Cost Benefit Analysis of Air Pollution Abatement Options in the Ger Area, Ulaanbaatar, and Health Benefits Using Contingent Valuation

O. Enkhtsolmon, T. Matsumoto, and Erkhembayar Tseveen

***Abstract*—We conducted a cost-benefit analysis of air pollution abatement options that considered income level by region in a residential sector of a ger area in Ulaanbaatar, Mongolia. The study selected three feasible measures, taking into account direct benefits (fuel savings), health benefits and investment costs. The net present value of the abatement combined options and the reduction of total suspended particulate (TSP) emissions during the investment timeframe were estimated. We also conducted double-bounded dichotomous contingent (DBDC) valuation surveys with 373 respondents to gather data on air pollution awareness and willingness to pay (WTP) for protection of health from air pollution. To assess the unit costs of health benefits, we relied on the willingness-to-pay study carried out as part of the CVM study, which derived a value of WTP of US$20.30, which is the value placed on protection of health from air pollution.**

As for the results, the air pollution abatement combined option can be seen to reduce emissions approximately 50 percent in Ulaanbaatar over 7 years.

***Index Terms*—Air pollution, cost-benefit analysis, contingent valuation, Ulaanbaatar.**

I. Introduction

Ulaanbaatar faces an air pollution problem, particularly during the winter months, and the pollution has several negative effects on human health. Currently, 60 percent of Ulaanbaatar's population lives in the ger[1] areas, and the proportion is growing. Ger area heating systems burn continuously during the winter season and their contribution to the overall air pollution level then reaches 70 percent and more in the ger areas and up to 60 percent in the city center. The residents of these areas use coal-fired stoves for both heating and cooking. Because ger area residents have no access to the district heating system, they have to depend on their own heating systems. The average households consumed about 4 t of raw coal and 3.18 t of wood during the heating season. Particulate matter PM_{10} and $PM_{2.5}$ concentrations in Ulaanbaatar are 3 to 6 times greater than Mongolian air quality standards (AQS), and annual average concentrations are $75 \sim 150\mu g/m^3$ and $150 \sim 250\mu g/m^3$, which is 7 to 15 times higher than the WHO standard ratio, and these are among the highest measured values recorded in any world capital (Table I, Table II).

TABLE I: Annual Average PM Concentration of Ulaanbaatar 2008.06-2009.05 [1]

Location	PM10 (μg/m³)	PM2.5 (μg/m³)	Exceedance ratio to AQS	
			Mongolia	WHO
Central city areas	150-250	75-150	3-6	7-15
Ger areas	350-700	200-350	7-14	17-35

TABLE II: Mongolian Air Quality Standards and WHO Air Quality Standards [2]

Pollutant		Average time	Mongolia AQG value (μg/m³)	WHO AQG value (μg/m³)
Sulfur dioxide	SO_2	10 mins	500	500
		20 mins	450	
		24 hours	20	20
		1 year	10	
Ozone	O_3	8 hours	100	100
Particulate matter	PM_{10}	24 hours	100	50
		1 year	50	20
Particulate matter	$PM_{2.5}$	24 hours	50	25
		1 year	25	10

We conducted cost-benefit analysis (CBA) for the air pollution abatement combined options. This study targeted air pollutant abatement options for the major source of coal fired stoves in the ger area, Ulaanbaatar.

II. Methods

We conducted a cost-benefit analysis of air pollution abatement options in a residential sector of the ger area considering income level by region. The combined various abatement options included relocation of ger area households into apartments, using electric heaters instead of coal stoves, and installing central heating systems.

We also conducted a double-bounded dichotomous choice (DBDC) contingent valuation (CV) survey with 373 respondents in October 2014 and collected complete information on air pollution awareness and respondents willingness to pay for protection of health from Air pollution. The survey was designed to collect data from a representative sample of respondents which living in the ger area and the apartment area in the Ulaanbaatar.

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[1]Traditional *gers* are nomadic felt tents with wooden lattice substructures, used by Mongolian nomads for centuries. The *ger* was an ideal living solution for nomads for so long because it is mobile, light-weight, and portable, making it well suited for easy moving.

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In addition, CBAs were conducted by comparing the costs such as investment costs of the measures and benefits such as health benefits. In order to estimate the health benefits obtained from willingness-to-pay (WTP), a study was carried out as part of the CV, and the emissions reductions were estimated by using the reductions in fuel consumption [3].

III. Questionnaire Survey

A. Survey Design

Pretest and pilot tests were conducted to assess the effectiveness of the survey. A pretest was conducted in September 2014 at Mongolian Science and Technology University. 40 students were interviewed in a pilot test which focused on the content of the WTP questions. The questionnaire consisted of three parts. The first section contained air pollution awareness questions, including queries about the current air pollution situation in Ulaanbaatar, understanding of PM2.5 and the relationship between PM2.5 and health, respiratory diseases and expenditures on treatment of these diseases, and understanding of the N95 standard mask for protecting health against PM2.5. The second part consisted of the contingent valuation survey. The final section contained socio-economic questions, including those relating to the gender, age, housing type, occupation, family size, and household income.

A final survey was conducted in October 2014. Questionnaire sheets were distributed and later collected by elementary school students, and questions were responded to by adults. Four elementary schools were randomly selected which are located in the ger area or the city center of Ulaanbaatar.

Our explanation involves three elements: 1) explanations about particulate matter (PM2.5) and health damages caused by PM2.5, and current concentrations of PM2.5 in Ulaanbaatar, 2) respondents' willingness to pay (WTP) for protection of health from particulate matter(PM2.5), and 3) payment objective and method.

The respondents were asked the following double-bounded dichotomous choice (BDDC) questions:

Air pollution abatement projects will be reducing Ulaanbaatar air pollution by 50% from 2014 to 2020. During the 7 years you need to protect your family health from air pollution. If you use a N95 standard mask it can protect your health from particulate matter (PM2.5) by more than 60%. Are you willing to pay some amount of money during the winter months (November to March) to protect your family's health from air pollution? You would have to pay this amount for 7 years.

Would you pay US$16.40 a month?

(1) Yes (2) No

If you answered yes to the first question, would you pay US$ 54.80 a month?

(1) Yes (2) No

If you answered no to the first question, would you pay US$ 8.20 a month?

(1) Yes (2) No

TABLE III: Description of the Independent Variables, and the Mean and Standard Deviation (S.D.) of the Responses

Variables	Description	Mean	S.D.	Frequency	Percentage
Gender	Male=1, female=2	1.58	0.49	352.00	94.4%
Age	1 (under 20), 2 (20-29), 3 (30-39), 4 (40-49), 5 (50-59), 6 (over 60)	2.83	1.27	364.00	97.6%
Housing type	Apartments=1, detached house in ger area=2, ger=3, student dormitory=4, other=5	1.90	0.91	367.00	98.4%
Employment status	Student=1, private company employee=2, state official=3, entrepreneur=4, unemployed=5, retired=6. other=7	3.30	1.84	362.00	97.1%
Family size	Number of family members	4.23	1.25	366.00	98.1%
Workers	Number of workers in family: 1 (1 worker), 2 (2 workers), 3 (3 workers), 4 (4 workers), 5 (other)	1.93	0.83	361.00	96.8%
Income	Family monthly income (unit: US$): 1 (below 82), 2 (82-274), 3 (274-493), 4 (493-712), 5 (712-932), 6 (932-1151), 7 (over 1151),	3.57	2.82	356.00	95.4%
Air quality of Ulaanbaatar	Air quality index: 1 (0-50,very good), 2 (51-100,good), 3 (101-150, moderate), 4 (151-200, bad), 5 (201-300 very bad), 6 (301-500, hazardous)	5.34	0.86	371.00	99.5%
Awareness of $PM_{2.5}$	do not know=1, know a little=2, know=3	1.67	0.72	372.00	99.7%
Awareness of health effect of $PM_{2.5}$	do not know=1, know a little=2, know=3	1.67	0.72	372.00	99.7%
Awareness of health protection from $PM_{2.5}$	do not know=1, know a little=2, know=3	1.52	0.65	372.00	99.7%
Awareness of N95 standard mask	Know well=1, know=2, using=3, do not know well=4, do not know=5	4.03	1.06	365.00	97.9%
Expenditures	Expenditure on respiratory disease treatment per year (Unit: US$) ___?	118.68	148.74	159.00	42.6%
Willing to use N95 mask	do not use=1, do not know=2, certainly use=3, use=4	2.84	0.85	357.00	95.7%

B. Methods and Results

In our study, the survey presented was well received, with a response rate of 93.3% (373/400). 2.7% of respondents did not answer the WTP questions.

The background and validity checking questions used in this study are listed in Table III. Detailed descriptions of the variables are also given in Table III. These variables include the respondent's demographic characteristics, socio-economic status, and the air pollution status in their resident areas from a subjective perspective.

The average age of respondents was from 30 to 39 years old. The mean household monthly income of respondents participating in our survey was about US$493, compared to the average household monthly income of US$579 in 2013, Statistics Department of Ulaanbaatar [4]. The percentage of respondents by housing type was apartment 40.2%, detached house in ger area 32.7%, ger 22.3%, and other 4.8%. The percentage of respondents' valuation for air quality of Ulaanbaatar was hazardous 53.4%, very bad 31.1%, bad 11%, and moderate 3.5%.

C. Estimation of WTP

In Table IV, the results of the WTP responses to the valuation questions can be seen, where the value is presented in US$ per month.

The dichotomous choice contingent valuation surveys can be improved by asking each respondent a second dichotomous choice question which depends on the response to the first question — if the first response is "yes," the second bid is some amount greater than the first bid; while if the first response is "no," the second bid is some amount smaller [5].

The data was used to survey Ulaanbaatar residents regarding their willingness to pay to protect their family's health from air pollution using N95 masks until air quality has improved.

TABLE IV: RESULTS OF THE WTP RESPONSES

	Bound on WTP (US$)			Responses to DBDC questions			
	T1	TU	TL	Yes-Yes (YY)	Yes-No (YN)	No-Yes (NY)	No-No (NN)
Group1	16.4	54.8	8.2	9	30	17	24
Group2	11.0	27.4	5.5	13	20	9	19
Group3	13.7	21.9	4.4	19	18	28	17
Group4	19.7	32.9	9.9	29	43	31	37

T1 represents the amounts presented the first time, TU the higher amounts presented the second time, and TL the lower amounts presented the second time. Estimation of WTP was calculated by the CVM double-bound of log-linear logit model using CVM.xsl version4 [6].

These results showed that 97% of respondents were able to express a positive WTP, and that average WTP was US$20.30 per household, per month. It would be payed during the highly polluted 5 months of the year. Estimated average value of WTP is shown in Table V.

TABLE V: RESULTS FOR WTP

Estimation result			Estimated WTP US$	
Variable	Coefficient	t value	Median value	14.35
constant	4.12	15.78		
ln(Bid)	-1.55	-16.14	Average value	20.30
n	363.00			
Log likelihood	-507.05			

IV. COST BENEFIT ANALYSIS

A. Introduction

We conducted a cost-benefit analysis of air pollution abatement options in the ger area of Ulaanbaatar (UB) considering income level by region. Abatement options included 1) ger area household's relocation into an apartment, 2) using electric heating, and 3) installing a central heating system.

Detailed descriptions of abatement options from 2014 to 2020 are shown in Table VI.

The city consists of two main areas: the city center, with high-rise office and apartment buildings, and the surrounding ger areas, with mainly low-rise one story detached houses and gers [7]. In this survey, the ger area was divided into three parts by region and income level: city center ger area close to the city, residential middle-income households, mid-tier ger area residential low-income households, and fringe ger area residential lowest income households [8].

TABLE VI: DESCRIPTION OF ABATEMENT OPTIONS BY YEAR

	Option 1: Number of households relocating into apartments	**Option 2**: Number of households using electric heaters	**Option 3**: Number of households installing central heating systems
2014	4,924	16,000	2,500
2015	10,650	17,000	2,500
2016	12,307	16,000	2,500
2017	13,774	16,000	2,500
2018	8,382	20,000	2,500
2019	3,200	19,000	2,500
2020	5,847	20,769	2,500
	59,084	124,769	17,500

Currently 184,229 households (60% of Ulaanbaatar's population) live in the ger areas, 54.5% in small detached houses, and 44.3% in gers.

Option (1) applies to 59,084 households which are in the city center and ger area relocation into apartments, and can be considered a ger area housing plan project.

Option (2) applies to 124,769 households living in mid-tier and fringe gers beginning to use electric heaters instead of coal stoves. If electric heaters were supplied in the ger area, it would increase electricity demand. Therefore, we analyzed the costs for combined measures, including electric heaters and wind power generation in the first Mongolian implementation project.

Option (3) applies to 17,500 households living in small detached houses in the mid-tier ger area and would involve installation of central heating systems.

B. Estimation of Pollutant Emissions Reductions

Annual average fuel consumption of ger area households was 3.49 t of coal and 3.27 t of wood when using ger stoves, and 4.49 t of coal and 2.99 t of wood when using wall stoves. These estimates are based on the number of households reducing fuel consumption through abatement options. Emission reductions were calculated using the following calculations. Ger area households fuel consumption and emission factors are shown in Table VII. Estimated TSP, PM_{10}, SO_X, and NO_X emissions reductions from abatement measures compared to BAU are shown in Fig. 1. Emission reductions were calculated using the following formula:

$$\text{Emission reductions} = \text{Coal reduction } (t) \times \text{coal emission factor (kg/t)} / 1{,}000 + \text{wood reduction } (t) \times \text{wood emission (kg/t)} / 1{,}000$$

TABLE VII: HOUSEHOLD FUEL CONSUMPTION AND EMISSION FACTORS [9]

	Fuel usage (t/year)		Emission factor (kg/t)				
	Ger stove	Wall stove	TSP	PM_{10}	SO_X	NO_X	CO
Coal	3.49	4.49	5.4	3.3	7.5	2.4	173.34
Wood	3.27	2.99	3.82	3.82	0.008	1.2	69.2

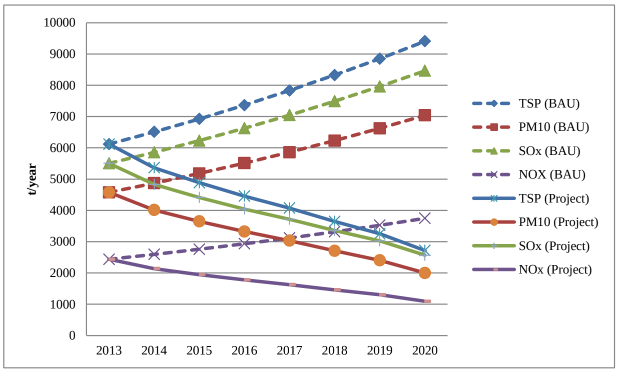

Fig. 1. Emission reductions by abatement options compared to BAU.

C. Estimation of Health Benefits

To assess the unit costs of health benefit, we relied on the willingness-to-pay study carried out as part of the CVM study, which derived a value of WTP of US$20.30, which is the value placed on protection of health from air pollution.

Respondents were willing to pay this amount for protecting their family's health from air pollution over 7 years, when Ulaanbaatar air pollution will have been reduced 50%.

Cost benefits were calculated using the following formula:

$$\text{Cost benefit} = \text{Number of households in year } t \times \text{WTP value} \times 5 \text{ month (highly polluted seasons)}$$

D. Estimation of Costs and Benefits

Net present value (NPV) of the cost is the initial investment in the pollution abatement options, and the benefit is the cost savings achieved through health protection WTP value [10], [11].

A 7-year timeframe was assumed with 13% discount rate [12] for all calculations.

NPV is expressed by Equation (1).

$$NPV = \sum_{t=1}^{n} \frac{Bt - Ct}{(1+r)^t} \tag{1}$$

Bt is the benefit in year *t*, *Ct* is cost in year *t*, and *r* is the discount rate.

E. Results of Cost-Benefit Analysis

The net present value (NPV) of air pollution abatement combined options and each of the abatement options, the investment cost and the 7-year average emission reductions are shown in Table VIII.

NPV of the combined options was estimated at US$-1499.73 million.

TABLE VIII: RESULTS OF COST BENEFIT ANALYSIS

2014-2020		Option 1: relocation into apartment	Option 2: use of electric heaters	Option 3: installing central heating system	Combined options
Emission reduction (%)	average	13%	22%	5%	41%
	max	23%	42%	7%	72%
Total emission reduction (t)	TSP	8620	14941	3259	26820
	PM_{10}	6341	11446	2398	20185
	SO_X	8144	12492	3079	23716
	NO_X	3471	5864	1313	10648
$ per t reduction	TSP	243994	33320	7479	97890
Investment costs US$ millions		2103	498	24	2625
Number of households		59084	124769	17500	201353
$ per households		35597	3990	1393	
Health benefits US$ millions					301.58
NPV US$ millions					-1499.73

We estimated that TSP and PM10 emissions would be reduced by 26,820t and 20,185t respectively and per *t* reduction of TSP would be US$97,890. As a result, the combined option average emission reduction was 41% and reached a maximum of 72% in the ger area over the 7 years.

Estimated emission reduction for each of the abatement options is shown in Fig. 2.

Option (1), average emission reduction by ger area households relocating into apartments, was 13%, and the maximum reached 23% in the ger area. The per t reduction of TSP was US$243,994, highest of the three cases, but the living environment in general can expect a wide range of benefits.

Option (2), average emission reduction by electric heating, was 22%, reaching maximum of 42% in the ger area. The per t of reduction of TSP was US$33,320.

Option (3), average emission reduction by installing central heating systems, was 5%, reaching a maximum of 7% in the ger area. The per t reduction of TSP was US$7,479.

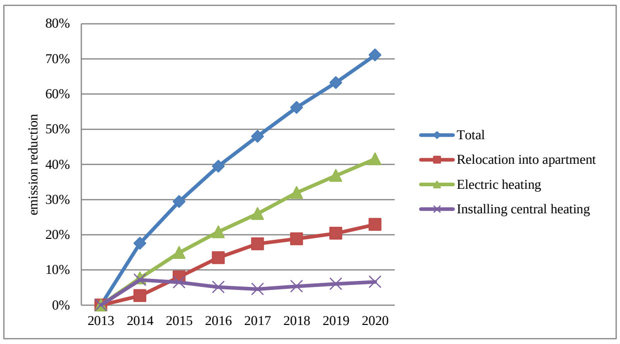

Fig. 2. Emission reductions by abatement options.

V. Conclusion

In this study, within a relatively short period of time we performed cost-benefit analyses for three feasible measures concerning air pollution in the ger area of Ulaanbaatar.

As for the results, the air pollution abatement combined option can be seen to reduce emissions approximately 50 percent in the Ulaanbaatar over 7 years. Reducing pollution concentrations would prevent illnesses, save lives and avoid enormous health costs.

The monetized health benefit through (DBCD) contingent valuation survey was estimated at 301.58 million US$ over the 7 years. The CVM results show all respondents expressing good attitudes about their willingness to pay to protect their family's health from air pollution, but they responded negatively that they lacked awareness about health impacts from polluted air and about health protection methods.

The abatement measures to improve air quality were prioritized according to cost benefit analysis and feasibility.

Relocation of ger households into apartments is a long term option. New apartment buildings are established in newly developed areas, and in existing ger areas, but progress is very slow and large scale investment is needed. If there is a possibility of mortgage interest rates becoming cheaper, the housing transfer would increase, this could become an effective measure and the living environment in general could expect a wide range of benefits.

With the use of electric heaters instead of coal stoves in the ger area, emission reduction could be large, assuming that people will actually refrain from using coal once they have obtained an electric heater. Cost of electric heating is significantly higher than the cost of heating with coal, so subsidies would be needed. It would also be necessary to provide large-scale investment to expand power generation capacity.

Ger area households installing central heating systems is a mid-term option, and could reduce emissions at low cost. There would be an increased contribution of emissions from the local heating system, but this is estimated to be small compared to the consumption of coal used for heating in ger stoves. The costs of construction, as well as the incremental capacity needed for local heating, would need to be incorporated in the cost analysis, and these costs would be very high.

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