OTC
Owner Team Consultation

Comparison of Coal-bed Methane to Other Energy Resources

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Introduction

Our team has been working on a coal-bed methane (CBM) to power project in Botswana for many months. The other day, a colleague asked me just how clean an energy source CBM really is. A simple enough question, but perhaps not so easy to answer.

The only way to do this, is to compare the environmental and social impacts of CBM to that of other, non-renewable, energy resources. Even then, one must keep in mind that every energy project is unique in terms of scope, location and impact. Any direct comparison of energy resources will thus depend on some level of generalisation.

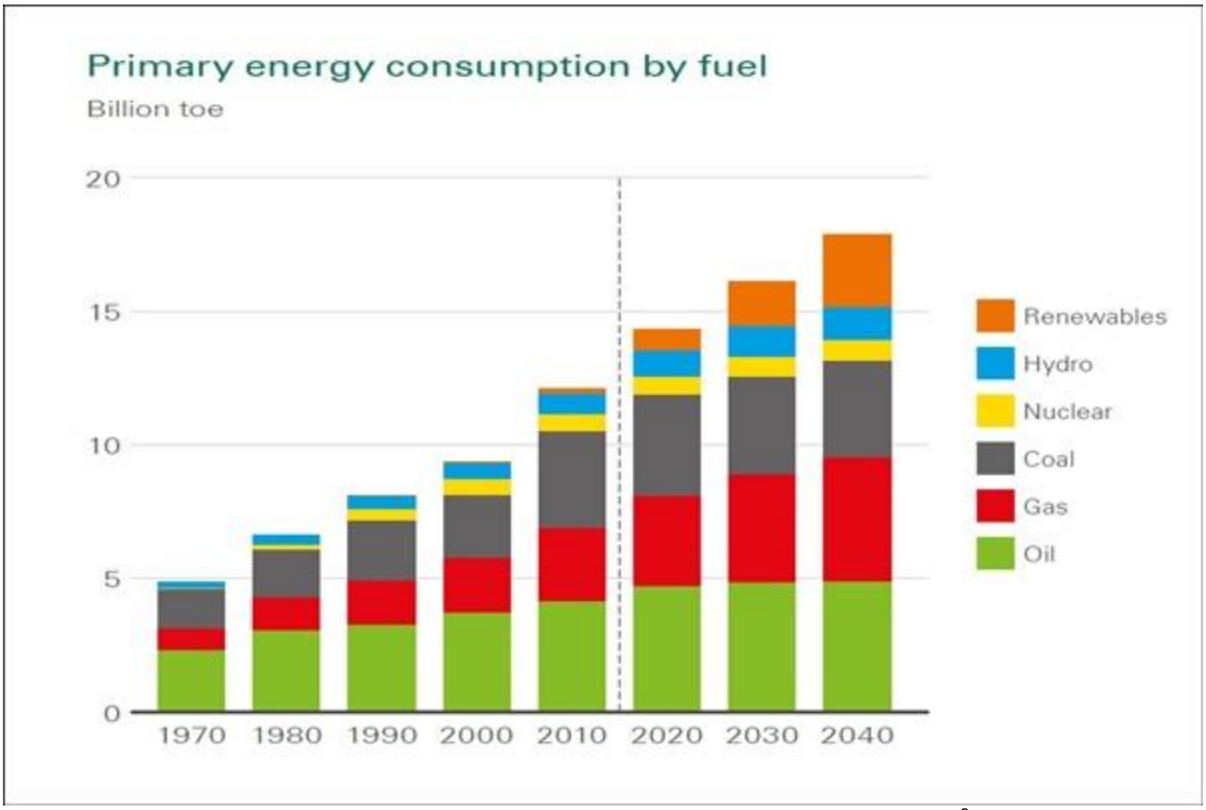
Although there are many different energy resources, I've decided to limit my comparison to the following five:

- Coal and coal mining;
- Oil extraction from reservoirs;
- Coal-bed methane (CBM) from coal seams;
- Shale gas (SG) from shale formations; and
- Conventional gas (CG).

In this article, I'll describe each of these resources briefly, consider some energy predictions, give an overview of the approach followed for the comparison, and present the findings. Having spent 40 years in the petrochemical and energy industries, I feel confident that I have the experience to attempt a comparison of this nature.

Energy predictions

Global economic growth is partly supported by population growth, but is primarily driven by increasing prosperity in developing economies, led by China and India (BP plc, 2019). BP plc (2019), in their latest *Energy Outlook,* predicts a steady growth in primary energy consumption to fuel this growth over the next 20 years, in what they refer to as the Evolving Transition scenario, as shown in Figure 1.



Note: 1 toe = 1 ton oil equivalent = 1 metric ton of oil = 1.4 metric tons of coal = 1270 m^3 of natural gas = 11.63 megawatt-hour (MWh) = 41.868 gigajoules (GJ).

Figure 1: Primary energy consumption by fuel (BP plc, 2019)

Coal consumption is expected to decline by 0.1% per annum over the period, with its importance in the global energy system declining to its lowest level since before the industrial revolution. This is supported by the fact that it is extremely difficult to obtain finance for energy projects based on coal.

BP plc (2019) estimates that renewables and natural gas will account for almost 85% of the growth in primary energy. Renewable energy is expected to grow at 7.1% per annum and is the fastest growing source of energy. Natural gas, at 1.7% growth per annum, grows much faster than either oil or coal, and overtakes coal to be the second largest source of global energy by 2040. Oil consumption is expected to increase at 0.3% per annum over the next 10 to 15 years, before plateauing in the 2030s.

Calculating the percentage, or share, contribution of each or the energy sources of the total energy demand, allows one to generate Figure 2. Figure 2 more clearly shows the actual and anticipated decline in the share of total primary energy of coal and oil. Figure 2 also shows the actual and anticipated rise in the shares of natural gas and renewable energy. The natural gas share represents the total of conventional gas, coal-bed methane and shale gas.

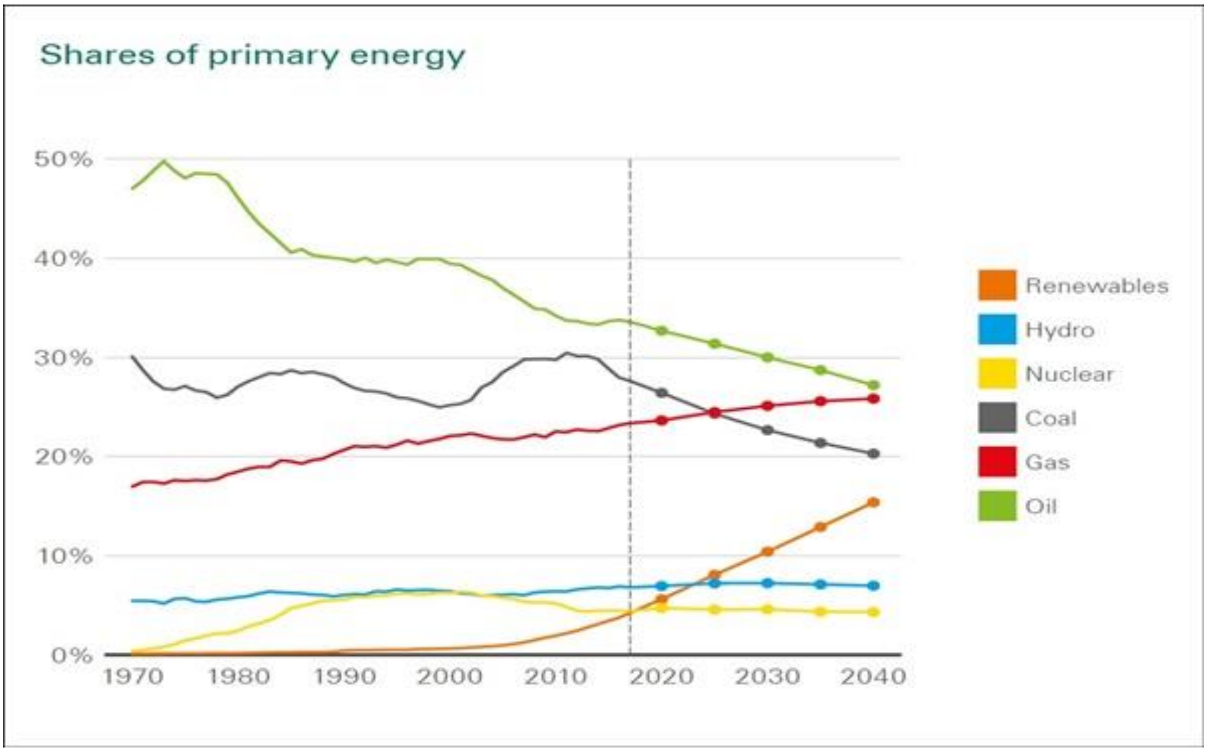


Figure 2: Shares of total primary energy (BP plc, 2019)

Description of energy resources

Coal and coal mining

Coal is a solid fossil fuel that was formed in several stages as the buried remains of land plants that lived 300 to 400 million years ago were subjected to intense heat and pressure over many millions of years. Coal is mostly carbon (C) but contains small amounts of sulphur (S), which are released into the air as sulphur dioxide (SO_2) when the coal burns. Burning coal also releases large amounts of the greenhouse gas carbon dioxide and trace amounts of mercury and radioactive materials.

Coal can be mined from underground mines using a bord and pillar approach, where pillars of coal are left standing to support the roof structure, or with a continuous miner, where all the coal in the seam is extracted and the roof is permitted to collapse behind the mined-out area. Coal can also be mined from open-cast mines where the covering layers of topsoil and rock are removed by drag-lines to expose the coal seams for blasting and collection. An alternative to the latter approach is strip mining, where the coal is sequentially exposed in narrow bands, to reduce the environmental impact. Geological conditions determine the most cost-effective method of mining.

Mining is one of the most dangerous jobs in the world. Coal miners are exposed to noise and dust and face the dangers of cave-ins and explosions at work. Note that in this comparison, only the environmental and social impacts of the mining, preparation and storage of coal are considered, not including the downstream impacts of coal utilisation.

Oil extraction from reservoirs

Crude oil is found in underground pockets called reservoirs. Oil slowly seeps out from where it was formed millions of years ago and migrates toward the Earth's surface. It continues this upward movement until it encounters a layer of rock that is impermeable. The oil then collects in reservoirs, which can be several thousand meters below the surface of the Earth. Crude oil is frequently found in reservoirs along with natural gas. In the past, natural gas was either burned or allowed to escape into the atmosphere.

Drilling for oil, both on land and at sea, is disruptive to the environment and can destroy natural habitats. Drilling muds are used for the lubrication and cooling of the drill bit and pipe. The muds also remove the cuttings that come from the bottom of the oil well and help prevent blowouts by acting as a sealant. There are different types of drilling muds used in oil drilling operations, but all release toxic chemicals that can affect land and marine life. Additionally, pipes to gather oil, roads and stations, and other accessory structures necessary for extracting oil compromise even larger portions of habitats. Oil platforms can cause enormous environmental disasters. Problems with the drilling equipment can cause the oil to leak out of the well and into the ocean. Repairing the well hundreds of meters below the ocean is extremely difficult, expensive, and slow. Millions of barrels of oil can spill into the ocean before the well is plugged.

Sulphur is the most common undesirable contaminant of crude oils, because its combustion generates sulphur dioxide, a leading precursor of acid rain. 'Sour' oils have more than 2% of sulphur, while 'sweet' crude oils have less than 0.5%, with some of them (especially oils from Nigeria, Australia and Indonesia) having less than 0.05% S.

Most oil spills are the result of accidents at oil wells or on the pipelines, ships, trains, and trucks that move oil from wells to refineries. Oil spills contaminate soil and water and may cause devastating explosions and fires. Many governments and industry are developing standards, regulations, and procedures to reduce the potential for accidents and spills and to clean up spills when they occur.

CBM from coal seams

Methane recovered from coal beds is referred to as CBM and is a type of natural gas that is trapped in coal seams. CBM is formed by microbial activity during coalification and early burial of organic rich sediments (biogenic process) and by thermal generation at higher temperatures with increasing depth of burial (thermogenic process). Methane is held in the coal seam by adsorption to the coal, combined with hydrostatic pressure of water in the coal cleats (cleats are natural fractures in coal). Production is accomplished by reducing the water pressure, allowing methane to be released from the cleat faces and micro-pores in the coal.

Coals have moderate intrinsic porosity, yet they can store up to six times more gas than an equivalent volume of sandstone at a similar pressure. Gas-storage capacity is determined primarily by a coal's rank. Higher-rank coals, bituminous and anthracite, have the greatest potential for methane storage. CBM is extracted by drilling wells into the coal bed of coal seams of up to 500 m deep, that are not economical to mine.

Concerns over CBM production stem from the need to withdraw large volumes of groundwater to decrease coal seam hydrostatic pressure, allowing release of methane gas. This water may contain high levels of dissolved salts and must be treated. In some cases, the coal seam is stimulated by limited hydraulic fracturing in order to improve methane movement to the well. Surface disturbances, in the form of roads, drilling pads, pipelines and production facilities impact regions where CBM extraction is being developed. Subsurface effects from typical CBM extraction practices must also be considered. Because of the shallow depth of many CBM basins, the potential exists that well stimulation may result in fractures growing out of the coal seam and affecting freshwater aquifers.

Proper environmental management practices can minimise the effects of CBM production and make it more socially acceptable. Innovative drilling technologies reduce damage to the surface. Better understanding of the surrounding rock properties improves stimulation practices. These options, plus responsible management of produced water, will lessen the impact of CBM extraction on existing ecosystems.

SG from shale formations

Shale gas (SG) is a form of natural gas found in sedimentary rock, called shale, which is composed of many tiny layers or laminations. Gas yield per well is low compared to conventional gas wells and many more wells are typically required for the same volume of gas production.

SG is extracted from shale formations of between 1 and 4 km below the earth's surface. Because of the low permeability of shale rock, SG wells are drilled horizontally along the shale beds and hydraulic fracturing (fracking) of the shale is always required to liberate the gas and create channels for it to flow through. Fracking involves the injection of fracking fluid (water, sand, gel, enzyme breakers, surfactants, bactericides, scale inhibitors and other chemicals) at high pressure down and across the horizontally drilled wells. The pressurised mixture causes the shale to crack. The fissures so created, are held open by the sand in the fracking fluid.

Fracking of shale rock requires much larger volumes and chemical loading than the hydraulic stimulation of CBM seams. The vertical growth of fissures can be up to 100m, compared to 4 to 10m for CBM. However, SG is typically extracted significantly deeper than CBM and, provided the geology and hydrogeology of the region is understood and considered in the fracking process, this need not have any detrimental effects on the surface or the potable water aquifers.

Surface disturbances in the form of roads, drilling pads, pipelines and production facilities, impact regions where SG extraction is being developed. The expected life of an SG well is much shorter than that of a CBM well.

Conventional gas

Natural gas obtained by drilling into gas reserves, is referred to as conventional gas (CG), to distinguish it from CBM or SG (unconventional gases). CG is trapped in porous and permeable geological formations such as sandstone, siltstone, and carbonates beneath impermeable rock. Natural gas was not formed in the rock formations, but has migrated and accumulated there. Conventional natural gas extraction does not require specialized technology and can be accessed from a single vertical well. It is relatively easy and cheap to produce, as the natural gas flows to the surface unaided by pumps or compressors.

Natural gas deposits are often found near oil deposits, or with oil deposits in the same reservoir. Deeper deposits, formed at higher temperatures and under more pressure, have more natural gas than oil. The deepest deposits can be made up of pure natural gas. Natural gas is primarily methane, but it almost always contains traces of heavier hydrocarbon molecules like ethane, propane, butane and benzene. The non-methane hydrocarbons are generally referred to as 'natural gas liquids' (NGL), even though some of them remain gases at room temperature. NGL are valuable commodities and must be extracted, along with other impurities, before the gas is considered 'pipeline quality.'

The benefit of CG is that it is cleaner burning than other fossil fuels. The combustion of natural gas produces negligible amounts of sulphur, mercury, and particulates. Burning natural gas does produce nitrogen oxides (NOx), which are precursors to smog, but at lower levels than fuels used for motor vehicles.

Approach followed for comparison

Parameters for comparison

The different energy resources were compared using 12 different parameters divided into two categories. The first category consists of environmental parameters, as follows:

- **Air Pollution:** This covers dust generation, greenhouse gas emissions during production and contribution to acid rain;
- **Water pollution:** This considers the potential impact of the operation on surface waters and the effect on water users;
- **Groundwater impacts:** The potential for cross contamination of water aquifers and the depletion of groundwater sources and its impact on current users;
- **Soil pollution:** Potential impact of the operations on soil quality and use. Does it impact the ability of the soil to be used for irrigation and livestock farming;

- **Visual impacts:** This considers the overall size, longevity, lighting and dust impact of the operation on passers-by;
- **Biodiversity:** The potential impact of the operation on the surrounding ecosystems, flora and fauna.

The second category consists of social, and socio-economic parameters, as follows:

- **Health risks:** Are health risks to the workers and community due to the impacts the operation, identified and properly understood, and can these be mitigated;
- **Noise impact:** Is noise from the operation expected to be a nuisance to the surrounding communities
- **Worker safety:** What is the safety performance of similar operations elsewhere in terms of worker fatalities and disabling injuries;
- **Cultural impacts:** What is the potential of the operation to impact on areas of high cultural significance to indigenous people;
- **Infrastructure:** What infrastructure (roads, schools, clinics, fire station, etc.) is required to support the operation and what will it contribute to the community; and
- **Job creation:** How many direct and indirect jobs will result from the operation and how sustainable is it. In this case, more is better.

Forced ranking

An approach of forced ranking was used, whereby the different energy sources were ranked from best to worst for each of the 12 parameters described above. The best performer for each parameter was given a score of one and the worst performer a score of five. Those in between, were given scores of two, three and four, depending on their rank.

In exceptional cases, where the impact of two, or more, of the sources were considered to have comparable impacts, the individual scores in question were totalised and averaged. In other words, if energy sources ranked in positions two and three were considered to have almost identical impacts, each would be allocated a score of 2,5.

Elimination of bias

In any comparison, the elimination of bias is essential. One way to reduce bias is to evaluate the different options against many parameters, as was done with the 12 parameters described above.

Another way is to use several assessors, say four to six, when doing the evaluation, and reaching consensus on the ranking. However, in this case it was not done and therefore I'm the only one to blame if my findings do not correspond with your opinions. I have tried to be as fair as possible in ranking the energy sources.

Discussion of findings

The results of the evaluation of the energy sources against the environmental parameters are presented in Figure 3 as a 3-D column chart. Remember that the impacts are not given absolute values, but results based on the ranking process.

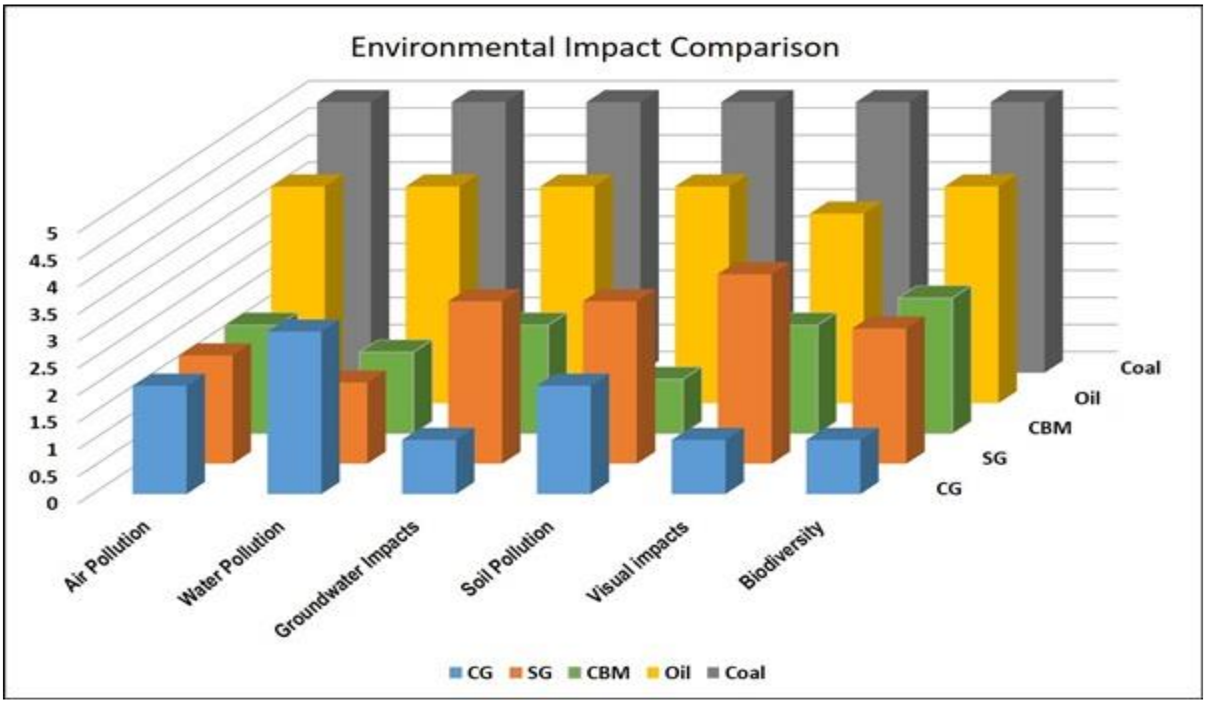


Figure 3: Environmental impact assessment for various energy sources

From Figure 3, it is obvious that coal and oil score badly in terms of impact on the environment. This is followed by natural gas from different sources, with conventional gas assessed as having the least impact. CBM has a lower environmental impact for most parameters than SG, but because it is accompanied by high yields of mostly saline water from relatively shallow wells, the impact on the water and soil could be greater.

The results of the evaluation of the energy sources against the social and socio-economic parameters are presented in Figure 4. From Figure 4, the picture is not so clear. Coal and oil again score the highest for most of the parameters considered. However, in terms of number of jobs created and associated infrastructure requirements, they score the lowest, which means they require more personnel (a positive) and infrastructure. CG is considered more dangerous than CBM and SG, because of the higher operating pressure and the known cases of blowouts.

The cumulative impacts of the energy sources are presented in Figure 5. In this case, the total score for the six environmental parameters for each of the energy sources was calculated and plotted. Similarly, for the six social parameters. Lastly, the total score as shown by the grey column in Figure 5 reflect the totals for the environmental impacts' score plus the social impacts' score. Coal is shown to be the least desirable source, followed by oil, SG, CBM, and CG.

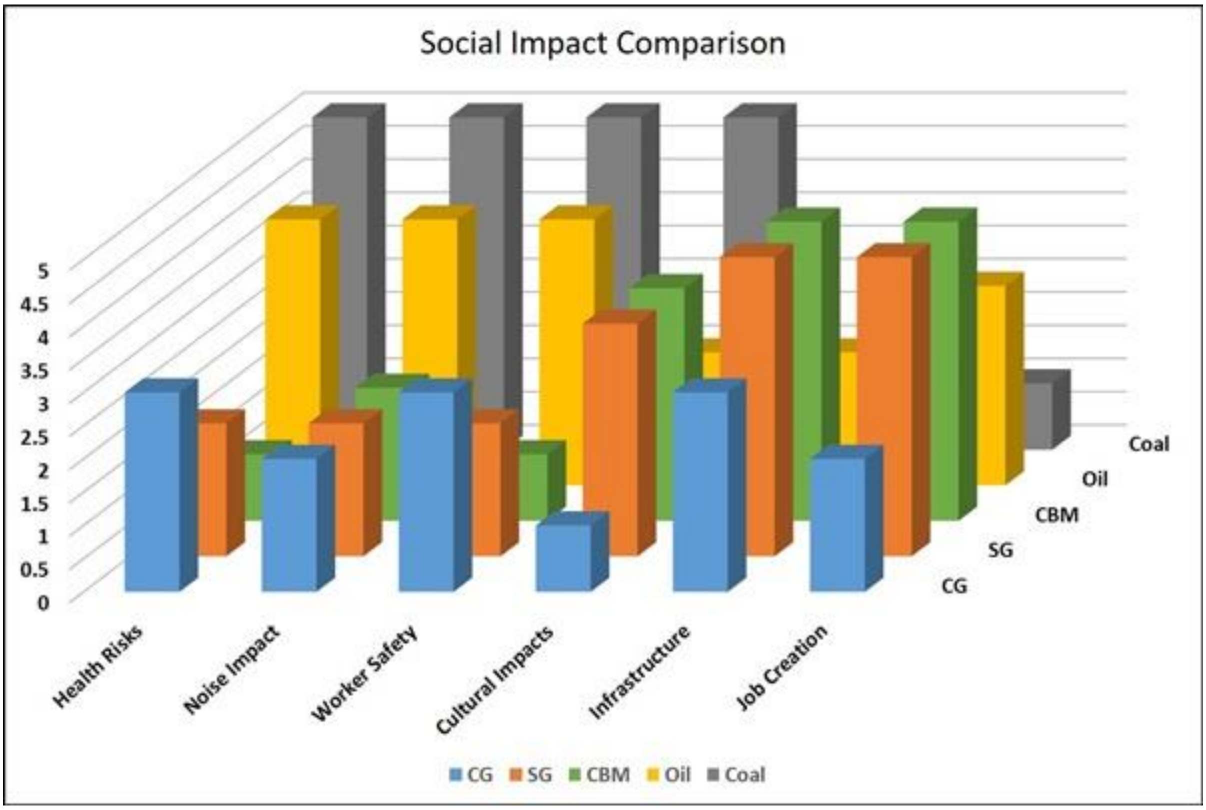


Figure 4: Social impact comparison for various energy resources

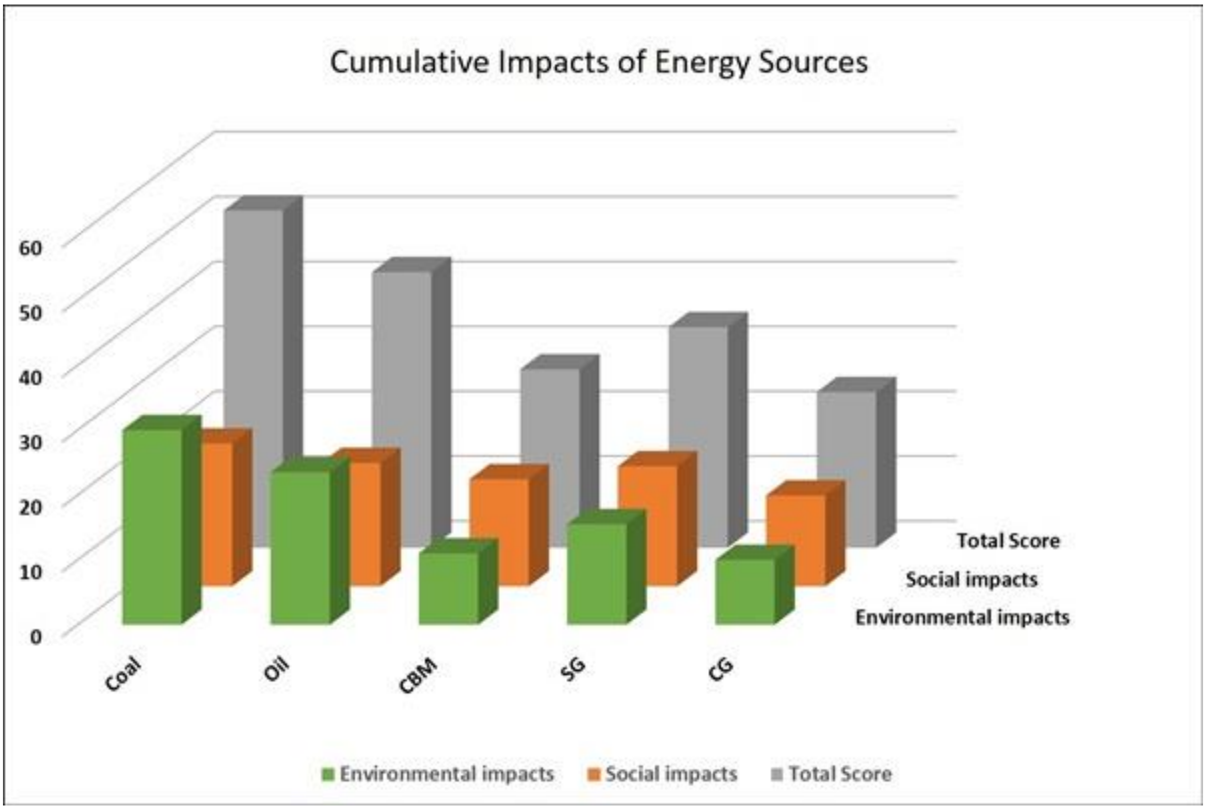


Figure 5: Cumulative impacts of energy sources

Concluding remarks

Natural gas remains the energy source with the lowest negative social and environmental impacts. Therefore, natural gas, is estimated to grow at 1.7% per annum, i.e. much faster than either oil or coal, and overtakes coal to be the second largest source of global energy by 2040 (BP plc, 2019). Natural gas is a combination of CG, CBM and SG. CG recovery is the overall winner in this comparison with the lowest social and environmental impacts. In the second position we have CBM, followed by SG. Even though SG is normally recovered at greater depths than CBM, the extent of fracking required to release the methane in shale is significantly more extensive.

Next in line is oil recovery from geological reservoirs. This is understandable when one considers the oil-related environmental disasters we have witnessed. Associated gas is also continuously flared from drilling operations. However, low yielding (i.e. nearly emptied) oil reservoirs can be used as a suitable geological formation for storage of carbon dioxide. The action of injecting carbon dioxide into a low yielding well will temporarily boost oil production from such a reservoir.

It comes as no surprise that coal is the energy source with the greatest negative impact on the environment. In terms of negative social impact, it also rates the highest, but by a very small margin. This result helps us understand the current furore over coal and the difficulty to obtain finance for coal-based projects.

References

BP plc, 2019, *BP energy outlook, 2019 edition*. Electronic document available from https://www.bp.com/en/global/corporate/news-and-insights/reports-and-publications.html. Downloaded on 10 April 2019.