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Cost–benefit Analysis of $PM_{2.5}$ Policy in Korea

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Abstract

$PM_{2.5}$ is one of the most harmful factors of air pollution in Korea, and its damage has been worsening year by year. The Korean government invested trillions of Korean won (KRW) to reduce the concentration of $PM_{2.5}$; however, the in-depth economic analysis is required to tackle this issue. This study aimed to estimate the health impacts and economic benefits of $PM_{2.5}$ reduction and examine the economic feasibility of the Korean government's investment in $PM_{2.5}$ reduction by conducting cost–benefit analysis (CBA). To determine the economic value and analyze cost–benefit relationship of the $PM_{2.5}$ policy, the study used the benefits mapping and analysis program (BenMAP) and net present value (NPV). The BenMAP was used to estimate the health impacts of $PM_{2.5}$ reduction and calculate economic benefits by transferring the estimated health impacts. The NPV was adopted to appraise the effectiveness of the Korean government's $PM_{2.5}$ policies. The results indicate that economic benefits ranged from USD 22 million to USD 79 million, and the NPV from USD 3.7 million to USD 20.3 million, depending on the level of reduction in $PM_{2.5}$ concentration. This study shows the effectiveness of Korea's air quality policy and the necessity of conducting economic evaluation of environmental policies.

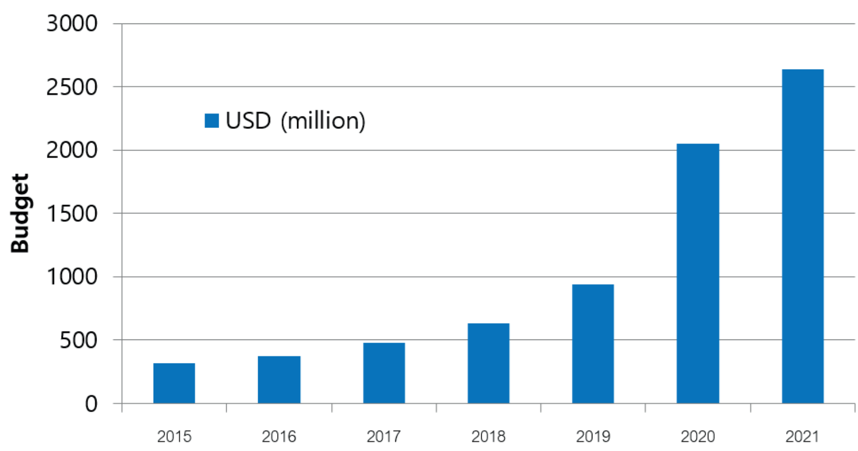
Keywords: Particulate matter; Air quality policy; Cost–benefit analysis; Benefit mapping and analysis program

1. Introduction

Recent findings showed that particulate matter (PM) is one of the main factors that increase the premature mortality rate (Lelieveld *et al.,* 2015; Anenberg *et al.,* 2019). Institute for Health Metrics and Evaluation (IHME) ranked the Global Burden of Disease (GBD) and demonstrated that PM is the next highest cause of death after high blood pressure, smoking, high blood sugar, and cholesterol (Cohen *et al.,* 2017). Particularly, fine particles that are 2.5 micrometers or less in diameter are often chemically combined with pollutants, like NOx, SOx, VOCs, and NH_3 (Ailshire and Clarke, 2015; Ministry of Environment of Korea [MOE], 2016). Because of these facts, $PM_{2.5}$ has a greater risk factor than PM_{10} (Li *et al.,* 2019).

Unfortunately, Korea is one of the most affected countries by $PM_{2.5}$. IHME reported that more than 17,000 people died from air pollution in Korea, and more than 90 % of them died from $PM_{2.5}$ (IHME, 2018). According to the MOE of Korea (2020), the annual mean concentration of $PM_{2.5}$ in Korea has not dramatically decreased. On the contrary, the number of days of high-concentration $PM_{2.5}$ has increased from 5 days in 2015 to 26 days in 2019. In addition, the highest concentration record of $PM_{2.5}$ has been increasing every year from 70 $\mu g/m^3$ in 2015 and 2016 to 135 $\mu g/m^3$ in 2019. Therefore, the Korean government has initiated measures and policies to reduce air pollutants, such as "The 2nd Basic Plan for Seoul Metropolitan Area Air Quality 2014 (BP2014)" in January 2014, "Special Measure for $PM_{2.5}$ 2016 (SM2016)" in January 2016, "Comprehensive Measure for $PM_{2.5}$ (CM2017)" in July 2017, "Special Act on the Reduction and Management of $PM_{2.5}$" in February 2019, and "Master Plan for $PM_{2.5}$ (MP2019)" in November 2019. To implement these actions, the budget of air quality policy has sharply increased from KRW 349.0 billion in 2015 to KRW 2.9 trillion in 2021 (MOE budget manual 2015–2021) as in Figure 1. According to MP2019, the Korean government also plans to invest KRW 20 trillion from 2020 to 2024 to reduce the $PM_{2.5}$ annual mean concentration by 16 µg/m³. Such a large-budget public policy needs to be assessed in terms of socioeconomic benefits (Hwang *et al.,* 2018). However, little is known about the effectiveness of environmental quality policies in Korea and whether they can provide the expected socioeconomic benefits (Park *et al.,* 2007; Kim, 2019).

Moreover, the budget-making process in the environmental sector tends to be political and based on normative thinking rather than calculated economic decision-making based on costs versus benefits tradeoff (Kim *et al.,* 2003). The MOE budget manual states that the goal of air quality policy is to reduce the concentration of $PM_{2.5}$ to the level recommended by the WHO, but it does not provide specific figures on costs or economic benefits of the policy (Kim, 2019). WHO and OECD (2015) estimated the economic costs of health effects from outdoor and indoor air pollution in 53 EU member states of the WHO, and they identified that $PM_{2.5}$ is the biggest factor in mortality and prevalence rate. The effects of environmental policies by monetary values are also valuable to gage the success of the policies (Kim *et al.,* 2003). Therefore, this study aimed to calculate the economic benefits of air quality policies through cost–benefit analysis (CBA) and reveal the economic feasibility of the current air quality policies.



	2015	2016	2017	2018	2019	2020	2021
KRW (billion)	349.0	411.5	527.6	702.0	1,043.9	2,273.3	2,922.7
USD (million)[a]	314.7	371.1	475.8	633.1	941.4	2,050.0	2,635.7

a. KRW converted to USD by the 2011 base exchange rate; USD 1 = KRW 1,108.9

Source: MOE.

Figure 1. Air quality policy budget in Korea (2015–2021).

2. Materials and Methods

2.1 Research design

This study adopted a quantitative research method to determine the economic value and analyze the cost–benefit relationship of the $PM_{2.5}$ policy. The quantitative research method was embodied through the environmental benefits mapping and analysis program (BenMAP) and the net present value (NPV). The BenMAP is a computer program developed by the US EPA to predict the health impacts (avoided deaths) and the economic value associated with air pollutant concentration (US EPA, 2018). Economic benefits were based on Korea's Value of Statistical Life (VSL) estimates and the benefit transfer method. CBA was conducted using the present value of benefits and costs by applying the NPV method. Three scenarios were examined: before BP2014, BP2014 (from 2015 to 2019), and MP2019.

2.2 Economic benefit estimation by scenario

2.2.1 Scenarios of the study

Four scenarios were assumed for each target concentration as in Figure 3. Scenario 1 represented the concentration of $PM_{2.5}$ was reduced to 20 μg/m³, which was the level set as the target concentration of MP2014. Scenario 2 represented the concentration reduced to 16 μg/m³, which was the target concentration set by the MP2019. Scenario 3 represented concentration reduced to 15 μg/m³, which is the concentration suggested by the MOE of Korea as an environmental standard for $PM_{2.5}$. Scenario 4 represented the concentration level suggested by WHO, 10 μg/m³.

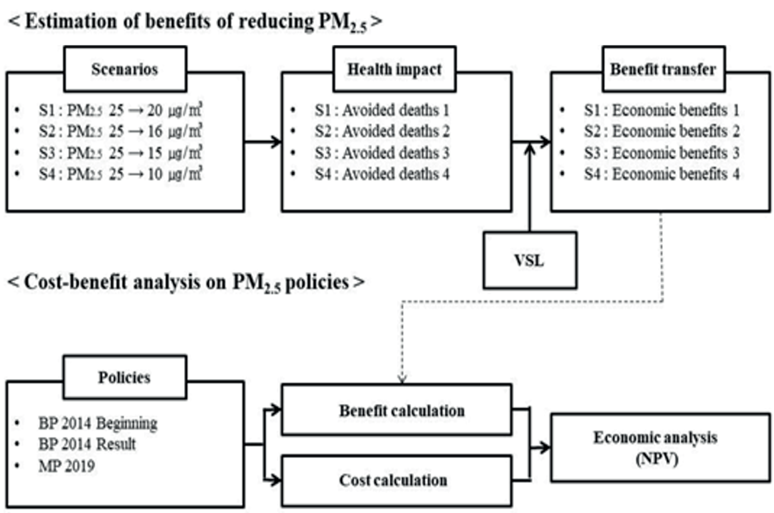


Figure 2. Research frame.

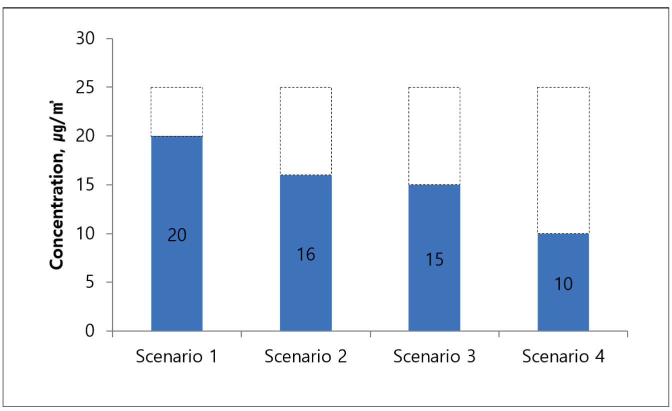


Figure 3. Target concentrations for each scenario.

2.2.2 BenMAP

Air pollution data, the number of target populations, the base mortality rate, and the function can be inputted into the BenMAP (Monitor rollback), or data stored by country on the GBD rollback application can be used in the BenMAP without additional input data (US EPA, 2018). Using the GBD rollback, researchers can estimate the benefits of improved air quality. Therefore, this application can estimate avoided deaths and economic benefits due to $PM_{2.5}$ reduction, even in countries with insufficient long term observation and analyses of pollutants such as Korea, where the $PM_{2.5}$ concentration has not changed significantly (between 23 μg/m³ and 26 μg/m³) in the last 10 years. Therefore, this research was conducted with the data provided by the WHO GBD rollback application in BenMAP to achieve the research objectives.

2.2.3 Functions of the study

The BenMAP GBD rollback application estimates the health impact of changes in air pollution concentration using the integrated exposure response function with data such as population data, air quality measurement data, and the mortality incidence of the study area.

Integrated Exposure Response function

$$= 1 + \pi(1 - \exp\{-\varphi z \delta\}) \quad (1)$$

Where z is max (0, $PM_{2.5} - cf$) with $cf \sim U(2.4, 5.9)$ denoting a uniform uncertainty distribution for the counterfactual, assuming no association < 2.4 μg/m³ and $1 + \pi$ is the maximum hazard ratio, with the rate of increase for low pollutant concentration governed by φ and for higher pollutant concentration by δ.

2.3 CBA of $PM_{2.5}$ policies

Apart from the economic benefit estimates based on the four scenarios, a CBA for $PM_{2.5}$ policies in Korea was conducted. Although CBA is a technique widely used in the private sector, it is valuable as an analysis tool for policy-making in the public sector (Jordan and Turnpenny, 2015; Thomas and Chindarkar, 2019). Since this enables systematic and objective comparison between policy options, it facilitates rational policy decisions by policymakers (OECD, 2012; Jordan and Turnpenny, 2015; Thomas and Chindarkar, 2019). First, the costs and benefits required to implement each alternative or project are calculated (Hwang, 2016; Buncle *et al.,* 2016). At this time, both costs and benefits are expressed monetarily, and the future value is converted into the present value (Brooks, 2016). In this study, among many types of CBA methods, NPV was adopted because it enables determining the scale of profitability. Since the cost adopts a fixed government budget, only the benefits are discounted. If the NPV is greater than zero, the investment project is accepted. If the NPV is less than zero, the investment project is rejected. Besides, by comparing the size of NPV, it is also used to select a more favorable investment. The NPV decision model is given below:

$$NPV = -CO + \sum_{t=1}^{n} \frac{CI_t}{(1+r)^t} \quad (2)$$

Where *CO* is the cash outflow, *t* is the time, *CI* is the cash inflow, and *r* is the discount rate.

2.3.1 Measurement of benefits.

For NPV, benefits mean cash inflows. Since the benefit estimated through the BenMAP is the total benefit of achieving the target concentration, the annual benefit is calculated by dividing the total benefit by the number of years over the policy period, assuming a discount rate of 3%, and calculating the NPV of benefits.

2.3.2 Measurement of costs

Costs can be estimated through the air environment policy budget of the MOE. Although all investments for air quality policies may not represent costs for $PM_{2.5}$ improvement, the current government has made $PM_{2.5}$ improvement a priority in air quality policy, and most air environment policies have focused on $PM_{2.5}$ reduction. Therefore, the air environment policy budget of the MOE was estimated as explicit costs for implementing the $PM_{2.5}$ policy.

3.Results and Discussion

3.1 Results

3.1.1 Estimating the benefits of $PM_{2.5}$ reduction

3.1.1.1 Avoided deaths

When the annual mean concentration of 25 µg/m³ in 2019 was reduced to the target value of BP2014, 20 µg/m³. Approximately 6,600 people could be freed from the risk of death. When the concentration reduced to the target value of MP2019, 16 µg/m³, approximately 13,000 people could be freed from the risk of death. If the MOE standard, 15 µg/m³, was achieved, approximately 15,000 people would be saved. And if the WHO guideline value (10 µg/m³) was achieved, approximately 24,000 people would be saved.

3.1.1.2 The statistical value of life (VSL)

Based on a base VSL of USD 3.83 million (2011 USD, PPP) derived from the OECD's WTP study, the estimated VSL of Korea was USD 3,290.306. The VSL estimation through the BenMAP is characterized by the size of a country's GDP. Therefore, Korea's VSL estimate was slightly smaller than the base VSL and higher than those of Asian countries, such as China (USD 747,033), India (USD 303,618), and Malaysia (USD 1,963,988).

3.1.1.3 Economic benefits

Based on the OECD VSL of Korea, economic benefits are derived by transferring the estimated avoided deaths. When the annual mean concentration (25 µg/m³) in 2019 was reduced to 20 µg/m³, the target value of BP2014, economic benefits of about USD 22 billion was obtained. When the annual mean was reduced to 16 µg/m³, the target value of MP2019, economic benefits of approximately USD 42 billion was estimated. Achieving the MOE standard of 15 µg/m³ resulted in an economic benefit of about USD 48 billion, and achieving the WHO value of 10 µg/m³, about USD 79 billion.

3.1.2 CBA of $PM_{2.5}$ policy

3.1.2.1 BP2014

This study estimated the NPV for both before the implementation of BP2014 and the five years of BP2014, respectively. BP2014 involved a total investment of USD 4,100.6 million from 2015 to 2024, and the benefit of reducing the $PM_{2.5}$ concentration from 25 µg/m³ to 20 µg/m³ was estimated as USD 22,000 million. In this case, the NPV was found as USD 14,656 million (USD 2011).

$$NPV = -4{,}110.6 + \sum_{n=1}^{10} \frac{22{,}000/10}{(1+0.03)^n}$$

BP2014 involved a total investment of 2,736.1 million from 2015 to 2019, and the $PM_{2.5}$ concentration decreased from 25 µg/m³ in 2015 to 23 µg/m³ in 2019. The benefit was estimated at USD 7,000 million.

Table 1. Air quality policy budget in Korea (2015–2021)

	2015	2016	2017	2018	2019	2020	2021
KRW (billion)	349.0	411.5	527.6	702.0	1,043.9	2,273.3	2,922.7
USD (million) [a]	314.7	371.1	475.8	633.1	941.4	2,050.0	2,635.7

a. KRW converted to USD by the 2011 base exchange rate; USD 1 = KRW 1,108.9

Source: MOE.

Table2. Base VSL by country (Unit: 2011 USD, PPP)

Country	OECD VSL (2011 USD, PPP)	GDP per capita, PPP ($)
India	303,618	6,996.6
China	747,033	16,829,9
Malaysia	1,963,988	29,619.7
Korea	3,290,306	43,143,0
Japan	3,628,787	43,235.7
UK	3,776,566	48,698.1
France	3,824,803	49,435.2
Germany	4,148,124	56,278.2
Australia	4,205,013	53,469.1
US	4,844,692	65,297.5

Source: The World Bank.

Table 3. Avoided deaths and economic benefits for each scenario

Policy	Target concentration (μg/m³)	Avoided deaths (thousand)	Economic benefits (USD billion)
Scenario 1 (BP2014)	20	6.6	22
Scenario 2 (MP2019)	16	13	42
Scenario 3 (MOE standard)	15	15	48
Scenario 4 (WHO guideline)	10	24	79

Table 4. Cost prior to BP2014

	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Total
KRW (billion)	540.5	559.8	578.4	598.6	592.2	355.4	331.7	332.5	334.5	334.6	4,558.2
USD[a] (million)	487.4	504.8	521.6	539.8	534.0	320.5	299.1	299.8	301.7	301.7	4,110.6

a. KRW converted to USD by the 2011 base exchange rate; USD 1 = KRW 1,108.9.

Source: BP2014.

Table 5. Cost of BP2014

	2015	2016	2017	2018	2019	Total
KRW (billion)	349.0	411.5	527.6	702.0	1,043.9	3,034.0
USD (million)[a]	314.7	371.1	475.8	633.1	941.4	2,736.1

a. KRW converted to USD by the 2011 base on exchange rate; USD 1 = KRW 1,108.9.

Source: MOE.

In this case, the NPV was USD 3,675 million (2011). The NPV of BP2014 is 1/4 times lower than that before the implementation of BP2014.

$$NPV = -2{,}736.1 + \sum_{n=1}^{5} \frac{7{,}000/5}{(1+0.03)^n}$$

3.1.2.2 MP2019

The Korean government announced MP2019 in 2019 to achieve a $PM_{2.5}$ concentration of 16 μg/m³ by 2024 through various $PM_{2.5}$ reduction policies for 5 years from 2020 to 2024. MP2019 involved a total investment of USD 18,213 million from 2020 to 2024, and the benefit of reducing the $PM_{2.5}$ concentration from 25 µg/m³ to 16 µg/m³ was estimated as USD 42 billion. In this case, the NPV was 20,257 million (USD 2011), which is about USD 5,601 million greater than that before BP2014 (USD 14,656 million).

$$NPV = -18{,}212.6 + \sum_{n=1}^{5} \frac{1{,}400}{(1+0.03)^n}$$

Compared to the scenario prior to BP2014, more costs were invested in MP2019, but the value of the estimated benefits increased as the target value was lower than 20 µg/m³ (16 µg/m³).

3.2 Discussion

3.2.1 Economic benefits

The economic benefits derived by transferring the estimated avoided deaths through the BenMAP showed a positive linear relationship with the decrease in $PM_{2.5}$ concentration. In other words, for every 1 µg/m³ reduction in $PM_{2.5}$ concentration, a gain of about USD 5 billion (2011 USD) could be achieved. It implies that efforts to reduce economic loss through $PM_{2.5}$ reduction are urgent to build a sustainable economy in Korea. However, the results of estimated economic benefits were different from those of other estimates. In this study, when the annual mean concentration of 25 µg/m³ was reduced to 20 µg/m³ (Scenario 1), an economic benefit of about USD 22 billion (USD 2011) was estimated. However, according to BP2014 announcement of the government, when the annual mean concentration of 25 µg/m³ was reduced to 20 µg/m³, about USD 5.3 billion (USD 2011) was obtained. The difference between the two figures may be because the Korean VSL was about three times higher than the previous estimates.

3.2.2 CBA

In this study, CBA was conducted on BP2014 and MP2019 the Korean government implemented to reduce $PM_{2.5}$ using the NPV method, which applies the concept of the time value of money. BP2014 initially aimed to reduce the $PM_{2.5}$ concentration from 25 µg/m³ to 20 µg/m³ by investing a total of USD 4,110.6 million from 2015 to 2024 (prior to BP2014). In this case, the economic benefit was estimated as USD 22,000 million, and the NPV was calculated as USD 14,656 million (USD 2011). BP2014 involved a total investment of USD 2,736.1 million from 2015 to 2019, and the $PM_{2.5}$ concentration decreased from 25 µg/m³ in 2015 to 23 µg/m³ in 2019. In this case, the economic benefit was estimated as USD 7,000 million, and the NPV was calculated as USD 3,675 million (USD 2011). From the CBA of BP2014, two implications can be drawn. First, the NPV of BP2014 was greater than 0, indicating that the investment over the past five years was effective.

Table 6. Cost of MP2019

	2020	2021	2022	2023	2024	Total
KRW (billion)	2,273.30	2,922.70	5,000.00[b]	5,000.00[b]	5,000.00[b]	20,196.0
USD (million)[a]	2,050.05	2,635.67	4,508.97	4,508.97	4,508.97	18,212.6

a. KRW converted to USD by the 2011 base exchange rate; USD 1 = KRW 1,108.9

b. Estimated amount

Source: MOE.

Table 7. NPV of Korean government's $PM_{2.5}$ reduction policies

	Period	Concentration (µg/m³)	NPV (USD billion)
Prior to BP2014	2015–2024	25 → 20	14.7
BP2014	2015–2019	25 → 23	3.7
MP2019	2020–2024	25 → 16	20.3

Table 8. Summary of results and discussion

Estimate from scenarios				Calculation from policies			
Scenario	**Target ($\mu g/m^3$)**	**Avoided deathes (thousand)**	**Economic benefits (USD billion)**	**Policy**	**Period**	**Concentration ($\mu g/m^3$)**	**NPV (USD billion)**
1[a]	20	6.6	22	Prior to BP2014	2015–2024	25 → 20	14.7
				BP2014	2015–2019	25 → 23	3.7
2[b]	16	13	42	MP2019	2020–2024	25 → 16	20.3

[a] Scenario 1 (BP2014), [b] Scenario 2 (MP2019).

However, a significant decrease in the NPV of BP2014 compared to that prior to BP2014 indicates that achieving the goals of air quality policy may not be as easy as planned. MP2019 aims to reduce the $PM_{2.5}$ concentration from 25 μg/m³ to 16 μg/m³ by investing USD 18,218 million from 2019 to 2024. In that case, the expected economic benefit is estimated as USD 42,000 million, and the NPV was calculated as USD 20,257 million (USD 2011). This is about USD 5,601 million greater than that before the implementation of BP2014 (USD 14,656 million). If MP2019 is faithfully implemented, economic benefits will be greater than those obtained through BP2014. However, as BP2014 results show the difficulty of achieving the goals of air quality policy, performing thorough on-site inspections and developing more effective and detailed policies are encouraged.

4. Conclusion

The monetary effects of environmental policies are also important to gage the success of the policies. Therefore, this study aimed to calculate the economic benefits of the Korean government's air quality policies through CBA. To do this, the study adopted the quantitative research methods involved the BenMAP and NPV. The results indicate that economic benefits ranged from USD 22 million to USD 79 million, and the NPV from USD 3.7 million to USD 20.3 million, depending on the level of reduction in $PM_{2.5}$ concentration. It means that benefits are greater compared with costs, and the need for $PM_{2.5}$ policy implementation was demonstrated not only in the normative perspective of environmental protection but also in terms of economic effectiveness. In this study, CBA results for $PM_{2.5}$ policies provide economic feasibility for policymakers to make investment decisions or implement regulatory enforcement for air quality improvement.

Although the results indicate net economic benefits owing to air quality policies in Korea, performing thorough on-site inspections and developing more effective and detailed policies are recommended to increase the return on investment.

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