Huge hopes for a Clean Air City: Lessons from Ulaanbaatar City Air Quality Problems and Prospects for a Sustainable Socio-Economic Development

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Abstract- Poor air quality has profound adverse effects on human health and ecosystems with further negative implications on future generations. Excessive urban air pollution in Ulaanbaatar city poses huge threats to a sustainable development in Mongolia. Worsening air quality problems in Ulaanbaatar city of Mongolia was concerned in this study. The state of air quality in Ulaanbaatar City was updated by reviewing lots of literature. Thereafter, implications for a sustainable development are drawn. Further, the state of the problem in terms of main pollution sources, effects and abatement approaches is compared and contrasted with air pollution cases in history (e.g. London fog of 1952 and Los Angeles photochemical smog) and even with cases in emerging economies of Africa and Asia. From the review, it is evident that relevant authorities in Ulaanbaatar city are on track in terms of the mix of the current pollution abatement strategies they already put in place in fighting pollution. This is mainly because the same measures currently in place yielded success in other urban cities worldwide. However, air quality is still problematic in the city. Therefore, there is a need to scale-up measures by investing more in pollution abatement technologies, financing activities and ensure commitment from various stakeholder i.e. public-private partnerships in pollution abatement. More so, there is a need for a continuous cycle of monitoring and evaluation of progress, taking corrective measures where necessary. This and only will raise positive prospects for a sustainable development

Index Terms- Air quality, urbanization, sustainable development; review; Mongolia

I. INTRODUCTION

Rapid population growth in most Asian countries including Mongolia has resulted in rapid urbanization, which in turn have come with increasing air pollution problems (HEI 2004). The same trend is evident in Mongolian cities including Ulaanbaatar city where air quality for most of the times is very poor (Nicolaou et al. 2005). To date, Ulaanbaatar is ranked amongst the top 5 cities in the world with worst air quality (Guttikunda et al. 2013). Guttikunda et al. (2013) reported that the annual average particulate matter concentrations between 2010-2013 were 136 ± 114 µg/m3 which was significantly higher than those regulated by the World Health Organization (WHO) guideline for PM10. Moreover, average air quality index for Ulaanbaatar in 2017 averaged above 150 which is considered unhealthy for sensitive groups (US Embassy Mongolia 2018). More so, recordings for air quality index for the winter season in 2018 have been shown to reach above 200 which is considered hazardous to humanity (US Embassy Mongolia 2018). Increasing vehicular population, energy demands (e.g. cooking and heating) and growing industrial sector in Ulaanbaatar city could have aggravated local air pollution. Among all of the factors, the growing demand for energy is mainly contributing to the air quality problem (Batjargal et al. 2010). According to Guttikunda (2008), high rate of urban population growth is mainly attributed to in-migration. People are moving from the village to the cities due to increased income and employment opportunities in cities. For instance, such income and employment opportunities are evident in the growing construction and mining sectors. The major pollution sources in Ulaanbaatar city according to an article by Guttikunda (2008) indicated that the major pollution sources in Ulaanbaatar city were: coal combustion, burning of biomass such as wood within households, burning of agricultural waste in farming areas, vehicular emissions, road dust from construction sites, and use of inefficient technologies in cooking and heating in Ger residential areas in Ulaanbaatar city.

Very cold winters in particular, has resulted in increasing demand for energy for heating and generated lots of particulate matter with a diameter less than 2.5 or 10 micrometres (PM2.5 or PM10) in the city, which has been illustrated by many researchers (Davy et al. 2011; World Bank 2011; Nicolaou et al. 2005). For instance, PM10 concentrations in winter were found to be at least double than that in summer in 2006 reported by National University of Mongolia (NUM) (Nicolaou et al. 2005). Furthermore, use of coal for various purposes in the domestic sector also aggravated particulate matter concentrations. For instance, in the domestic sector, the growing population residing in Gers have also contributed to the air quality problem. The government's restrictive policies on in-migration have largely contributed to the growth of Ger areas (residential areas) in Ulaanbaatar city (Guttikunda 2008). In Ger (residential areas), residents use traditional cooking stoves and boilers which are low efficiency, and hence elevated air quality problems in

Ulaanbaatar city. Overall, the different sources of air pollution in the city are worrying as poor air quality has its own negative effects on the human health.

Air pollution poses serious health risks to people exposed to it. Ulaanbaatar city is not an exception to the World Health Organization (WHO) listed the city among the top five cities with the worst air quality in the world recently (Guttikunda et al. 2013). Within Mongolia, poor air quality has been linked to various health related problems including abortions (Enkhmaa et al. 2014), mortality (Hoffmann et al. 2012) and various other acute health effects (Pope III and Dockery 1992; Smith 1993). In other words, exposure to fine particulate matter with an aerodynamic diameter 2.5 µm (PM2.5) generated by combustion maybe especially damage to human health (Schlesinger et al. 2006).

This and other reasons have made air quality an issue of major concern in the city. Despite a number of plans and interventions were implemented to control air pollution in Mongolia, including: particulate matter monitoring, improved cooking stoves technology, pollution control at power plants, introduction of solar water heating among others (Guttikunda 2008; Guttikunda et al. 2013), air quality is still a major problem up to now.

Given this background, the aims of this study were 1) intended to analyze closely the state, extent, and effects of urban air pollution; 2) identified potential pollution abatement actions possible through a massive review study; 3) proffered implications for a sustainable socio-economic development in Ulaanbaatar city. The rest of the article is organized as follows: section 2 outlines the motivation of study while section 3 gives a synthesis of the state of urban air pollution in Ulaanbaatar. Section 4 expansively synthesis literature on the wider socioeconomic and environmental effects of poor urban air quality. Section 5 outlines some of the pollution abatement actions tried by the Mongolian government and also suggest possible more effective abatement actions the government can adopt for significant improvement in air quality. Moreover, section 6 gives the implications of excessive air pollution on prospects of a sustainable socioeconomic development in Mongolia. Sections. Review summaries and conclusions are given in section 7.

II. STATE OF AIR QUALITY IN ULAANBAATAR CITY AND COMPARED WITH OTHER MEGACITIES WORLDWIDE

2.1. Air pollution in Ulaanbaatar city

Ulaanbaatar is the capital of Mongolia and it is highly populated and has much of industrial activity. To date, it is the main political, economic, cultural, scientific and business center of the country (Amarsaikhan et al. 2011). In addition, the city is also home to the central government and main public and private institutions of higher learning and best medical service. The concentration of industrial activity amongst other covariates is the most important reason for so much poor air quality. This section gives a brief overview of the state, main factors contributing to poor air quality in the city.

a) State of air quality in Ulaanbaatar city during 2011-2016

Although the concentrations of $PM_{2.5}$ and PM_{10} showed a declining trend in the city after 2011, the improvement still is not sufficient for population and ecosystem health in the city (Fig.1 & 2

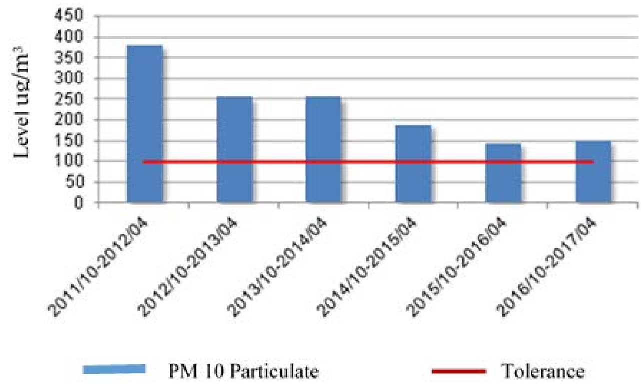

***Figure 1**: Average concentration of PM_{10} for the period 2011-2017 in UB, (Gov M 2018)*

Compared the trends of concentrations of $PM_{2.5}$ and PM_{10} (Fig. 2), a similar trend in air quality was observed for the period 2011-2017. However, it should be noted that the average air quality index for both $PM_{2.5}$ and PM_{10} were still classified as hazardous for the human health in the city. Concentrations of $PM_{2.5}$ and PM_{10} during 2011-2016 were still above the red line and ranged between 140 and 370 AQI for PM_{10} which was considered lightly to pollute by air quality standards classification. This showed that air quality remains a problem in Ulaanbaatar city.

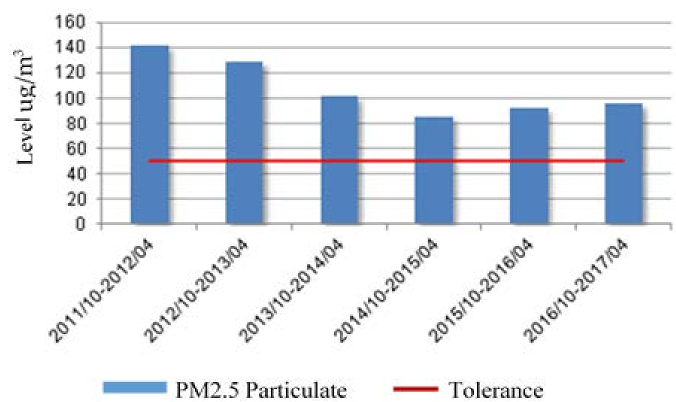

***Figure 2:** Average seasonal concentrations of $PM_{2.5}$ particulate matter, 2011-2017 (Gov M 2018).*

For $PM_{2.5}$, the concentrations of $PM_{2.5}$ shown in figure 2 were all above 60 ug/m^3 which by standard air quality standard classifications for $PM_{2.5}$ air quality is still very poor.

b) Background to the air quality problem and major causes.

A study by Allen et al. (2013) gave a very useful brief background to Mongolia and Ulaanbaatar city's air quality problem. Rapid urbanization and population growth are reported to increase largely since the mid-1990s. To date, Ulaanbaatar

(the capital city) is home to over 1.11 million people, a figure which represents more than 40% of the total population in Mongolia (2.74 million people) (Allen et al. 2013; Mongolia 2010). This growth in industrial activity and population has led to a serious deterioration in the city's poor air quality. As highlighted earlier in the introduction, much of the growth in population is evident in low-income areas (Ger areas) which are dominated by the use of coal for heating (Bank 2004). According to the Asian Word Development Bank, more than 50% of Ulaanbaatar's population live in Ger areas (Asian Development Bank 2006). There are approximately 160,000 Gers in Ulaanbaatar and each was believed to consume or burn an average of 5 tons coal and 3 m^3 of wood per year (Guttikunda 2008). In addition, various other sources as highlighted also contribute to air pollution. The vehicular increase which mainly uses leaded gasoline as fuel (HEI 2004), coal-fuelled heat and power plants, heat only boilers and wind-blown dust are some of the main noted sources (Allen et al. 2013).
However, many studies pointed that reliance on coal for energy was the prime source of poor air quality in the Ulaanbaatar. Davy et al. (2011) indicated that much of the particulate matter ($PM_{2.5}$) in Ulaanbaatar city was from coal combustion. Moreover, geographical location of the city also worsens the poor air quality in Ulaanbaatar. The city is located in a valley surrounded by mountains to the north and south (Asian Development Bank 2006). The topography also combined with extensive emissions, and temperature inversions are believed to cause very high and toxic pollution concentrations in winter periods (Davy et al. 2011) (why?pls explained in details). This brief background of the city enhances understanding of the nature of air quality problems in Ulaanbaatar. The results of comparison urban air pollution in this city with megacities of the world and other major cities in Asia were given in the next sub-section.

2.2. Urban air pollution in Asian cities and megacities of the world

2.2.1. Air pollution and urbanization

How does poor air quality compare to other major cities in the world particularly in Asia? Nearly 50% of the world's population now resides in urban areas because of more and better income, employment and quality of life in general (Molina et al. 2004). The proportion of people living in urban cities now is even higher and continues to increase. Several of such urban centers may be defined as metropolitan areas with inhabitants of more than 10 million people. The higher concentration of people in such small areas exerts pressure on the ecosystem. There is obviously higher demand for things like energy and other goods and services. Recently, air pollution has become one of the most important concerns and a problem for most megacities (Fang et al. 2009; HEI 2004; Kanakidou et al. 2011; Mage et al. 1996; Parrish et al. 2011). Growing use of coal for burning usually escalates the level of degradation of air quality. Industrial activity in such cities, traffic, mining and other related sectors chiefly adds to air quality problems. Resultantly, a number of health-related concerns posed by poor quality have also been raised in mega-cities. It is, therefore, an area of serious concern that needs action from various stakeholders to try and improve the situation.

2.2.2. Comparing air quality in Ulaanbaatar with other cities in Asia and the rest of the world

The major question to ask is "How does poor air quality in Ulaanbaatar city compares to that of main cities in Asia and megacities of the world? For a quick sight on the severity of the poor air quality problem in Ulaanbaatar as compared to some cities worldwide see Figure 3. With data shown in figure 3, it is evident that PM_{10} concentration was highest in the Ulaanbaatar city when the comparison was made of another city with the Ger areas only. The maximum PM_{10} concentration for UB Ger city areas was at around 700 ug/m^3 which was way above average for the rest of the cities listed. Even the average PM_{10} concentration for the main city areas is lower than that of the city Ger areas, it is still high than that of all the cities shown in the figure. This again shows the bad state of air quality in UB compared to other cities.

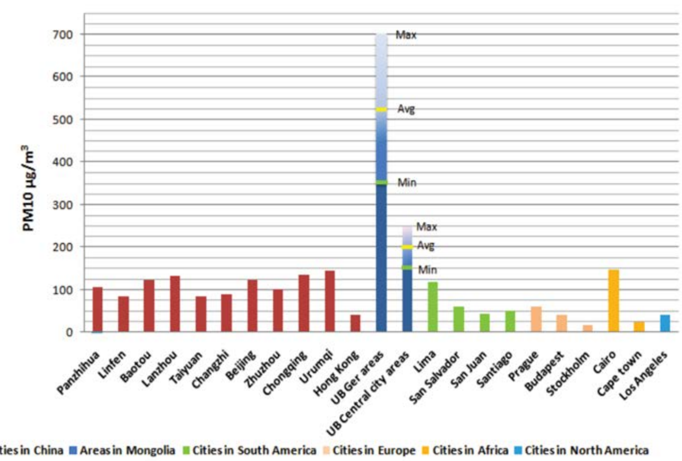

Figure 3: *Comparing state of air pollution in UB PM10 concentrations in Chinese and other World cities (World Bank 2011)*

Take into consideration of the development dimension into question, air pollution in the city still cannot be justified with the level of development. It was understandable that air pollution was getting worse mainly because of energy demand in the city which are mainly being met through the burning of coal. However, neighboring cities Beijing with higher levels of industrial activity and development, air quality was poor but at much lower levels than that of UB city. As highlighted earlier some other factors could be explanations i.e. poor city planning which exacerbate the air quality problem.

2.2.3. Situation in World's megacities History of air pollution and industrialization

It was said that air pollution issues have often been associated with industrialization in now well-developed cities such as Los Angeles. Los Angeles has been subject to air pollution since the 1950's (Parrish et al. 2011). Photochemical smog was first recognized a severe environmental hazard in Los Angeles due to extensive air pollution from industrialization activities. Since then, photochemical smog has been the subject of extensive air pollution control efforts since the 1950's (Cox et al. 2010).

Although several other kinds of smog occur or have occurred elsewhere, photochemical smog (or Los Angeles-type smog) was a yellow-brown haze produced by the reaction of sunlight with exhaust from automobiles and power plants that burn coal (Bailey et al. 2002). Ozone, nitrogen dioxide, and other volatile organic compounds that make up this smog irritate eyes and nasal passages. These are particularly dangerous to people who have heart disease, asthma, or other respiratory illnesses, and to anyone who exercises or does manual labor outdoors when smog is heavy.

Related, we have another significant cause of urban air pollution often cited in Literature-London smog. In December 1952, a heavy, motionless layer of smoky, dusty fumes from coal stoves and local factories settled in London basin (Davis 2002). The thick sulfurous smoky fog affected traffic and a lot of other activities in the city that day. More recently, more cases of significant air pollution have been noticed in developing and developed cities across the world. For instance, air pollution has become a major concern in megacities of China. Beijing, Shanghai, and Guangzhou are some of the cities with significant cases of air pollution. Rapid industrial growth, urbanization and heavy reliance on coal are some of the major reasons behind air quality problems in these aforementioned cities. Coal accounts for more than 70% of total energy consumption and emissions from coal combustion are the major anthropogenic contributors to air pollution in the country (Chan and Yao 2008). Urbanization, in particular, has been rapid in China. From 1980 to 2005, urban population increased from 19.6% to 40.5% (Chan and Yao 2008). In addition, a number of cities increased and over 170 cities have over 1 million inhabitants as of 2004. These trends highlight the rate and intensity of urbanization in the Asian country. This, however, has come with excessive air pollution which is evident to date.

In addition, this study also cited air pollution problems in developing cities such as Istanbul, Cairo, and Athens. All the three cities experienced heavy pollution from the transportation sector with more than 2 million cars in Athens and Greece and more than 1 million in Cairo (Kanakidou et al. 2011). Older cars were found in Cairo when compared to the other two cities. For instance, urbanization and industrial growth could be attributed to air quality issues in Cairo. Cairo's air pollutants mainly come from residential combustion and industries. The main pollutants are CO and NOx and non-methane volatile organic compounds from road transport (Kanakidou et al. 2011). In Athens and Istanbul, on-road traffic is the major contributor to CO, NOx and non-methane volatile organic compounds. Resident combustion and cargo shipping are also significant pollution contributors. A lot of other megacities in different parts of the world not mentioned in this brief review experience air pollution problems today. For instance, Dhaka (Bangladesh), Karachi (Pakistan) etc. were among the developing countries with poorest air quality (Gurjar et al. 2010).

III. Effects of Heavy Air Pollution on Human Health, Economic and Ecosystem in UB

3.1. Ecosystem effects

Air pollution in UB city also leads to various other ecosystem health and or related effects. For instance, visual impairment (poor visibility) is one major effect on the ecosystem caused by air pollution. Mostly in the winter season, visibility could be very poor which negatively affect traffic movement and sometimes resulting in traffic congestion and road accidents. The connection between pollutants and visibility impairment was related to fine particulate matter $PM_{2.5}$ but it was also accompanied by high levels of other pollutants such as soot and dust (Watson 2002). Urban haze in Beijing is one example of the commonly perceived effect of excessive concentrations of PM. In Ulaanbaatar city, urban haze is also a major phenomenon, especially in the Ger areas.

Other noticeable impacts on the ecosystem in the UB city include acid and nitrogen deposition which enormously affects forestry and vegetation in and around the city. The detrimental impacts of acids formed from SO_2 and NOx emissions on waterbodies, forests, and farmlands have been documented in the literature (Cáceres et al. 1980; Ortiz et al. 1982; Trier 1984; Trier and Firinguetti 1994). In addition, Photochemical Oxidant Damage was also a major effect of air pollution on ecosystems noted in the literature. Photochemical produced oxidants and their precursors frequently produce high levels of O_3 and other oxidants that transport from one major city to the next, subjecting the intervening suburbs, forests, and agricultural areas to high oxidant exposures (Guttikunda et al. 2003). Exposure to O_3 and related photochemical oxidants is known to damage both native and agricultural vegetation. This also has been reported in UB city although current literature confirming the phenomenon is still scarce.

Also, Photosynthetically Active Radiation (PAR) especially in Asian megacities including UB city, have also been found to have effects on plant processes. Recent model analyses demonstrate the impact of Asian megacity SO_2 emissions on regional pollution. High SO_2 and other gaseous precursors can result in high levels of fine PM, with absorption and scattering properties that significantly influence both the direct and diffuse components of photosynthetically, active radiation (PAR) (Cohan et al. 2002).

3.2. Human Health effects

Megacities tended to be at risk and their inhabitants were vulnerable to air pollution-induced adverse health impacts (Gurjar et al. 2010; Molina and Molina 2004). For instance, Gurjar et al. (2010) reported that poor air quality linked to mortality and morbidity in selected world megacities. This was also the case in Mongolia as a number of studies have linked poor air quality to human health problems in the city (Nakao et al. 2017). A recent study for Mongolia showed that investigated the lung function in Ulaanbaatar city subjects aged between 40 to 79 years found the crude prevalence of airflow limitation of about 11.5%. The study, however, showed that the health effects of poor air quality were worse in older subjects (the Aged), and in those with lower body mass indexes (BMI) and also in those subjects who smoke (Nakao et al. 2017).

In support of the observed health effects of poor air quality on the health of city inhabitants in Ulaanbaatar city, a number of the studies from different parts of the world have also related poor air quality to human health. A number of studies have associated air pollution with specific health and health-related effects. For instance, WHO estimated that urban air pollution contributed to about 800 000 deaths and 4.6 million lost life-years yearly worldwide (WHO 2002). More so, according to HEI (2004), airborne particles have been of particular concern because of epidemiological study findings linking diseases like lung cancer and cardiopulmonary mortality to fine particulate matter. Excessive air pollution especially in the form of Polycyclic aromatic hydrocarbons (PAHs) originating mainly from motor vehicle emissions, oil refineries, forest fires, and cooking if inhaled, may cause changes in human development (Perera et al. 2003). Other studies have also shown that elevated air pollution might cause DNA damage in male sperm cells (Selevan et al. 2000). It, therefore, entailed that air pollution affects not only contemporary but also future generations (Somers et al. 2004). Considering that residents in Ger areas burned coal for heating directly in their houses particularly in winter, such health effects could be true for UB residents. However, no specific study for UB was found to have analyzed such effects at the time of this study.

Health studies in Mexico have also indicated that a 1% change in daily mortality could be attributed to 10 g/m^3 increase in PM_{10} (Molina and Molina 2002). This compares to 0.6% per 10 g/m^3 increase derived from a meta-analysis of epidemiological studies conducted around the world. In New Delhi, India, an increase of more than 20% in chronic obstructive pulmonary disease and acute coronary events attributed to air pollution were found in a study reported by Pande et al. (2002). More so, a significant positive association between PM pollution and daily non-traumatic deaths, as well as other deaths (e.g. respiratory diseases and cardiovascular diseases) in India (Cropper et al. 1997). In China, a significant association between sulfur dioxide levels and daily mortality were found throughout the year in Beijing (Xu et al. 1994). Precisely, the mortality risk was estimated to be elevated by 11% with each doubling in sulfur dioxide concentrations. In South America, Santiago, Chile a strong association between premature mortality and PM_{10} (Sanhueza et al. 1999). In Sao Paulo, Brazil, significant effects of PM on respiratory functions in children were found (Saldiva et al. 1994). Increased mortality in elderly people associated with high PM levels has also been documented (Braga et al. 2001; Saldiva et al. 1995).

3.3. Effects of air pollution on economy

Air pollution could also negatively impact the economy. However, no specific study for Mongolia that analyzed the effects of air pollution on the economy. However, given the noted impacts of poor air quality on urban ecosystems and on human health, it was possible that the excessive air pollution was burdening the Mongolian economy in a number of ways. Firstly, poor health due to excessive air pollution could burden the Mongolian through the increased budget on the health sector. With more sick patients, the government will definitely budget more on health. Secondly, with a sick population which happens to be laborers in the country, their poor health could reduce productivity as they work less and spent most of their time seeking medical attention. This could negatively impact on the economy. Finally, since poor air quality has been linked with poor urban ecosystem health, it was plausible that slow traffic, accidents and other related problems which slow business in the city negatively affects the economy too. More research is, however, needed in quantifying the effects of poor air quality on the economy in Mongolia.

IV. Pollution Abatement actions present, challenges and successes

Pollution abatement success stories are what every inhabitant of Ulaanbaatar hopes for. There is a need for serious action to improve air quality in that beautiful city of Mongolia. It is important to review what the current actions are and recorded successes before suggesting further improvements in abatement action. In the next sub-section, current pollution abatement actions in UB are discussed.

4.1. *Main pollution abatement actions adopted in Ulaanbaatar City.*

a) Approaches to implementing pollution abatement actions

With excessive pollution in the recent past, responsible authorities have tried to use a number of strategies to curb the excessive air pollution in the city of Ulaanbaatar. Current action has mainly focused on finding the various ways of reducing emissions, especially from the Ger areas. Ger area heating, heat only boilers and suspended dust has been the three main targets for reducing emissions in Ulaanbaatar city. Air pollution abatement programs in the city have followed a structured approach to a continuous strict cycle of planning, implementing, evaluation and corrective measures in abatement strategies (World Bank 2011). Research, government action and action from the private sector including non-governmental organizations have included a number of measures with the aim of improving air quality in the city. Some of the measures include: (a) improved assessment of air quality, its distribution and variation in order to understand pollution levels, (b) evaluation of the environmental damage caused by air pollution, (c) assessment of the most feasible pollution abatement actions, (d) evaluating the cost and benefits of possible abatement strategies, (e) prioritizing abatement options based on cost-benefit analysis outcomes and other considerations, (f) implementation, monitoring and evaluation of abatement strategies.

b) Policy Actions

Policy actions in UB yielded establishment of the Air quality division under the Nature Environmental Protection Department of the Capital City in 2006, which was later upgraded to Air Quality Department of the Capital City in February 2009. Recently, a number of the project from non-governmental organizations have been undertaking projects for the same cause "improving air quality in Ulaanbaatar City". For instance, the

"Capacity Development Project for Air pollution control in Ulaanbaatar City Mongolia" by the Japan International Cooperation Agency (2013) and another project by World Bank (2011) which was mainly evaluating air quality conditions in the city and the health implications.

c) Specific pollution abatement actions in place

Some of the specific actions evident from literature which were mainly based on an in-depth understanding of the pollution sources, effects and related factors (see Figure 4) include the following: exploring use of alternative fuels and efficient technologies, setting long-term strategies for emission prevention and reductions, developing low and cost-effective alternative technologies in cooking and heating, cleaner vehicle technologies, emission standards, improved inspection programmes and exhaust and promoting change of lifestyle i.e. public transport use as opposed to private transport. Specific measures and impact (including expected long-term impacts are given in table 1.)

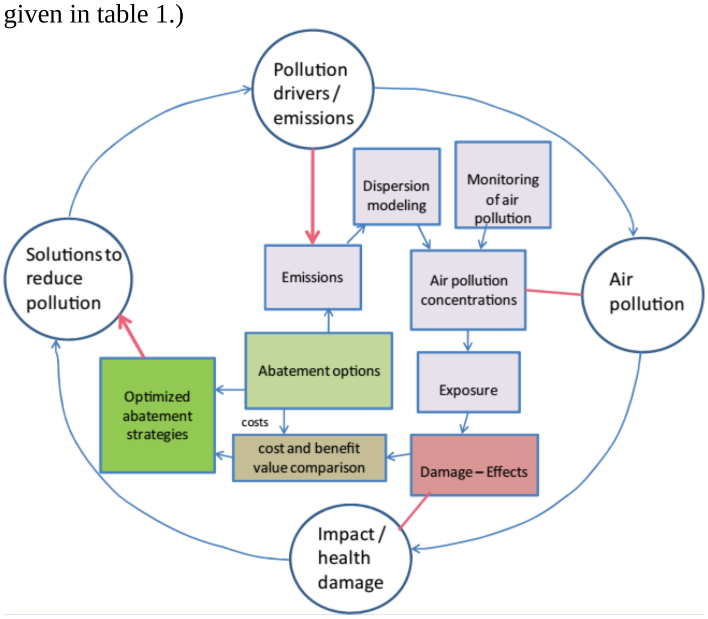

***Figure 4:** Concept for developing effective air quality abatement strategies in Ulaanbaatar city adapted from (World Bank 2011).*

In the table, two a number of pollution abatement actions in Ulaanbaatar city are given and their impacts including future expected impacts. Shown are actions already in place and whose impacts are already shown by the slight reductions in pollutant concentrations (as measured by PM2.5 & 10).

Table 1: Pollution abatement strategies in Ulaanbaatar city and their expected long-term impacts.

Action	**Anticipated impact**	**notes**
Adoption of Improved cookstoves	Immediate reduction in particulate matter in the atmosphere.	Projects supported by government incentives (50% subsidy) are in place to improve adoption of improved cookstoves. More so, Programs are in place for scaling up.
Pollution control at power plants and promoting energy efficiency at heat only boilers	Improving efficiency of existing boilers, replacement of old heating boilers or connecting to new centralized district heating facilities will have an immediate 30-40 percent reduction in heat only boilers' contribution to ambient air pollution.	This intervention can reduce dispersed pollution by abolishing small-scale boilers and upgrading them to district heating system
Controlling fugitive dust on paved and unpaved roads	Intervention is expected to reduce spring and summertime on-road fugitive source. Reduction in particulate matter concentration in the atmosphere	A larger intervention for capture of fugitive dust via wet sweeping and conversion of a large section of unpaved roads to paved roads will have the largest impact in the Ger areas
Solar water heating systems for new housing complexes	Impact on air quality will be immediate due to reduction in demand for district heating when possible	Initial costs are normally high hence success is hugely determined by government support.
Public transport system	Reduction in vehicular emissions	Effectiveness will depend on the extent of improvements in public transport infrastructures and by growth in the passenger vehicles and barriers.
Garbage collection and gasification of urban waste	Impact of this intervention on air quality is immediate, but small in proportion compared to other actions e.g. improved cooking stoves technologies.	Collectively, a positive measure with fruitful impacts on air quality despite their minimal expected impact.
Fuel substitution	clean coal technology briquettes for cooking stoves and industrial heat only	This intervention has the largest impact on the cookstoves and heat only boilers, for not

	boilers are expected to have a high impact on the ambient particulate matter.	only emissions are reduced from scattered low-lying sources, but also a single point source offering better control options
Awareness and education	Improvement in institutional capacity for regulation and enforcement	An essential part of the campaign to promote energy efficiency at the household and industrial level.
Particulate pollution monitoring	Enhances the Institutional capacity of air quality division in identifying the pollution hot spots.	Air quality monitoring is essential to evaluate the impact of air pollution reduction measures.

Notes: list not exhaustive but it shows some of the most common actions in place: more can be found in the following sources:(Guttikunda 2008; Guttikunda et al. 2003; Guttikunda et al. 2013; World Bank 2011).

4.2. What can be done for the future? : Lessons from successful pollution abatement actions in other cities.

What does the future hold for Ulaanbaatar city's air quality? Based on some success stories on air pollution abatement, a number of actions can be effective in further improving air quality in the city. Future actions will need to reinforce/upscale current actions and where necessary new actions are to be taken for improved air quality and hence human and ecosystem health in the city. Some recommendations for further improvements in air quality in Ulaanbaatar are given in table 2. Important to note is, however, that the same measures currently in implementation in Ulaanbaatar are the most noted factors for successful improvement in air quality in big cities. The only important thing to stress is that ultimate improvement in air quality will depend on the level of commitment, investment, effective cooperation from the various stakeholders (from residents to policymakers) and prioritization. Successful air pollution control in various other urban areas in the world is attributed to actions shown in table 2. From policy, education, and awareness, institutional measures, enforcement actions, and technical measures.

Table 2: Air pollution control measures in urban cities

Action categories	**Actions types**
Enforcement initiatives	Identify and target gross polluters, Provide complaint phone or text message numbers for visual sighting of polluters
Institutional measures	Identify and encourage champions for change, Formulate a Clean Air Group that includes industry, fuel providers, and nongovernmental organizations
Education and publicity of air quality information	Publish and broadcast Air Quality Indices, Promote a regular media outlet for air quality stories to keep up interest, Offer environmental education in primary schools and agricultural extension services
Policy actions/initiatives	Produce and distribute unleaded gasoline, Phase-in improved technology vehicles and engines through tighter standards, Remove fuel subsidies, Abolish burning of garbage and other biomass, Lower taxes on clean products
Road, traffic and transport management	Make public transportation affordable or even free for downtown destinations, Train and bus drivers know about air pollution and fuel use, Promote fuel efficiency for cars and industry, Establish one-way traffic with synchronized signals, Pave roads, including access roads
Technology related measures	Eliminate refuelling leaks, Reduce sulphur content of diesel fuel and gasoline to 500 ppm or lower, Require new gasoline-powered vehicles to have operational catalytic converters, Mandate inspection and maintenance for commercial vehicles, Design and disseminate better stoves for coal briquettes, wood pellets, and other solid fuels, Focus on less-polluting, better-ventilated kitchens, Promote more efficient agricultural burning methods.

Notes: Summary of the measures adapted from (Chow et al. 2004; Jain and Khare 2008).

Recommendations are given based on success factors of urban pollution control in megacities around the world. However, important to note is the fact that there is no universal response to everything. What may have worked in one city does not necessarily mean it will work elsewhere. Measures must always be implemented in ways that suit current and local conditions. Jain and Khare (2008) give a pictorial view (Figure 3) of how the various pollution abatement actions interlink to effect on improved air quality.

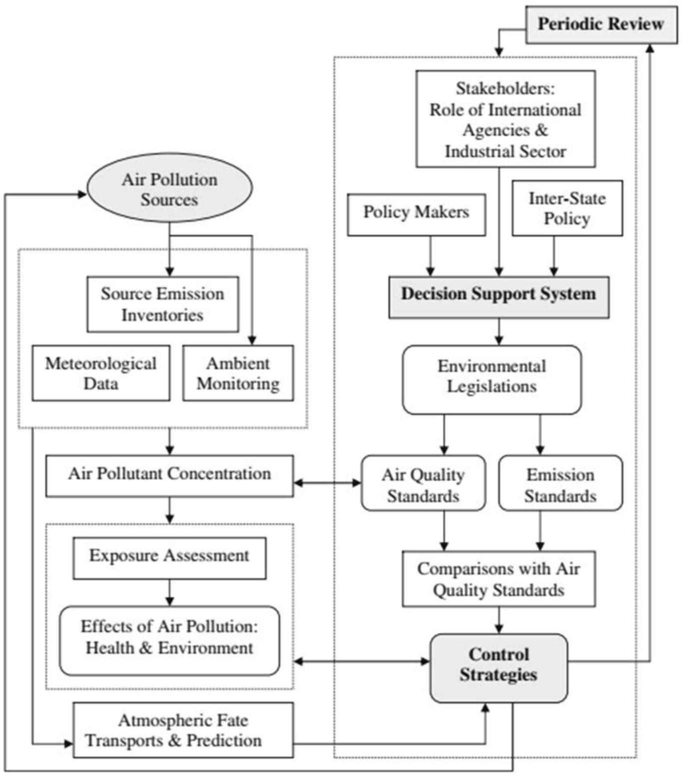

Figure 5: Air quality management in big cities a pictorial view

The next sub-section gives some implications of urban air pollution, effects and abatement efforts for a sustainable socio-economic development in Ulaanbaatar and other cities in Mongolia.

V. IMPLICATIONS FOR A SUSTAINABLE SOCIO-ECONOMIC DEVELOPMENT

First of all, poor air quality is known to have serious health implications both human and ecosystem health. Excessive air pollution assuming a business as a usual approach (zero abatements) will jeopardize the well-being of residents of the city. a number of chronic health diseases like Asthma, lung diseases, DNA damages, and various other pulmonary, respiratory and cardiovascular diseases will have far-reaching harming effects on the active labor force now and for the future (the young). Given the importance of an active and healthy labor force on the economic development of the country zero abatement actions will cripple hopes of a sustainable development in Mongolia. Same applies, poor air quality has devastating effects on the urban ecosystem. Urban farmland, forests and tourism activities which support livelihoods of the urban people will be crippled. Again this has far-reaching implications on prospects of attaining a sustainable socio-economic development in the country. It, therefore, implies that pollution abatement in the different sectors housing, transport, waste management, energy, and construction are not an option for the Mongolian government. Achieving a sustainable socioeconomic development will only be achieved if the government with the help of other stakeholders (NGOs, the private sector, residents of the city) if serious actions on the environments are implemented. Upscaling on current measures will be critical. More so, strict monitoring and continuous evaluation of abatement actions underway will be utmost important too.

VI. CONCLUSION

This study reviewed reports, scientific publications, and grey literature to develop a deep understanding of the problem of poor air quality in Ulaanbaatar city of Mongolia and implications for a sustainable development. Precisely, the article touched on the nature and causes of urban air pollution in Ulaanbaatar city. From the review, it is evident that the main contributing factor to pollution is related to energy demands in the city of which coal is the main source of energy. However, contributions to pollution from the use of inefficient technologies such as the Ger in households, vehicular emissions, burning of biomass and dust from constructions cannot be ignored. The extent of pollution in the city is comparable to what has happened in other big cities in the world and even current experiences in some other cities today. In literature, famous examples of problematic air quality problems include the London Smog of 1952, Photochemical smog in Los Angeles in the 20th century. However, in the recent past, it has also become a common problem in both developed and the developing world as we have cases like Beijing, Shanghai, Athens, Mumbai, Cairo and Istanbul just to name a few. Poor air quality is a major barrier to a sustainable development in Mongolia as it comes with serious adverse human health and ecosystems' health effects. In Ulaanbaatar city and generally in literature excessive air pollution has been linked to various diseases especially cardiovascular, respiratory and pulmonary diseases. More so, excessive has been linked to mortality too. Important to note is also that poor air quality not only affect current generations but future generations are also hugely affected. Apart from human health problems, poor air quality also implicates negatively on urban environment ecosystems which affect livelihoods and even pose further human health problems.

It is also evident from the review that the only way to keep hopes of achieving a sustainable development is to mitigate/reduce/control air pollution being guided by the main sources of pollution. A number of measures are already in place to curb air pollution in Ulaanbaatar to include: policy and institutional measures, improved technologies adoption, enforcement actions, transport management, continuous research and education and awareness campaigns. However, urban air pollution is still a major problem in the city. There is a need to scale-up measures by investing more in pollution abatement technologies, financing activities and ensure commitment from various stakeholder i.e. public-private partnerships in pollution abatement. More so, there is a need for a continuous cycle of monitoring and evaluation of progress, taking corrective measures where necessary. Controlling pollution to acceptable levels will be the only option available for achieving a sustainable socioeconomic development in Ulaanbaatar city and Mongolia at large.

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