Application of Hubbert Peak Theory to Stimulate Biogas Production

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Abstract- Assessing the amount of fossil fuels remained in the subsurface, specifically oil and gas has been debated extensively since the introduction of Hubbert Peak Theory in 1956. The economic model of Pakistan relies greatly on natural gas. Thus, estimating the volume of natural gas recoverable in the future becomes critical for the development of the country. The main objective of this paper is to examine the applicability of Hubbert Peak Theory in order to determine the ultimate gas recovery under a pessimistic scenario assuming that no further reserves will be discovered in the future. This is useful information because reaching the peak will have implications for Pakistan. Data analysis suggests that Pakistan will most probably peak in natural gas production in 2016 and decline afterwards. Year 2055 is perhaps the point around which the production will approach zero. The results are so alarming that if no major initiative is taken by the government to address the issue then Pakistan's economy will have to face dire consequences. Biogas can serve as a viable alternative to meet the hiking demand of gas, utilizing its own widely available resources. Livestock, bagasse and waste landfills are capable of producing 415.3 million Bcf of biogas annually which if produced today, can substitute 22.5% of the total energy originated from natural gas supplied in the fiscal year 2012-13. The outcomes of this paper might also be applicable to other developing countries having similar resources.

Keywords- Hubbert Peak Theory, Ultimate Recovery, Natural Gas, Biogas, Pakistan.

1. Introduction

Today, fossil fuels fulfil the majority of the world's primary energy requirement. As per the existing consumption rate, the available coal, natural gas and oil reserves will last for another 130, 60 and 42 years respectively which is alarming [1]. Natural gas has been known as a very valuable resource for hundreds of years. Natural gas was mostly used to light occasional house lamps and streetlamps in the early days. However since the technological advancement and improvement in distribution channels took place, natural gas started being used in several different ways which were never thought before. There are numerous applications for this resource that it is difficult to provide a comprehensive list of everything it is used for. Specifically, natural gas is a major source of hydrogen supply for synthesis of ammonia, glass and plastics [2]. Natural gas might be a transparent gas but its future is very cloudy. It is due to its extensive use that this fossil fuel peaked production and has begun to deplete in most countries around the world. After a peak is achieved, production drops until the resource is depleted. This phenomenon is referred to as 'Hubbert's Peak' [3,4]. Estimating the amount of fossil fuels in the subsurface is one of the hot topics in energy economics as discussed in many papers, reports and studies.

Maggio and Cacciola, 2009 determined the world's peak production of crude oil and natural gas liquid (NGL) and the time it occurs on the basis of some reliable data using Hubbert Peak Theory. Their results yield that a production peak ranging from 29.3 to 32.1 Gb/year will occur somewhere in between 2009 and 2021. Their claim seems probable as several other studies confirm that the peak is forthcoming and the rise in oil prices internationally recorded in the past few years could be related to the proximity of this episode [5]. Tao and Li, 2007 also used the Hubbert's Peak Theory followed by a generic STELLA model to stimulate Hubbert Peak for China's coal production. Their simulations suggest that the coal peak in China will come between 2025 and 2032 with production at about 3339 to 4452 million tonnes. They proposed China's coal dominated energy policy to be changed soon and form a new energy portfolio related to supply diversification [6]. Djotaroeno, 2010 predicted the peak year for oil production in Suriname for various scenarios and probabilistic estimates. Her simulations indicate that the peak production ranging 5 to 22 MMSTB per year will occur between 2004 and 2039. They encourage the policy makers of Suriname to develop their reserves and resources for the sake of sustainability [7].

The production of natural gas in Pakistan comes from 190 gas fields out of which 27.5%, 22.6%, 23.2% and 8.2% is being used in power generation, industry, household and transportation respectively [8]. It is evident from the numbers that the economic model of Pakistan relies greatly on natural gas so estimating the volume of natural gas recoverable in future, becomes critical for the development of the country. The main objective of this paper is to examine the applicability of Hubbert Peak Theory in order to determine the ultimate recovery under a pessimistic scenario assuming that no further gas reserves will be discovered in future. If one knows the level of ultimate recovery for producing natural gas, it will be possible to approximate when Hubbert Peak will be reached, when it will start declining and how long it will last. This is useful information because reaching the peak will have implications for Pakistan.

Once the peak is reached, growth of the economy starts collapsing until the alternate resources of energy become accessible [7]. Biogas, an alternate of natural gas is produced as a result of anaerobic digestion of waste. Biomass is one great resource that can serve as a fuel for economic growth of a country. By the use of a renewable resource like biogas, the peak would be delayed and the country would be able to sustain its gas needs. Thus, it is equally important to determine the potential opportunities that Pakistan have for biogas production. This case study includes six sections. Sections 2 provide the reader with a background on Hubbert Peak Theory and its uncertainties. Section 3 gives a description of natural gas industry in Pakistan and presents data analysis and research findings evaluating whether the outcome is aligned with the research objective or not. Section 4 highlights two of the most distinguished natural gas import projects under consideration by the government of Pakistan while Section 5 reflects on the various resources that Pakistan has for producing biogas. Conclusions and recommendations are made in the final section.

The existing research on predicting peak oil and gas production time and levels has mainly focused on the US or on the world. There is very less or almost no research conducted on Pakistan's natural gas reserves using the Hubbert's methodology. This study uses logistic curve fit developed by Hubbert to estimate the peak production timing of natural gas in Pakistan and determines the point around which the production will approach zero. Furthermore, the results encourage exploiting the country's own biomass resources potential including livestock, bagasse and wastes for producing biogas and replacing with natural gas to delay the peak production timing and lead towards the concept of sustainable development.

2. Hubbert Peak Theory

2.1. Background of Hubbert Peak Theory

An American geophysicist Marion King Hubbert developed a model of known oil reserves in the U.S. and presented in a paper to American Petroleum Institute in 1956. He forecasted that the oil production for U.S would peak between 1965 and 1970. His analysis was rejected and faced opposition until 1970, when the oil production in U.S. actually started to decay [9]. The Hubbert Peak Theory apprehends the long term rate of production and depletion in fossil fuels. Hubbert's theory says that finite resources start depleting with zero production and that in the early stages; the rate of production tends to grow exponentially with time but this rate cannot be sustained forever [10]. Production plateau is formed once the peak is achieved and declines further. Cost of the resource begins to increase when the production rate drops due to resource depletion. Hubbert combined together the oil production for the lower 48 states of U.S. to determine the oil production peak [11]. He placed large fields at the beginning and small fields at the end as in case of oil exploration, the combined values moulded a bell shaped curve referred to as the Hubbert Curve [12] as shown in Figure 1.
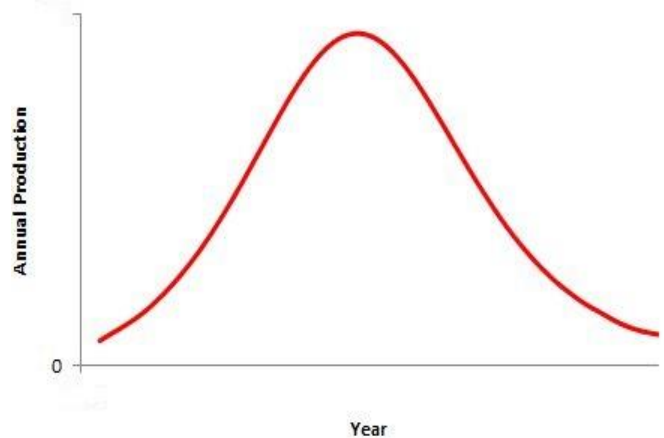

Fig. 1. Hubbert Curve.

2.2. Mathematics behind Hubbert Peak Theory

Two sets of data are needed to determine the Hubbert's Peak. One is annual production 'P' and the other is cumulative production 'Q'. By the aid of a calculation sheet, 'P/Q' is calculated for each year and plotted against 'Q'. A regression analysis should be done over the plotted data to fit a straight line starting from the year where the values show an approximately linear negative trend. Equation 1 corresponds to the equation of a straight line which is determined from the graph.

$$P/Q = mQ + a \qquad (1)$$

where 'm' is the slope of the straight line while 'a' is the y-intercept stands for intrinsic growth rate.

With the above equation, value of 'Q' can be determined for which 'P/Q' is zero. This 'Q' is usually referred to as ultimate recovery. Ultimate recovery represented by 'Qt' is the maximum cumulative production that can ever be achieved. All of Hubbert's theory follows from drawing this straight line. Equation of line is resolved for 'P' which gives Equation 2 describing the mathematical statement of the Hubbert Theory.

$$P = a\,[1 - (Q\,/\,Qt)]\,Q \qquad (2)$$

where the bit inside the parenthesis i.e. '(1 – Q/Qt)' is the segment of the total fossil fuel left to be produced. Equation 2 relates to a bell shaped curved, specifically a 'logistic' curve.

2.3. Uncertainties

As with any model, there are some uncertainties associated to the estimation of oil and gas resources. It is significant to know the classification of resources on the basis of uncertainty and probabilistic distribution of these uncertainties as it is the foundation for choosing the variables that will manage by either Scenario Planning or Monte Carlo Simulation [7]. The level of uncertainty lessens as more data becomes available. Therefore, as resources decrease, reserves increase at the same time when continuing from discovery to production [13]. Few major uncertainties attached to these kinds of studies are as follows:

2.3.1. Peak Production Timing

Timing of peak production varies due to various factors including amount of resource still in the ground, alternative technology, environmental constraints, cost, political risks and future demand. Although such uncertainty is inevitable but reducing this uncertainty to a significant extent could help government policymakers, energy suppliers and users [14]. In case of natural gas, peak production is less relevant as compared to their peak oil and peak coal counterparts due to the fact that natural gas is not exported in huge numbers. Excessively high costs restrict natural gas to be exported creating a closed nature of these markets. As a result of these closed markets it becomes more significant to investigate the time when natural gas will peak in a particular region [15].

2.3.2. Amount of Resource in Ground and Maximum Production Possible

Geology being the limiting factor for estimating oil and gas reserves leads to an enormous uncertainty. Many countries in the world still don't know the full potential of their explored wells and there is no comprehensive valuation of reserves from unconventional sources [14]. Proved reserves of dry natural gas in U.S. reported an increase of 12% in 2010 from 2009 to 304.6 Tcf [16]. Although the estimates show radical growth in terms of production in U.S., the ability to predict the actual quantity of gas in the ground and its efficient extraction is always a question mark [17]. As technology advances, more oil and gas can be extracted which gives rise to the estimates. Exploration companies apply enhanced recovery technologies to extract the maximum amount out of a well [7].

2.3.3. Global Supply and Demand

Uncertainty about the natural gas demand in future will influence how rapidly the remaining gas is consumed and contributes to the uncertainty about timing of peak production. Natural gas consumption averaged 69.7 Bcf/d in 2012. EIA predicts that the consumption will average 70.1 Bcf/d in 2013 and 69.7 Bcf/d in 2014 [18]. Global gas demand increased 2.7% per year over the last decade [19]. Center for Global Energy Studies (CGES) expects demand to grow at an average rate of 1.8% annually between 2010 and 2035 [20]. It seems like natural gas supplies will become increasingly stressed in future. Europe has already passed its production peak [7] while U.S. will peak in natural gas production in the next two years. Asian economic growth will result into the excess supply from the Middle East and the countries of the former Soviet Union [15]. Environmental concerns about greenhouse gas emissions may affect future demands also if these concerns transformed into regulations to promote use of biofuels [7].

2.3.4. Rate of Production Decline after the Peak

Rate of production decline after a peak has been achieved is an important factor because the decline will have adverse effects over the economy if it is more abrupt. Future production and exploration is also influenced by the political and the investment risk factors [7]. 35.5% decline in conventional natural gas production has been recorded in U.S. for 2006 to 2011 but these declines have been disguised in the form of sheer increase in shale gas production [15].

3. Application of Hubbert Peak Theory

3.1. Case Study Area

Pakistan has a total area of 796,095 Sq. km. [21] and a population of 184.35 million [22]. The country with a GDP of 232.3 billion USD in 2013 [23] is selected as the case study area. Pakistan is one of the largest consumers of natural gas in the world which has the total resource potential of 282 Tcf with 24 Tcf of recoverable reserves and approximately 4 Bcf/d of production. Total production

remained 1,559 Bcf during the year 2012 showing a 6% growth when compared to the last year. There are a total of 146 non-associated natural gas fields in Pakistan while 44 associated gas fields operated by 15 companies [8].

3.2. Natural Gas Sector of Pakistan

3.2.1. Natural Gas Proved Reserves and Production

The sedimentary basins are spread over an area of 827,268 km^2 in Pakistan while one third of the total area i.e. 274,641 km^2 is under exploration. All of the gas production in the country comes from onshore fields. Gas reserves, estimated to be around 10 Tcf, were discovered at Sui located at the largest province of Pakistan i.e. Balochistan in 1952. Successful gas exploration movements opened new shires in Balochistan, Sindh and Punjab. As of September, 2012, a total of 810 exploratory wells have been drilled in the country out of which 794 are onshore while 16 drilled offshore. A total investment of 810 million USD was made in 2010 for drilling operations with 30 new wells drilled. According to an assessment done to figure out Yet-to-Find reserves at an un-risked value for both onshore and offshore basins, 66.3 Tcf of natural gas can be explored but unfortunately the country's gas reserves are declining for last few years [24].
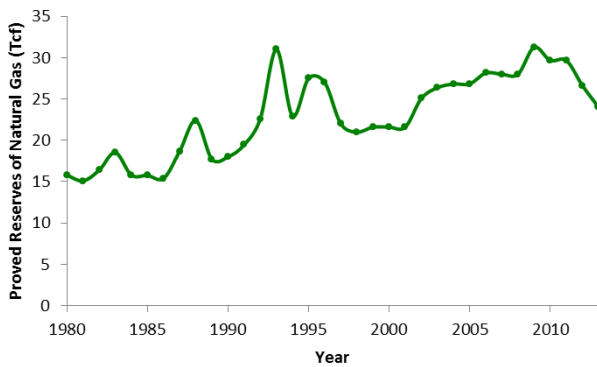

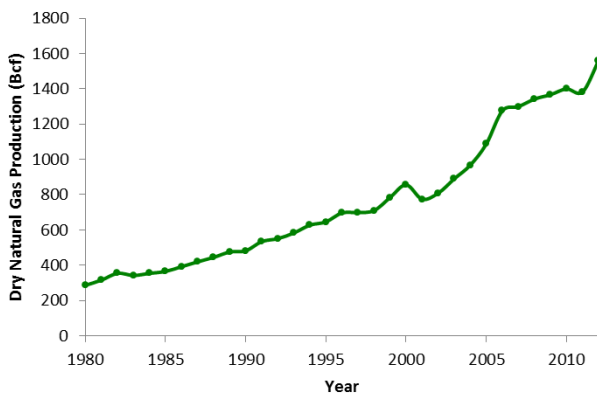**Fig. 2.** Proved reserves of natural gas in Pakistan from the year 1980 to 2013.

Fig. 3. Dry natural gas production in Pakistan from the year 1980 to 2012.

Figure 2 shows the trend of proved reserves of natural gas from the year 1980 to 2013 recorded by EIA. Proved reserves of almost 24 Tcf were reported in 2013 [25].

Pakistan is at the 30th spot in proved reserves in the world by CIA [26]. Figure 3 shows the dry natural gas production from the year 1980 to 2012 observed by EIA. It is obvious from the last 32 year trend that except 2001 and 2011, Pakistan has always produced more than the previous year [24] and in 2012 it produced 1,559 Bcf of dry natural gas [8]. Decline in reserve replacement ratio is a critical issue for Pakistan as no major discovery has been made over the last few years.

3.2.2. Natural Gas Consumption

Pakistan is facing gas shortage due to low growth in natural gas supplies and its misallocation. During fiscal year 2012-13, 1,139,253 Mmcf of natural gas is supplied showing a 2.2% decline from last year. Low gas supplies have been compensated by the imports of crude oil as of almost 14.5 billion USD worth every year [8]. The consumption pattern of natural gas from 1980 to 2011 released by EIA is shown in Figure 4 [25]. Although it is evident from the figure that consumption is growing continuously since 1980 but from the year 2001, consumption rate escalated much more than the previous years. Government of Pakistan framed a Gas Allocation and Management Policy in 2005 which highlights a merit order in case of low gas supply. However, the policy is being violated continuously since its birth by the gas allocation authorities. According to the policy, industry and CNG were prioritized fourth on the list but generally became the leading beneficiary of gas supplies from 2005 to 2011. Power sector proved to be the major loser with 33% reduction in gas allocation during this period. But in the year 2012-13, highest share of gas usage is reported in power sector (27.5%) with an overall negative growth of 3.7 Mmcf in total consumption [8].
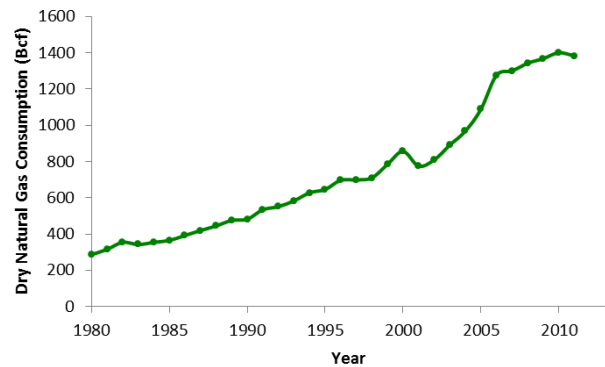

Fig. 4. Dry natural gas consumption in Pakistan from year 1980 to 2011.

3.3. Data Analysis and Research Findings

In order to apply Hubbert's methodology discussed in Section 2.2, a graphical plot is obtained by transforming the Pakistan gas production data available in Figure 3 into the required form as shown in Figure 5. Figure 5 indicates that the graph of the Pakistan production history settles down to a fairly good straight line from 1990 to 2012. Equation 3 is the equation of straight line obtained from Figure 6 by plotting the selected data of Figure 5 on a more precise scale.
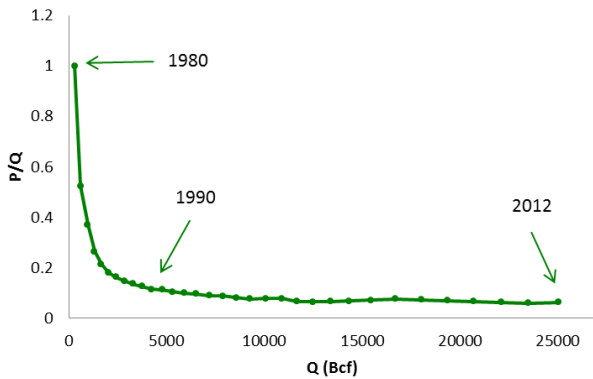
$$P/Q = (-2 \times 10^{-6})\ Q + 0.1066 \qquad (3)$$
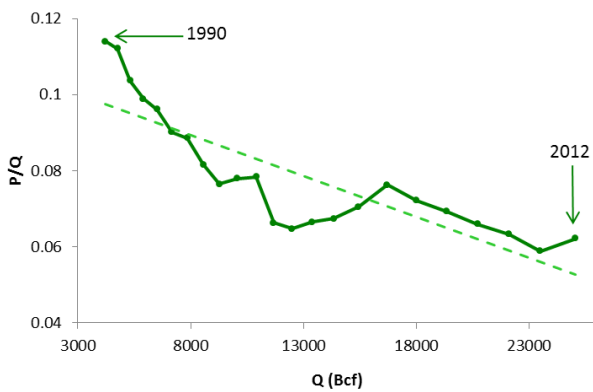

Fig. 5. Pakistan gas production history

Fig. 6. Estimation of the Pakistan ultimate recovery.

Ultimate recovery that Pakistan can ever produce is determined from the above equation and found out to be 53.3 Tcf. This value can be validated from Table 1 by adding the latest value of proven reserves (24 Tcf shown in Figure 2) and the cumulative production up till now (25.1 Tcf shown in Figure 5) under the pessimistic scenario. A difference of ~4 Tcf is due to the regression ($R^2 = 0.7063$) in fitting a straight line over the data shown in Figure 6. Equation 4 is responsible for Hubbert's curve acquired for natural gas in Pakistan as illustrated in Figure 7.

$$P = 0.1066\ [1 - (Q\ /\ 53.3)]\ Q \qquad (4)$$

Table 1. Ultimate recovery estimate for pessimistic scenario

Description	Tcf
Proven Reserves	24.001
Cumulative Production	25.068
Ultimate Recovery	49.069

It is clear from Figure 7 that Pakistan will peak in natural gas production in 2016 most probably and decline afterwards as the current trend shadows Hubbert curve developed for the country. Year 2055 is perhaps the point around which the production will approach to zero. Therefore, there is a strong need of discovering alternate options to meet the gas demand of the country for sustainable future. Alternate options can

either be the import of natural gas or utilizing the enormous potential of biogas from various available resources, both discussed in Sections 4 and 5 respectively.
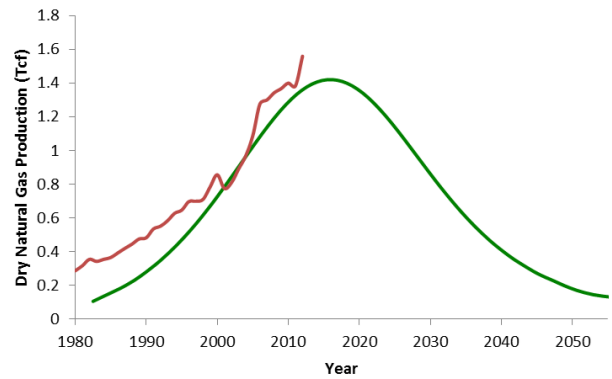

Fig. 7. Dry natural gas production in Pakistan from the year 1980 to 2012.

4. Natural Gas Import Projects

Pakistan's economy has been greatly influenced over the last few years due to gas shortage. Whether it is power sector or transportation, industrial sector or fertilizers for agriculture, immense pressure has been imposed on the government to deal with its gas shortages. In addition to enhance domestic gas exploration within the limits of the country, government has taken initiatives to import natural gas from Iran and Turkmenistan via pipeline [24]. Following are the two most distinguished projects under consideration by the government of Pakistan for gas import.

4.1. Iran Pipeline (IP) Project

The Iran-Pakistan pipeline will start from Iranian onshore gas plant at Assaluyeh running 1,150 km up to the Pakistan border. Both countries are responsible for constructing the pipeline within their territories. Iran has already built 900 km portion of 56 inches diameter pipeline from Assaluyeh to Iran Shehr while remaining 100-200 km to the border is under design. Pakistan will have to build 780 km of pipeline from border to the main distribution system [24]. Once the pipeline becomes operational, 750 Mmcf of natural gas will be transferred to Pakistan every day. Later on the gas supply will increase up to 1 Bcf daily. The project will be completed by the end of 2014 [27].

4.2. Tajikistan-Afghanistan-Pakistan-India (TAPI) Project

After the withdrawal of India from IP pipeline project, Pakistan and Iran have decided to go ahead with IP project but as the energy need of the country is increasing rapidly, Pakistan is also considering another gas pipeline project called Turkmenistan-Afghanistan-Pakistan-India (TAPI) pipeline project for additional gas. The project consists of a 1,680 km pipeline starting from south Yolotan in Turkmenistan and ending somewhere in India [24]. 56 inches diameter pipeline with a design capacity of 3.1 Bcf will be providing 1.3 Bcf to both Pakistan and India while 0.494 Bcf

65

will be sold to Afghanistan. The project is strongly backed by U.S. and favoured over opposing IP project. Asian Development Bank (ADB) has been appointed as legal-technical consultant of the project [28]. The project is planned to complete in 2017 [24].

5. Biogas Production in Pakistan

5.1. Potential Resources for Biogas Production

Fossil fuels are not only finite as determined by Hubbert's estimation but also expensive to extract. Therefore importing natural gas can be a good option to cope with the energy crises but this step will not reduce the dependency over this vary fossil fuel. Pakistan has never imported nor exported natural gas in its history yet [25] and biogas can serve as a viable alternative to meet the climbing demands of gas, utilizing its own widely available resources without relying on any other country. Being an agricultural country, livestock and sugarcane are the two most abundant resources available in Pakistan for producing biogas. Other than these, waste landfills can also add significantly towards the deficit. The potential contribution of the aforementioned resources is calculated in the following sub sections. Pakistan can also discover its potential from poultry waste, citrus pulp, paper industry and slaughter houses [29].

5.1.1. Livestock

Pakistan's livestock sector grows at a rate of 4% every year [30]. 3.7% growth in livestock is recorded last year i.e. 2012-13 [31]. Livestock population in Pakistan is 172 million animals out of which 72 million are the cumulative number of cattle and buffaloes as shown in Table 2 [31]. Manure of these animals can be used for the generation of biogas. If these animals produce on an average 10 kg of manure daily would result in 720 million kg of dung. According to an estimate, 20 kg of wet mass of dung generates 1 cubic meter of biogas [32], [33]. Assuming half of this dung (360 million kg) is collected and utilized for biogas generation then around 18 million cubic meter of biogas can be produced daily (6,570 million cubic meter annually).

Table 2. Livestock population of Pakistan in millions [31]

Species	2010-11	2011-12	2012-13
Cattle	35.6	36.9	38.3
Buffalo	31.7	32.7	33.7
Sheep	28.1	28.4	28.8
Goat	61.5	63.1	64.9
Camels	1.0	1.0	1.0
Horses	0.4	0.4	0.4
Asses	4.7	4.8	4.9
Miles	0.2	0.2	0.2

5.1.2. Waste Landfills

According to the report released by Pakistan Environmental Protection Agency (Pak-EPA) for the solid waste generation in Pakistan in 2005, waste is produced at a rate of 0.283 and 0.453 kg per capita per day in rural and urban areas respectively [34]. By using these production rates, total waste generated by the current population is found out to be 24,079,203 tons per year as shown in Table 3. Solid waste collection system in cities owned by the local government and other operating services presently averages only 50% of the total waste although 75% of the total should be collected to ensure these cities to be relatively clean [35]. Also, only 5% of the total waste generated in Pakistan is landfilled [36]; [37]. First Order Decay (FOD) model developed by IPCC has been followed to reach the potential. FOD model is one of those methods applied extensively for determining methane emissions from landfills capable of converting into energy and can be studied further from the IPCC reference manual and the study recently published by Zuberi et al. [37]. Due to the robust dependence of the model on the waste characteristics, it is important to use the suitable approach for the calculations. Therefore, 'bulk waste approach' is used in this case. FOD model determined that waste landfills in Pakistan are capable of emitting 64.5 million cubic meter of biogas each year which should be arrested and used as an energy source. The yield will increase up to 967.5 million cubic meter of biogas annually (2.6 million cubic meter daily) if 75% of the waste is collected today and landfilled 50% of it.

5.1.3. Bagasse

Pakistan is the 5th largest producer of sugarcane in the world with an average production of 50 million tons annually leaving behind 10 million tons of bagasse which is an enormous resource for producing biogas [30]. Pakistan produced 62.5 million tons of sugarcane in year 2012-13 against the target of 59 ton set by the government for the same year with an increase of 7% from last year [31]. There are 85 sugar mills in Pakistan [8] having potential to generate 11.6 million cubic meter of biogas daily (4,234 million cubic meter annually).

5.2. On-going Projects

With the support of government of Pakistan, Biogas Support Program (BSP) was initiated in 2000 to install 1,200 biogas plants for household. So far the program has accomplished its initial mandate and another 10,000 biogas units are expected to be installed in next 3 years. 27% of the total biogas potential is likely to be achieved by then [38]. Also, Pakistan Dairy Development Company (PDDC) installed 450 biogas plants till May, 2009 and soon after July, 2009, the number increased up to 556 instalments [39]. According to Pakistan Economic Survey 2012-2013, 1,400 biogas plants are in the installation phase through Rural Support Programs Network (RSPN) with the cost of 356 million PKR granted by the Dutch government [8]. Pakistan Council of Renewable Energy Technologies (PCRET) is also playing its part in the expansion of biogas units throughout the country. PCRET has aimed to produce 0.3 million cubic

Table 3. Estimated solid waste generation in Pakistan based on population of 2012-2013

	Population (million)	Solid Waste Generation Rate (kg/c/day)	Waste Generated (tons/day)	(tons/year)
Urban Areas	69.87	0.453	31,651	11,552,655
Rural Areas	114.48	0.283	32,397	11,825,212
Total	184.35	-	64,048	23,377,867
Hazardous waste (add 3%)	-	-	1,921	701,336
Grand Total	-	-	65,969	24,079,203

meter of biogas by installing 500,000 plants all over the country [29]. PCRET has already installed around 1,500 household units, 3 community sized plants and 1 large thermophilic unit but these plants failed to operate for a longer run and it is suggested to promote big sized units by using Japanese technology [40].

Alternative Energy Development Board (AEDB) is taking key measures specifically for generating power from biogas. AEDB has issued letter of intent (LoI) to M/s Lumen Energia and M/s Pak Ethanol Pvt. Ltd. to establish 12 MW power plants in Jhang and 9 MW power plants in Matli, Sindh respectively. Another LoI has been issued to build a 12 MW power plant in Sindh based on biogas and agricultural waste supported by the investors from U.S. and local entrepreneurs [8]. The board is presently working on a project funded by New Zealand Aid (NZAID) to generate 250 kW of power from biogas, utilizing the waste of 400,000 cattle in Landhi cattle colony, Karachi. The project is intended to produce 30 MW in future. AEDB is also providing technical assistance to construct a biogas power plant in Shakarganj sugar mill with a generation capacity of 8.25 MW [41]. 7 MW plant already exists at the same sugar mill in Jhang. 27 MW power plant fueled by biomass and waste is operational at Al-Moiz industries, D. I. Khan while 14 new waste to energy projects capable of producing 213 MW power are given generation license by NEPRA [8].

5.3. Motivation for Biogas Production

Biogas industry is well developed in China, India and Nepal. China had a 5% share of biogas in the total gas energy supply in 2007 producing 2 million cubic meter of biogas from 6.8 million household and 1,000 big and medium size digesters [30]. India installed 2.7 million biogas units throughout the country by 1996 and an extensive work is still in progress to utilize maximum of its potential [42]. 92.2% of the total energy consumption in Nepal during 1992-93 was fueled by biomass resources [43] and over 180,000 biogas plants were installed within the borders during 1973-74 to 2006-07 [44]. In spite of having positive examples in the neighbouring countries, Pakistan remains at the lower side in harvesting its numerous resources. Peak production timing and rate of decline calculated in Section 3 are so alarming that if no major step is taken by the government to address the issue, not only the economy of Pakistan will face a huge debacle but also the prosperity of the nation will be greatly affected.

Natural gas is highly subsidized in Pakistan which makes biogas production less competitive [45]. Also, the equipment is imported due to the absence of local manufacturing industry which heightens the cost of biogas generation projects [46]. Large capital investment tied with less efficient and smaller capacity models makes this technology resistible in the region. Although government has taken some good initiatives discussed in the previous section but no clear policy from the government has been introduced yet for making these renewable energy resources feasible over the use of conventional natural gas [30]. In a country of population around 184.35 million [22], such projects are simply not enough to fulfil the demand of the people suffering from gas shortage and energy. The needs are beyond these initiatives. Biogas utilization will shrink reliance on natural gas and increase security of national energy supply. Biogas is environmentally friendly as combusting biogas reduces global warming impact since net carbon dioxide emission is zero. Also, untreated manure conversion to biogas by anaerobic digestion minimizes methane emissions [47]. Table 4 shows that the total potential yield of biogas from livestock, bagasse and landfills is 415.3 Bcf. Approximately 22.5% of the total energy originated from natural gas supplied in the fiscal year 2012-13 can be substituted by biogas if produced today. The most significant impact will be the delay in peak production timing causing proven reserves of natural gas to last longer.

Table 4. Potential yield of biogas per year from various resources

Resource	Potential Contribution	
	Mmcf	Bcf
Livestock	6,570	231.8
Bagasse	4,234	149.4
Landfills	967.5	34.1
Total	11,771.5	415.3

6. Conclusion

For every oil and gas producing country, it is extremely important to know when the reserves are going to last for each scenario and always take provisions considering the worst case scenario. The information about an estimate of peak production timing and lifespan of the finite resources for a country like Pakistan is essential because it can support the government in shaping up new policies and it stimulates the development of alternatives for natural gas. Either increase in ultimate recovery or substituting portion of recovery from renewable resource such as biogas defers the

lifetime of the gas assets. More output is generated in this way. Ultimate recovery under pessimistic scenario reveals that the last year of gas production will be somewhere around 2055 while the peak year appears to be 2016 or nearby. Since the decline in the production of natural gas strongly depends on the discovery of new reserves and timely substitution of the alternatives discussed previously, this study requires constant review and regular update in the future for better and more refined estimates.

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