LNG–ASIA'S POLLUTION SOLUTION?

GNL–SOLUTION DE LA POLLUTION EN ASIE?

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ABSTRACT

LNG is typically used to bring the benefits of reticulated gas to communities where the spatial distribution, supply economics or lack of gas reserves precludes a reliable source of natural gas. For these reasons, many potential importers of LNG are countries where current demand for energy is met by fuels of biological origin (such as dung, wood, bagasse etc) or by local fuels of poor quality, such as lignite coal.

As the world's population increases many of these countries suffer from a high concentration of use of these fuels in rapidly expanding urban areas, leading to high morbidity and sickness from air pollution problems caused by particulates, sulphur oxides and smog. This is particularly so where industrial expansion occurs close to urban areas using high-sulphur lignite coal as the energy source. In addition, regional air quality problems such as acid rain are exacerbated. The use of natural gas from LNG for industrial expansion and/or domestic reticulation will help to improve urban air quality in these areas.

This paper presents an overview of developing countries in the Asian context. It identifies current regional and urban air quality issues, including greenhouse gas emissions, costs of pollution damage and future population trends. Against this background, the paper examines the magnitude and type of air quality improvement that might be generated in these areas by using natural gas from planned and projected imports of LNG.

RESUME

Le GNL sert typiquement à offrir les avantages du gaz naturel à des communautés où la distribution spatiale, l'économie de l'alimentation ou le manque de réserves de gaz naturel excluent une source fiable de gaz naturel. Pour ces raisons, beaucoup d'importateurs potentiels du GNL sont des pays où la demande pour l'énergie est actuellement satisfaite par des combustibles d'origine biologique (tels que la fiente, le bois, la bagasse etc. …) ou par des combustibles locaux de mauvaise qualité, tels que le charbon à lignite.

A mesure que la population du monde s'accroît, beaucoup d'entre ces pays souffrent d'une haute concentration d'emploi de ces combustibles dans des zones urbaines en voie d'expansion, aboutissant à des niveaux élevés de morbidité et de maladies liés à la pollution de l'air provoquée par des particules, des oxydes de soufre et du smog. C'est

surtout le cas là où l'expansion industrielle a lieu près de zones urbaines qui utilisent comme source d'énergie le charbon à lignite riche en soufre. En outre, d'autres problèmes liés à la qualité de l'air, tels que la pluie acide, sont exacerbés. L'emploi du gaz naturel venant du GNL dans le cadre de l'expansion industrielle et/ou de l'alimentation domestique contribuera à l'amélioration de la qualité de l'air urbain dans ces zones.

Cette communication présente une vue d'ensemble des pays en voie de développement dans le contexte asiatique. Elle identifie d'importantes questions actuelles concernant la qualité de l'air régional et urbain, y compris l'émission des gaz de serre, les coûts des dégâts provoqués par la pollution et les évolutions démographiques à l'avenir. Contre cet arrière-plan, la communication examine l'importance et les traits principaux de l'amélioration de la qualité de l'air que l'on pourrait générer dans ces domaines en utilisant du gaz naturel provenant d'importations programmées et projetées du GNL.

LNG–ASIA'S POLLUTION SOLUTION?

ASIAN GROWTH TRENDS

Today approximately 60% of the world's population, or 3.8 billion people live in Asia. UN forecasts predict that this number will increase to approximately 4.5 billion by the year 2020 (refer to Figure 1) [1]. This is a remarkable rate of population growth that is unprecedented in history.

A closer examination of the population growth happening throughout the Asian Developing Countries (ADCs) reveals an important phenomena: populations are not increasing at similar rates in all areas and this has led to sharp changes in the demographics of countries. Urban populations are increasing at an average rate of 3%, nearly double the overall rate of population growth (1.6%) in ADCs [2]. This trend, which is in large part due to migration from rural areas, is resulting in growth of towns into cities and cities into 'megacities', a term coined by the United Nations Environment Programme (UNEP) to describe cities of greater than 8 million. In total, approximately 32% of ADC populations live in urban areas [3].

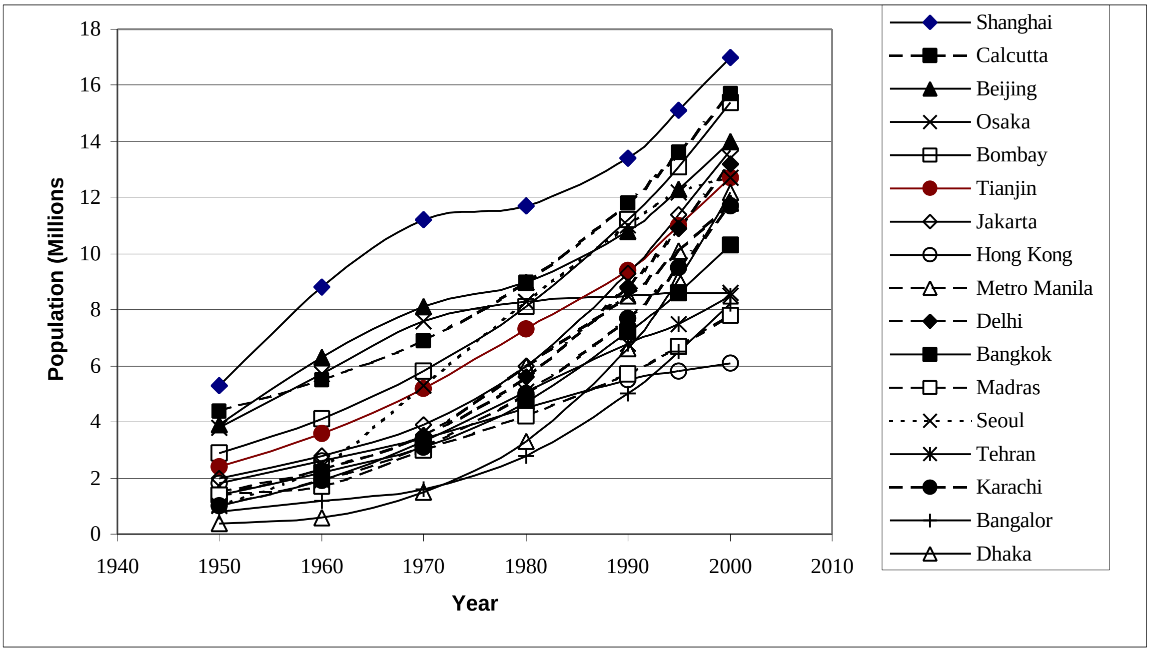

Figure 1: Population Growth of Largest Asian Cities and Inset: Estimated and Projected Population of Asia (United Nations, 1998) [4]

In the same period from 1950 to 2000 in which ADCs have had rapid population growth they have also enjoyed vigorous economic growth. The average increase in GDP has been almost 10% over the last decade. It should be noted however that this average masks substantial differences between the economies of different countries and also does not satisfactorily resolve the 'dip' associated with the Asian financial crisis that began in 1996 (illustrated in Figure 2). Not-withstanding these qualifications, the projections for future growth through to 2020 are very positive and range from an average of 7% to 10% annual increase in GDP [5].

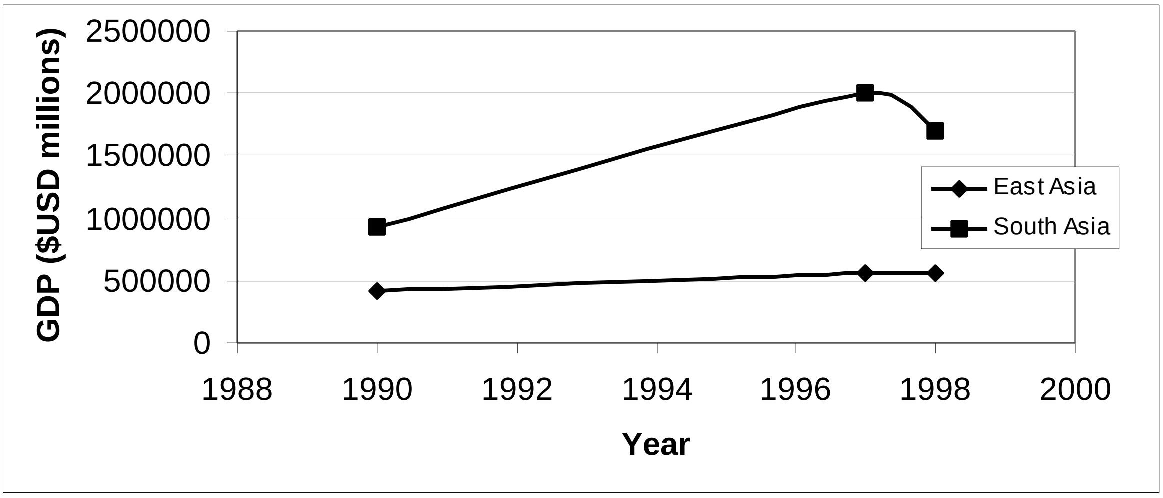

Figure 2: Change in Gross Domestic Product of East and South Asia Regions (Nakicenovic *et al*., 1998 [5])

The growth in both the population and economies of the region has created a significant increase in the region's demand for energy. For example, the demand for commercial energy use alone has grown at an estimated 4% per year [5]. In rural and urban areas of ADCs this demand for energy has traditionally been met by fuels of biological origin, such as wood, dung and bagasse, and by local fuels of poor quality such as lignite coals.

Sources of air pollution in Asia include power generation, industry, transport and the domestic sector and many of the fuels and conversion technologies currently used are characterised by a relatively high intensity of pollutant emissions per unit of energy produced. The causes of this high pollutant intensity have been attributed to a high reliance on coal, inefficient combustion of low quality fuels, obsolete power stations and the infrequent application of emission control technologies. Taken together, the above factors have led to significant increases in air pollution in many parts of Asia.

There are interesting parallels to the Asian situation in the large increases noted in air pollution during and after the industrial revolution in both Western Europe and North America. In these regions periods of rapid increase in energy consumption were associated with significant deterioration of air quality.

Prior to the industrial revolution in the above regions, the energy consumption was typically below 0.5 tonnes oil equivalent (TOE) per capita [7]. The development of the steam engine powered by coal led to the average consumption increasing to about 2.0 TOE per capita by the mid nineteenth century. The demand for energy has continued to rise in developed countries led by increasing economic wealth and technological development. The demand for energy has produced a diversification of energy sources and the development of electricity as a carrier for energy has led to the per capita energy consumption exceeding 3.4 TOE in OECD countries.

The increase in air pollution caused by inefficient conversion of fuels to energy that accompanied industrialisation became a major issue in Western Europe and North America in the late 19^{th} and early 20^{th} centuries. Large-scale air pollution events, such as the 1952 London smog that resulted in the deaths of approximately 4,000 Londoners, were the catalyst for air pollution reform in these countries. Since the 1970s all OECD

MAIN CONTENTS

countries have enacted air pollution regulations and international agreements to limit air pollution from sources and across national boundaries. For example, Europe and North America adopted the Convention on Long-Range Transboundary Air Pollution in 1979.

In Britain many coalmines were closed down during the Thatcher government of the 1980s and the UK turned to natural gas from the North Sea as a clean replacement fuel in what was been termed the 'dash for gas'. Anthropogenic emissions of SO_2 in the UK have been declining since peak levels in the 1970s [8]. Over the same time the NOx emissions have also been stabilised [9]. It appears that these improvements in air quality can be linked in part to the UK's changing fuel mix.

In contrast to the trend of improved air quality in the urban areas of developed countries, the emissions of air pollutants in the cities of ADCs over the same period have been increasing rapidly [10] and so have the economic and societal costs of this deterioration of air quality.

MAIN AIR POLLUTANTS

The main air pollutants of environmental and health concern in the Asian region are particulate matter (PM), sulphur dioxide (SO_2), oxides of nitrogen (NOx), ozone (O_3), lead and carbon monoxide (CO).

Particulate matter varies in size and composition according to its origin. The greatest concentration of particulates is usually measured in urban areas from the burning of two-stroke and diesel fuels in transport and industrial sources.

Sulphur dioxide air pollution is predominantly created when the sulphur contained in coal or diesel is burned. In the US and Europe approximately 65% of total SO_2 emissions are from coal-fired plants used for industry and power generation [11]; [12]. Within China this proportion is greater, with 80% of SO_2 emissions originating from the industrial and power sectors [13].

Oxides of nitrogen are gases formed in two ways; firstly, when high combustion temperatures, such as in auto engines or power plants cause oxygen and nitrogen to combine (thermal NOx), and secondly, when nitrogen contained *in* the fuels reacts with oxygen in the air during combustion (fuel NOx) [14]. NOx not only have direct effects as a pollutant, but also play a role in the formation of other pollutants, particularly ozone (O_3), a photochemical smog reaction product.

Carbon rich fuels, particularly coal and oil, produce CO emissions when burned incompletely The greatest concentration of CO occurs when fossil fuels such as coal are used as a domestic fuel in poorly ventilated areas such as houses.

HEALTH EFFECTS OF AIR POLLUTANTS

The literature discussing the effects of air pollutants on health is extensive. Adverse health effects include respiratory diseases, such as asthma and chronic bronchitis, and a significant mortality for both adults and infants as indicated in Table 1 below.

Table 1: Health outcomes for Air Pollutants (from UK Department of Health, 1998 [15])

Pollutant	Health Outcome
PM_{10} **SO_2** **O_3**	Premature deaths Respiratory hospital admissions
NO_2	Respiratory hospital admissions

According to World Health Organisation (WHO) estimates [16] approximately 80,000 people die prematurely *every day* as a result of air pollution. Of these 3 million annual deaths, roughly 90% occur in developing countries.

Particulates causing the most concern to human health are the small inhalable particles, less than 10 µm (PM-10), which are able to penetrate to the lungs, resulting in respiratory diseases. Physiologically, SO_2 can cause swelling in the airway tissues making breathing more difficult. Asthmatics and children are particularly vulnerable to SO_2 [17].

Photochemical smog, a chemical cocktail often seen over cities, is formed by the reaction of hydrocarbons with NOx in the presence of sunlight. The major product of this reaction is ozone. Ozone affects pulmonary tissue decreasing the body's ability to breathe and prolonged exposure can increase susceptibility to bacterial infection [18]. Smog produced ozone can severely aggravate bronchial conditions such as asthma.

Carbon monoxide has a toxic effect due to its characteristic of displacing oxygen from haemoglobin in the blood stream, effectively starving the body of oxygen.

ENVIRONMENTAL EFFECTS OF AIR POLLUTION

Sulphur dioxide undergoes a chemical reaction in the atmosphere to form sulphates and sulphuric acid. Deposition of SO_2 with rainfall increases the acidity of the rainfall leading to the phenomena of 'acid rain', which can have devastating effects. NOx in the atmosphere can be converted to fine particles that in turn can also contribute to acid rain.

Acid rain is a major problem across large parts of Asia. Rainfall in China, Japan and Thailand has been found to be ten times more acidic than unpolluted rain. [19] Large sections of southern and eastern China, and northern and eastern India are expected to be effected by increasingly acidic rainfall in the next decade.

In China, acid rain has currently affected around 40% of the land area [20] and acid hazes are estimated to cause US$14 billion annually in damages to agriculture and health. [21] Agriculturally, acid rain can affect crops, waterways (and hence fisheries) and forests. The human health effects include causing respiratory damage when inhaled. Reducing acid rain is clearly economically important as well as environmentally important.

NOx contributes indirectly to global warning through atmospheric reactions producing tropospheric ozone and is not currently assigned a Global Warming Potential (GWP) by the Intergovernmental Panel on Climate Change (IPCC). Ozone is a direct contributer to radiative forcing in the atmosphere.

FATE OF AIR POLLUTION

Widespread and severe air pollution has been observed in the eleven 'megacities' in the Asian region, however, air pollution problems continue to affect both rural and urban areas.

Both modelling and direct measurement of air pollution have shown that the rate of deposition and concentration of air pollutants is not necessarily related to the amount of emissions generated by that region. Much of the air pollution generated is transported by winds across regional, and even national boundaries before it is deposited [22], for example emissions from China contribute 13% of the total sulphur deposition in South Korea and are believed to contribute to acid deposition in Japan [23].

Because the majority of emitted pollutants are transported only short distances there may be wide inter-regional variation in deposition rates [23]. For example, in China, acid rain occurs mainly to the south of the Yangzi River [24], even though this area is not the highest source of SO_2 emissions. Evaluation of the soils in these areas has indicated that the critical load of sulphur deposition is being exceeded for 80% of the forest area (Xie *et al.*, 1995). Continued exceedence of the critical load will lead to long-term harmful effects on the ecosystem and soil structure [25].

Computer based modelling of the deposition of SO_2 in urban areas of Beijing and Bombay [32] found that large areas of these cities are exposed to levels as much as twice the WHO guidelines.

ASIAN AIR QUALITY

Emissions Within Asian Developing Countries

Monitoring of air quality parameters in ADCs occurs at varying levels of intensity and regularity and in some ADCs remains a low government priority. Consequently the data available is irregular and this relative paucity of information makes comparison between regions and interpretation of long-term trends difficult. Most of the data quoted in this section of the paper originates from China where several landmark studies have been performed. There is evidence that other ADCs have air quality problems of the same severity as China, however the data is often of poor quality or remains unpublished.

The table below provides some 1997 data on the air pollutants sulphur dioxide and particulate matter in various Asian cities. According to the World Health Organisation, Asia has 12 cities out of 15 with the world’s highest concentrations of particulate matter and sulphur dioxide in the ambient air and many Asian cities often exceed WHO standards for air quality.

Table 2 – Concentrations of particulates and sulphur dioxide in Asian cities

Ambient Concentrations of Suspended Particulate Matter and Sulphate Dioxide Emissions in Selected Asian Cities			
Country	**City**	**Suspended particulate matter (annual mean micrograms/m^3**	**Sulphur dioxide (annual mean micrograms/m^3**
China	Beijing	(*) 370	(*) 115
India	Calcutta	(*) 393	54
Indonesia	Jakarta	(*) 271	n.a.
Japan	Tokyo	50	20
Malaysia	Kuala Lumpur	(*) 119	24
Philippines	Manila	(*) 90	34
Thailand	Bangkok	(*) 105	14

Note: (*) exceeds World Health Organisation guidelines; n.a. = not available.
Source: World Bank 1997.

In 1992, a country-by-country inventory of the SO_2 and NOx emissions throughout Asia was conducted [26]. This data, reproduced below as Table 3, has been subject to further analysis in a separate study [27] and when plotted the results clearly indicate the presence of emission 'hotspots' with highest SO_2 and NOx emissions in the eastern parts of China. This is not surprising, as Eastern China is a relatively developed area with a multi-sectoral industry base and is densely populated.

The most comprehensive country data set of air pollutants available exists for China, where emissions of SO_2, NOx and CO from regional areas have been determined as part of the ongoing 'China-Map' programme [24]. China also established the first comprehensive monitoring of air quality in the early 1980s when a program to systematically study the acid rain problem occurring in parts of the country was initiated [28].

The results of the China Map study of pollution indicate an increase in SO_2 emissions of 9.4% between 1990 and 1995. The largest sources of SO_2 were the industrial and power sectors, contributing about 53% and 27% respectively [29]. Combined, the 80% contribution of industrial and power sectors to total SO_2 emissions is higher than observed in Europe and North America (approximately 65%), primarily because of the relatively high sulphur content of the coal burned and the low efficiency of power generation in China.

The study revealed that emissions of NOx in China also increased by a figure of 26% between 1990 and 1995 [29].

Table 3: Percentage Increase in Emissions of SO_2 and NOx in Asia 1975 to 1987 (Kato and Akimoto, 1995 [26])

Country	% increase in SO_2 (GgS/year)	% increase in NOx (GgN/year)
Afghanistan	31.7	47.5
Bangladesh	23.7	42.9
Brunei	200.0	466.7
Cambodia	150.0	42.3
China	96.4	97.8
Taiwan	-0.7	161.4
Hong Kong	37.6	164.3
India	86.1	85.2
Indonesia	143.0	92.1
Japan	-59.9	-16.9
North Korea	41.9	44.7
South Korea	11.6	152.6
Laos	28.6	16.7
Macao	740.0	150.0
Malaysia	35.5	97.1
Maldives	N/D	N/D
Mongolia	159.3	133.0
Myanmar	78.6	20.0
Nepal	189.5	181.5
Pakistan	158.5	129.7
Philippines	-54.2	6.7
Singapore	83.2	103.0
Sri Lanka	25.9	66.2
Thailand	173.2	111.6
Vietnam	-3.5	-17.0
TOTAL	59.0	64.9

Carbon monoxide emissions increased approximately 15% in the study period. However, in contrast to SO_2 and NOx, the largest contributor was not the industrial or power sectors, rather it was the domestic sector, with approximately 75% of total CO emissions [29]. Within this sector approximately 84% of CO emissions were due to the burning of biofuels. Electric power generators contributed less than 1% of total CO emissions overall. [14].

The study also found industry in China produced 42% of the total emissions, with the next largest contributor the power sector with 34% of the total. Transportation contributed only 12% but was notable for its rapid rate of increase.

PREDICTIONS OF FUTURE EMISSIONS

Predictions of the likely change in quantity of air pollutants emitted from ADCs have been estimated by several different researchers (for example refer to Qi *et al.*, [30]; Streets and Waldhoff, 2000 [29]; and Foell *et al*., 1995 [10]) for different scenarios.

The scenarios considered the effects of changes in regulatory policy, application of technology and energy diversification. Nevertheless, in all cases it is predicted that the emission of main air pollutants will continue to increase. However, the magnitude of increase can be varied substantially ranging between 20 and 120%, between now and the year 2020, depending on the scenario chosen.

Again taking China as an example, a Pew Center study *Electricity Options for China* [20] provides some future predictions against a 1995 baseline. In this study, power generation and consumption are expected to triple by 2015. If fuel mix and emission controls remain the same as at present then emissions of sulphur dioxide would also be expected to triple, reaching nearly 20 million tons a year. It is reasonable to expect that emissions of particulates and NOx will also triple.

The UNEP GEO-2000 study, *Reducing Air Pollution in Asia and the Pacific*, also suggests that levels of SO_2 and NOx will each triple by 2030, under a business as usual scenario, when compared to a 1990 baseline [19].

While the above studies are not directly comparable they do illustrate that pursuing business as usual patterns of production, technology and emission abatement in the ADCs is not sustainable and that some changes must occur to reduce the future economic and societal and imposts attributed to increased air pollution. The next section of this paper will examine likely scenarios for finding a cost effective solution to the chronic air pollution found in many ADCs.

FINDING THE SOLUTION TO AIR POLLUTION in asia

A critical challenge for ADCs is to commence reduction of emissions at an earlier point than that of the developed countries. The ADCs have the potential to avoid the large increase in emissions observed as the Western countries moved towards more industrialised economies. They can do this by ‘leapfrogging’ less efficient and more polluting technologies such as ‘dirty’ coal and instead moving straight to clean energy fuels such as natural gas from LNG.

This concept of ‘leapfrogging’ technology and its impact on air pollution can best be illustrated by using the concepts of the Environmental Kuznets Curve (EKC).

The Environmental Kuznets Curve (EKC) asserts that there exists an inverted U-relationship between pollution levels and economic affluence for any country. It theorises that the environment will become increasingly polluted and natural resources more and more depleted as a country goes through its industrialisation phase and becomes more affluent. Then after passing a critical point of national wealth, the levels of pollution and resource depletion peak and begin to decline as illustrated by Figure 3.

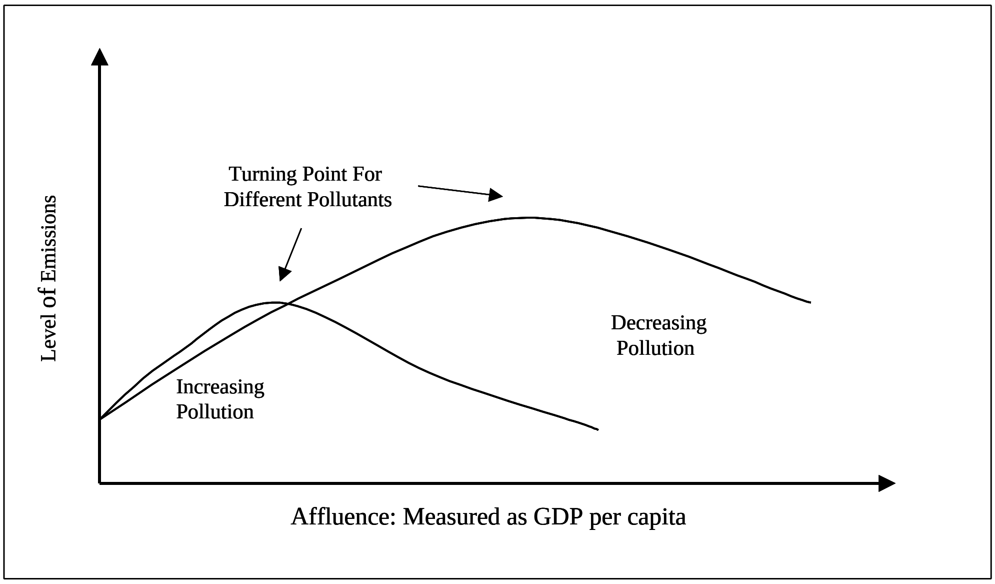

Figure 3: Environmental Kuznets Curve

The EKC typically demonstrates a downward trend in pollution emissions after reaching a turning point of national wealth expressed as GDP per capita. As wealth increases, the ability and willingness of the population to set aside capital for protection of health and environmental quality also increases [31]. Importantly, not all pollutants are considered equally; those emissions with direct health effects will generally be addressed before those of a more long-term or global nature [32]. This preferential response to reducing emissions leads to the turning point for various pollutants occurring at different levels of wealth.

A review of the research into quantifying the EKC turning points for various air pollutants [33] found that the turning points for SO_2 and PM-10 occur at about $6,000 US GDP, while the turning points for NOx and CO occur at about $14,000 US GDP per capita. In comparison World Bank figures for the GDP per capita of South Asia and East Asia are $US 433 and $US 931 [34]. This would suggest that these regions are still on the upward slope of the EKC, that is emissions are increasing as population and wealth grows. This impression of the ADCs is strengthened by reference to the emission trends shown previously in Table 3.

Hence the critical challenge for ADCs is to instigate action to pursue a much shallower Kuznet curve to reduce air pollution at a much lower level of per capita GDP [35].

Abatement in Western industrialised nations has come at a relatively high economic cost, with many early abatement options requiring end of pipe solutions retrofitted to existing installations. Ongoing developments in technology have now resulted in better abatement options, including fuel switching, more efficient gas turbines incorporating combined gas/steam cycles or combined heat and power concepts and more recently commercially available fuel cells, microturbines and better gas storage technologies.

Using the learning from the Western industrialised economies' experience, and selecting from a broad range of available technologies and fuels, ADCs can choose better economic solutions to air pollution abatement and thus avoid the trap of attaining enough economic momentum to avoid costly abatement technology.

For incremental or replacement electricity demand in the ADCs, natural gas supplied from LNG can offer a competitive tariff as well as an opportunity to acquire efficient state of the art technology and build capacity. In addition the use of LNG will reduce air pollution and green house gas emissions.

The requirement for the end-of-pipe solutions on new energy infrastructure is obviated with increased gas usage, leading to extra capital available to clean up older pollution sources. This should result in least cost pollution abatement and achieve the desired result of a declining EKC at a lower GDP per capita than developed countries have historically achieved.

In the view of T. Baalu, the Indian Minister for Environment and Forests, "technology holds the key to accelerated economic development; identification, acquisition, development and promotion of cleaner technologies is therefore imperative." [36] Changing the fuel mix to include a clean fuel such as LNG can play a major part in this approach.

REGULATORY CHANGES

As well as an economic imperative to find least cost abatement options, ADCs are starting to experience community pressure to reduce air pollution, chiefly because of societal and health costs, but also because of its environmental cost.

Asian governments can respond to community and economic concerns about air quality by establishing policies that directly influence changes in fuel mix, emissions standards and the use of clean technology. Regulatory policies can accelerate change, but regulation by itself will not drive improvements unless the cost of abatement is affordable to the country.

Developed economies with cleaner urban air commonly have stringent environmental regulations [37]. Similarities in Asia with the older industrial economies of Europe and the United States can be seen in the development of environmental policies in Japan and Korea. In these countries environmental regulation of air pollution proceeded through three distinct phases. The first phase was a period of rapid economic growth and industrialisation characterised by sectoral-based policies aimed at reducing air and water pollution. The second phase entailed a more comprehensive approach and the consolidation of policy measures and the enacting of umbrella laws for environmental protection. The third phase is the implementation of 'sophisticated environmental policies'. [38]

Many Asian countries are moving towards establishing stringent regulatory policies. For example, recent changes in China include the setting of control zones for SO_2 such that enterprises will need to apply for quota based emission permits according to the legislation *Amendments to the Air Pollution Prevention and Control Law, 2000*.

China also has new legislation relating to redundant technology, the *Clean Production Law* and the *Catalogue of Outdated Technology Processes and Products*. The purpose of the *Catalogue* is to phase out technology that does not meet criteria for energy efficiency, total energy consumption, pollution generation levels, adherence to clean production principles and the technology necessary to achieve economies of scale [39].

The Chinese government has introduced a tax on high-sulfur coal and is aiming to phase out coal from city centres. At least 40 coal-free zones have been established and there are also new planning policies focussed on constructing natural gas pipelines in cities.

In ADCs, policies that encourage and support fuel switching offer significant abatement at least cost. LNG in particular is the clean fuel of choice, because of its emission efficiency as well as the economies of scale obtained in establishing gas infrastructure and facilities.

DIVERSIFICATION OF FUEL MIX

Coal is the dominant energy source within ADCs, accounting for almost 48% of the total primary energy use. Biomass and other renewable energy sources, such as wood and agriculture waste remain the main energy source for most of the rural population, and represent the next largest portion of total primary energy at almost 35%. In comparison, natural gas provides less than 3% of the total primary energy, a percentage that is predicted to increase to about 10% by the year 2020 [5].

Where gas has been used to replace other fossil fuels there have been dramatic reductions in the emission of air pollutants. A prime example is that of Vienna, where a program was commenced in the early 1980s to increase the use of gas. Measures taken included the increased use of natural gas in the city's thermal power stations and the reticulation of gas to new residential areas. Between 1982 and 1995 the share of gas increased to 43% of primary energy use. Over the same time SO_2 emissions decreased more than 98% and NO_2 emissions by more than 85% [40].

Where domestic supplies of natural gas are not available or there is a limited resource the importation of LNG provides an economically viable way for Asian countries to increase the natural gas component of their fuel mix. It is easily transported and can be used as reticulated gas in domestic, commercial and industrial applications.

The process by which natural gas is liquefied and refrigerated to produce LNG also removes sulphur and other impurities. Hence, LNG is a fuel that has a low sulphur, nitrogen and particulate content, no matter what the quality of the original gas source. As a result, when natural gas from LNG is used as a fuel, it produces relatively standardised low sulphur emissions when compared to its competitor fuels and even to domestically produced natural gas that may be of variable quality.

Because natural gas sustains more efficient combustion it generates less CO emissions. This is relevant because the indoor concentration of air pollutants in Asian households is often higher than the outdoor concentration due to the poor quality of fuels used (that is coal, coal gas and biofuels) and inefficiency in combustion [41]. The combustion of biomass fuels that provide a third of household primary energy in developing countries, [42], also emit considerably higher quantities of CO and NOx per unit energy.

The beneficial effect of using natural gas as a domestic energy source was illustrated by a study performed in Beijing, China where the measured indoor concentration of SOx and PM-10 was shown to be significantly less than in households using natural gas than those burning coal.[41].

Changing the fuel mix used in power generation to increase the share of natural gas will result in improved energy efficiency. At present, the thermal efficiency of coal-fired plants in China is around 29%, and in India it is below 30%, whereas combined cycle gas power stations in the same locations have an energy efficiency of greater than 50%.

Switching from diesel to compressed natural gas (CNG) in the transport sector would also have a major effect, reducing emissions of particulates, especially in urban areas [19.]

Fuel switching by increasing the share of natural gas, was examined in the study by UNEP's GEO-2000, [19] which looked at alternative packages to reduce air pollution in Asia and the Pacific. It concluded that "fuel switching, with the accelerated introduction of clean technology is the most efficient in terms of reducing emissions of SO_2, NOx and suspended particulate matter."

The Pew Center study [20] which modelled electricity options for China looked at a range of scenarios such as controlling sulphur emissions by using fees, using clean coal technologies, natural gas options and changes to regulatory policy. It found that simply introducing fees for sulphur dioxide emissions resulted in the greatest reduction of SO_2 (around 40%). However, when using natural gas instead of coal (combined with improved turbine efficiency and a low tax on SO_2), a 35% reduction in SO_2 could be expected. This indicates that changing the fuel mix to increase the share of natural gas can have an almost equal effect on air quality as introducing sulphur taxes, but with other associated benefits, such as reduced emissions of greenhouse gases and high overall energy efficiency.

It has been established in many studies of lifecycle greenhouse gas emissions of LNG and natural gas over competitor fuels (coal, diesel, oil) that natural gas has lower greenhouse gas emissions per unit of energy produced. [43]. For example, natural gas produces 40% less CO_2 than hard coal primarily due to its chemical structure that has a lower carbon/hydrogen ratio than other fuels. Therefore, not only does the gas option provide improved air quality, with reduced SO_2, NOx, particulates and CO, using gas results in around half the greenhouse gas emissions of other fossil fuels.

In the case of greenhouse gas emissions, where the rules of the United Nations Framework Convention on Climate Change and the Kyoto Protocol are still being negotiated, it is possible that the use of gas based technology with LNG could deliver multiple benefits to ADCs. The advent of the Clean Development Mechanism offers a method of getting elevated levels of technology transfer and capacity building for projects that reduce greenhouse gases below an agreed baseline. There exists also the possibility of new and streamlined sources of ODA and GEF assistance for ADCs to adopt low emission technologies. Whatever the outcome, greenhouse gas abatement will drive energy generation towards natural gas as a rather long lived transition fuel and by doing so will assist in a collateral reduction of other forms of air pollution.

ECONOMIES OF SCALE

Economies of scale in industry are a factor that influences the downward trend of air pollutant emissions. Economic growth allows for more industries to reach the critical size at which the installation costs for abatement technology can be borne without adversely inhibiting production costs and profits.

For example, power generation based on natural gas from LNG involves substantial capital investment but attracts lower operating costs than generation by other fuels. The combination of high fixed costs and low operating costs means that the average cost per unit of abated pollution will fall as the amount of generation from LNG increases.

Many of the existing power stations in China and India are old installations and very few have pollution control technology fitted. [44] For example, coal-fired plants in the Chinese city of Shanxi account for around nearly 30% of the city's SO_2 and particulate emissions [45].

However, even new coal plants with the best available control technology still emit approximately 0.07 kg NOx/GJ and 0.15 kg SO_2/GJ. Older coal fired power stations emit 3.3 times as much NOx and nearly 20 times as much SO_2 [46].

Instead of building new coal-fired power stations, or even investing in clean coal technologies, a similar financial investment in gas-fired power stations can result in around a 30% reduction in SO_2 emissions.

EMISSION EFFICIENCY

Technology costs and pollution efficiencies (mass pollutant produced per unit per production) generally improve with experience. Increases in energy efficiency and cost reduction allow developing economies to not only increase the quantities of energy produced but also to do so with declining costs and emission. Typically costs of technology are initially high during the research and development phase and then taper off as improvements and commercialisation continue. Gas turbine technology has been developed and commercialised since the 1950s and consequently has reached levels of high efficiency and with relatively low costs. [5] A US environmental research group, the Environmental Working Group has found that natural gas burning power plants can achieve pollution rates well below US Federal standards. [46]

Emissions to the atmosphere from fossil fuel combustion depend on the characteristics of the fuel and the efficiency by which it can be utilised. A gaseous fuel usually can be combusted more completely and efficiently than either coal or oil. The recovery of waste heat from natural gas combustion is relatively simple because the flue gases are not contaminated by particles or corrosive sulphur compounds.

CONCLUSION

The developing countries of Asia are undergoing a period of rapid population growth, urbanisation and industrialisation. Parallels can be drawn to similar periods within the history of developed countries however there are key differences in the accelerated rate and sheer scale of change occurring within ADCs.

Air emissions from the increasing number of factories, industries and power stations necessary for economic growth, in combination with emissions from domestic fuels, have resulted in dangerously high concentrations of air pollutants in many cities of ADCs. The incidence of illness and premature deaths associated with this increased air pollution is a large social and economic burden, as is the substantial cost of damage from acid rain.

Forecasts of emission of air pollutants have indicated potential increases of between 20 to 120% by the year 2020. Emissions of SO_2 and particulates have attracted the most attention due to their relatively immediate and localised effects. The regulatory and policy actions needed by ADCs to abate emissions should focus on three core areas: diversification of energy, improved technology and scale of economy:

Firstly, the characteristics of LNG itself mean that per unit of energy produced it produces less air pollutant emissions. Increasing the proportional use of LNG as a component of the energy mix will result in reduction in emission of air pollutants, especially SO_2 and particulates which are of major health concern. LNG also results in substantially less greenhouse gas emissions than other fossil fuels.

In addition, the use of natural gas from LNG itself guarantees low sulphur as this must be removed prior to liquefaction. In this respect it is potentially 'cleaner' than domestic natural gas that may contain variable amounts of sulphur, nitrogenous compounds and carbon dioxide;

Secondly, LNG-based energy production uses proven technologies with high efficiency and relatively low emissions, whereas the low emission technologies for competitor fuels are still in development with unproven reliability for large-scale operation;

Thirdly, LNG-based power generation provides scope for economies of scale in the abatement of air emissions. Once such a plant is established, the average cost per unit of abated pollution will fall as the quantity of energy produced increases.

Implementation of strategies in the ADCs based on increasing the proportion of LNG-based energy in their primary energy supply have a latent potential to cut emissions of major pollutants such as sulphur and nitrogen oxides by approximately 30% when compared to business as usual forecasts by 2020. Such a reduction in emissions, when combined with modest technology improvements would reduce the economic burden imposed by higher levels of pollution whilst assisting the ADCs to remain on their desired path of sustainable growth.

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