Russia should at the moment be in the last 30% of its reserves. Qatar and Iran will reach this position in 2042 and 2050, respectively. The reason Qatar, the dashed black curve, is behind Iran, the red solid one, is its faster production and lower reserves. From this comparison, it is more obvious why an energy plan based on natural gas production could be more valuable for Iran. According to these predictions, Iran can probably take Russia’s and Qatar’s place in the world market in the near future.

Energy Outlook. The oil and natural gas production rates of Iran and four other countries have been compared. However, the global energy policy does not welcome fossil fuels in recent years. Thus, it is worth taking a look at other sources of energy production for Iran and the selected countries, as well. Figure 14a,b presents the world’s and Iran’s share of primary energy in 2020. As is clear in these figures, Iran’s main sources of energy are still oil and natural gas. Thus, analysis of oil and gas for Iran means almost all of the energy in the country. Interestingly, it can be seen that the oil consumption share for Iran is fairly equal to that in the

Figure 13. Hubbert last prediction curves for the three main natural gas producers in world. Red −−−: Iran. Green -: Russia Federation; - - -: Qatar.
The remainder of energy for Iran is supplied from natural gas, the cleanest fossil fuel as mentioned before, recalling that Iran uses almost no coal reserves. In the case of green resources, Iran needs more years to reach the global picture. For instance, for the renewable resources, Iran’s share is only about 0.2%, which is around 20 times less than the world share of 5.7%. Besides, the share of nuclear energy and hydropower is less than 1% in Iran, compared to 5.4% and 6.9% in the world, even though Iran has had huge investments in these two sections; today, the harvest of energy still remains limited.1

Table 3 summarizes the growth rates of the share of primary energy in the five selected countries. Oil, natural gas, coal, nuclear energy, hydropower, and other renewables are introduced in this table. This table assumed a ten-year growth from 2010 to 2020 based on the latest BP (British Petroleum Oil Industry Company) annual report and tries to provide a better insight into the energy development in each country. Some of the percentages in the table directly indicate the specific outlook and trends of countries. For instance, although the nuclear energy share is less than 1% in Iran, it has grown by about 46.9% in the last ten years, which is rather considerable. A similar trend can be seen for the hydropower and renewables as well. Thus, Iran may be considered at the beginning of the sustainable energy development roadmap in renewables with a noticeable growth rate in nuclear energy. Other countries have different policies in the case of nuclear energy and hydropower that can be related to regional circumstances. Hydropower requires a rich source of running water, and nuclear energy is produced with expensive equipment. Besides, nuclear power plants should be run in safe places with the lowest risk of destruction.27 In the case of renewable energy, Saudi Arabia and the Russian Federation have grown, especially Saudi Arabia which showed its high proficiency in renewable energy production. On the contrary, Iraq and Qatar show growth in nonrenewable energy consumption, which is usually an indicator for the start a new era in the industrial development of a country, where a robust energy resource is needed.21

**Table 3. Growth of the Share of Primary Energy**

| primary energy       | Iran    | Saudi Arabia | Iraq    | Russian Federation | Qatar |
|----------------------|---------|--------------|---------|--------------------|-------|
| Oil                  | 0.4%    | 2.6%         | 3.0%    | 2.0%               | 8.3%  |
| Natural gas          | 5.2%    | 4.1%         | 11.0%   | 1.1%               | 5.6%  |
| Coal                 | 2.7%    | 16.4%        | -       | −0.8%              | -     |
| Nuclear energy       | 46.9%   | -            | -       | 1.9%               | -     |
| Hydropower           | 15.1%   | -            | −1.9%   | 0.5%               | -     |
| Renewables           | 14.5%   | 109.2%       | -       | 16.6%              | -     |

*(−) indicates the growth rate has been less than 0.05%.*

**Figure 14.** Share of primary energies for (a) the world and (b) Iran.
This implies that if the gas production continues to speed up and collapses to the Hubbert prediction curve, as is so at the moment, there will be a time that it goes under the oil curve again. Presently, the prediction is around the year 2083, when the oil production can retain its dominant importance again.

In addition, Figure 15 evidently shows the difference between oil and natural gas production policy. As said before, oil and natural gas production are affected by different circumstances. For instance, the natural gas production rate of Iran is nearly three times the oil production rate, when the normalized curves are compared. On one hand, this fact can indicate that the natural gas production is not affected by unstable international circumstances such as the sanctions, in contrast to the oil production. On the other hand, it shows an increasing desire for natural gas worldwide, which can be attributed to the lower environmental issues of natural gas. Essentially, these differences have led natural gas to be the main fuel product in Iran, for both internal and international usage.

### SUMMARY AND CONCLUSIONS

The nonrenewable energy resources of Iran including oil and natural gas are extensively studied using the Hubbert theory, and comparisons with main rivals are made. Detailed information on Iran oil and gas production rates, the maximum rate, and the peak year are estimated. Additionally, the effect of local consumption on the production rate is examined. Iran has had many fluctuations and three main declines in the oil production rate, which are not related to the Hubbert predictions and are mostly attributed to international sanctions. Compared to rivals, at the moment, Iran has a lower level production, despite its rich reserves, which naturally has pros and cons on the energy policy. However, Iran has the opportunity to use the excess oil in the downstream industry and export its production in the form of electricity, for instance. Iran has no fluctuations in gas production and experiences a robust rate, which collapses well on the Hubbert prediction. This regular production is mainly associated with the high local consumption of natural gas and the particular energy policies of Iran on natural gas production as an alternative energy option. Due to rich natural gas reserves and the low production rate in Iran, peak production is predicted to happen in the 2040s. Thus, considering that the global gas consumption has increased in recent years, compared to rivals, Iran has a good position to export natural gas and develop its gas-based industries. The results indicate that Iran can benefit natural gas production more than oil production in energy policy unless international sanctions are decreased. With this vision, Iran can return to the world energy market main list again, especially due to the fact that the value of oil and natural gas products is much higher than selling itself. In this observation, global energy policies related to reducing pollution and the importance of downstream industries are effective. Moreover, the analysis of complementary developments in energy policy shows that countries with a certain amount of stable development in nonrenewable primary energy have been moving toward green energy in the last 10 years. Iran is one of them, which has had growth in renewable energy and hydropower and a considerable climb in nuclear energy. Although this study concentrates on Iran’s nonrenewable reserves, its implications are not limited to that. The prediction curves of four countries and their brief analysis can be used as initial data for further detailed investigation of each country. Moreover, the provided comparisons could be beneficial for setting up energy policies for those countries as well. Besides, Iran’s future policies would affect the global energy market and would perhaps widen the options of industrial countries for their primary energy supply.

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#### NOMENCLATURE

- $\alpha_{\text{Iran}}$: The Hubbert curve belongs to 1965–1978 time span of Iran oil production; $\alpha_{\text{Iraq}}$: The Hubbert curve for 1965–1980 time span of Iraq oil production; $\alpha_{\text{Saudi}}$: The Hubbert curve for 1965–1981 time span of Saudi Arabia oil production; $\beta_{\text{Iran}}$: The Hubbert curve for 1978–2011 time span of Iran oil production; $\beta_{\text{Iraq}}$: The Hubbert curve for 1980–1991 time span of Iraq oil production; $\beta_{\text{Saudi}}$: The Hubbert curve for 1981–2020 time span of Saudi Arabia oil production; $\gamma_{\text{Iran}}$: The Hubbert curve for 2011–2020 time span of Iran oil production; $\gamma_{\text{Iraq}}$: The Hubbert curve for 1991–2020 time span of Iraq oil production; $a$: Time constant; $b$: Growth constant; $B_{\text{cm}}$: Billion cubic meters; $c$: Function constant parameters in data optimization; $M_{\text{b}}$: Million Barrels; $Q_{\text{uo}}$: Ultimate production; $Q_{\text{cum}}$: Cumulative production; $Q_{\text{lo}}$: Local consumption; $Q_{\text{max}}$: Maximum production rate (statistical); $Q_{\text{pe}}$: Peak production rate (analytical); $R$: Production rate; $R_{\text{s}}$: Square coefficient of determination; $\text{SSE}$, sum of squared errors; $t_{\text{p}}$: Year of the maximum production (statistical); $t_{\text{pe}}$: Year of the peak production rate (analytical); $\text{TSS}$, Total sum of squared deviation from the mean value; $U_{\text{p}}$: The area under the Hubbert’s curve

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