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Health impact assessment of $PM_{2.5}$-related mitigation scenarios using local risk coefficient estimates in 9 Japanese cities

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ABSTRACT

Previous studies have highlighted the negative effects of $PM_{2.5}$ on mortality, expressed in terms of attributable deaths and life years lost. However, there are very few studies assessing the health impacts of air pollution in terms of economic burden/benefits. This study assessed the health impact of two hypothetical interventions among sex- and age-specific risk populations using a robust risk estimation and economic valuation process. We utilized the sex- and age-stratified daily all-cause mortality together with the daily $PM_{2.5}$ of the 9 Japanese cities from 2002 to 2008 in estimating the relative risks. The estimated risks were then utilized for the economic valuation of co-benefits/burden with respect to the two hypothetical $PM_{2.5}$-related mitigation scenarios, in comparison to status quo, namely: i) decrease to Japanese standards, and ii) decrease to WHO standards. Impact of these interventions on health were assessed using the following HIA metrics: attributable mortality, attributable years life lost, and environmental health impact. A 10-μg/m^3 increase in $PM_{2.5}$ would increase the risk by 0.52% (95% CI: −0.91% to 1.99%) for all-cause mortality, with varying risk estimates per subgroup. High economic burdens were estimated at status quo, with particularly distinct burden difference for age-specific mortality; 0.40 trillion yen (0–64 y.o.) and 1.50 trillion yen (> 64 y.o.). If stricter standards, relative to status quo, were to be enforced, i.e. WHO standard, there is a potential to yield economic benefits in the same risk population; 0.26 trillion yen (0–64 y.o.) and 0.98 trillion yen (> 64 y.o.). We did not observe any substantial difference with the burden and benefit related to sex-specific mortality. Using the estimated local risk coefficients complemented with the valuation of the risks, policymaking entities will have the opportunity to operate their own HIA to assess the relevant air pollution-related health impacts.

1. Introduction

Previous studies have indicated the negative effects of particulate matter with an aerodynamic diameter below 2.5 microgram per cubic meter ($PM_{2.5}$) on human health (Anenberg et al., 2010; Anenberg et al., 2012; Cohen et al., 2017). Its related health impacts, in terms of attributable number of deaths as well as years life lost, have been thoroughly documented and were utilized as indicators for the burden of the disease studies (Cohen et al., 2017; Cohen et al., 2005; Forouzanfar et al., 2015). The past decade has focused on the development in the exposure-response modeling in investigating the effects of $PM_{2.5}$ on all-cause mortality (Krewski et al., 2009; Pope III et al., 2011a, b). Coupled with these advancements are the uncertainties and limitations affecting the risk estimation process, which include but are not limited to population demographics, existing control measures, causal relationship between health impacts and $PM_{2.5}$ exposure, and shape of the exposure-response function, among others (EPA, 2009; NRC, 2002). Amidst these challenges, these country and multi-city studies paved way for the development of better risk determination techniques and policy-relevant results (Faustini et al., 2011; Katsouyanni et al., 2009; Zanobetti et al., 2014), which were instrumental in bringing forth the focus towards the quantification of the air pollution-related mortality into the regional/global policy arena (Forouzanfar et al., 2015; WHO, 2016; WHO Regional Office for Europe, 2013, 2016).

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Advancements in the risk estimation was further complemented with the estimation of the relevant output, outcome and impact measures in the form of a health impact assessment (HIA). HIA serves as a key decision-making tool for development planning, with its roots traced back from the traditional environmental impact assessment (Harris-Roxas et al., 2012; Lock, 2000). It combines various procedures and methods in evaluating the impact of specific interventions and its potential health effects on population health (Bos, 2006). HIA studies, particularly for air pollution, have denoted health impacts in terms of attributable number (AN) of mortality, its related years life lost (YLL), and a popularly utilized metric of disability adjusted life years (DALY) (Martenies et al., 2015; Narain and Sall, 2016). Some have valued health impact in terms of the value of statistical life (VSL) and value of statistical life years (VSLY) (Cropper and Khanna, 2014; Hammitt, 2007). While there are those in similar fields of exposure science, which calculated the metric of environmental impact (EI) by valuing the damage through the combination of DALY and VSLY (Xiao et al., 2016); in this study we refer to EI as environmental health (EH) impact a product of YLL and VSLY. Several HIA studies were done globally and nationally, which attempt to determine the health impact of air pollution on health (Anenberg et al., 2010; Anenberg et al., 2012; Fann et al., 2012; Forouzanfar et al., 2015; WHO Regional Office for Europe, 2016). However, only a few were able to determine the monetary health burden/benefits relative to the decrease in $PM_{2.5}$ concentration.

In this study, we utilized the Japanese context to illustrate the assessment of the health impacts of hypothetical interventions. In the 1950s, Japan's main source of pollution was due to the rapid industrialization of the thriving economy. Policy-driven efforts to address the adverse air pollution conditions has been institutionalized through the passage of the Basic Law for Environmental Pollution Control in 1967 and the 1968 Air Pollution Control Law (Hashimoto, 1989; Wakamatsu et al., 2013). The enforcement of these policies resulted to the gradual and steady decrease of the annual suspended particulate matter (SPM) and $PM_{2.5}$ concentrations in the country (Wakamatsu et al., 2013). Progressive policies were enacted through the years to complement both local and international agreements with regard to air pollution control. Despite these efforts, economic valuation of the $PM_{2.5}$-related health effects have not been fully elucidated.

This study assessed the health impact of two hypothetical interventions in Japan using a localized risk estimation and valuation process. Further analyses were carried out to determine the potential effect modification by sex and age.

2. Methods

2.1. Risk estimation

Daily background ambient $PM_{2.5}$ of the nine Japanese cities from 2002 to 2008, measured using tapered element oscillating microbalance (TEOM), were provided by the National Institute of Environmental Studies (NIES). Same period of daily meteorological variables, such as average temperature and average relative humidity, were also obtained from NIES. All-cause mortality, coded with the International Classification of Diseases 10th revision (ICD-10: A00-Y89), was obtained from the Ministry of Health, Labour, and Welfare. All-cause mortality was further stratified into two mortality subgroups, namely: age (0–64, and > 64 years old) and sex (women and men). Previous research observed the potential effect modification by sex (Clougherty, 2011; Ranciere et al., 2017) and age (Gouveia and Fletcher, 2000) in the effect of air pollution on mortality. Sex modification may be related to the physiological differences with regard to respiratory absorption of gaseous elements (Jones and Lam, 2006), or may also be due to the difference in the permeability of the blood-gas barrier (Brauner et al., 2009). On the other hand, the decreased physiological integrity of the elderly, as a result of the aging process, has been linked to their higher risks to air pollution (Gouveia and Fletcher, 2000; Schwartz and Dockery, 1992). Hereafter, we interchangeably used mortality subgroup, subgroup and risk population, bearing the same contextual meaning. Available and statistically-managed mortality, meteorological and air pollution data from nine Japanese cities, located from north to south (Fig. 1), were utilized in this study.

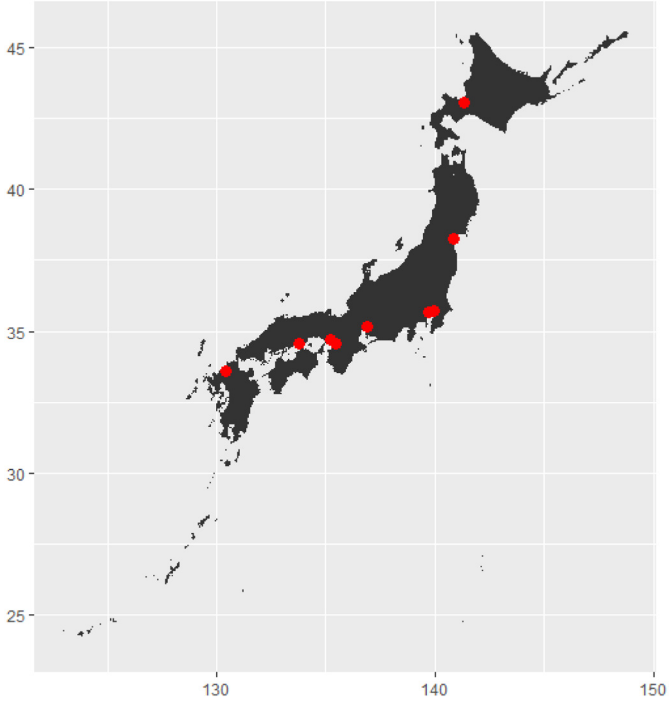

Fig. 1. Geographical location of the nine cities across Japan.
Red dots indicate the locations of the cities, from northern most city of Sapporo, to the southern city of Fukuoka. The cities are lined up with almost an across country representation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The study areas, where the two-stage risk estimation was carried out, are distributed geographically across the country as shown in Fig. 1. The southernmost study area is Fukuoka, while the northernmost study area is Sapporo. Temperature-wise, southern areas are warmer than those in the northern areas, which is also evident in the mean temperature recorded in Table 1.

We used a two-stage hierarchical analysis to infer the underlying concentration-response curve, by modeling daily mortality with daily $PM_{2.5}$ using a distributed lag non-linear model (DLNM). DLNM relaxes the assumption of linearity, which allows a robust modeling of the exposure-response relationship. Though most exposure-response studies were based on linear assumptions, recent advances in the field showcased that there are departures from linearity (Krewski et al., 2009; Pope III et al., 2009, 2011a). In order to accommodate these various functional shapes, as well as the bi-dimensional relationship of $PM_{2.5}$ and mortality, we used Poisson regression with an over dispersion parameter, coupled with penalized DLNM to flexibly estimate the city-specific risk curves (Gasparrini, 2011, 2014); detailed model specification can be seen in Eq. (1). Mortality subgroup-specific, city-specific risk coefficients were then pooled via random effects meta-analysis, and summarized as subgroup-specific pooled estimates.

$$\begin{gathered}\mu_{ct} \sim Poisson\\ \log(\mu_{ct}) = \alpha + cb_{pm} + cb_{tave} + ns(date, 7 \times 7) + ns(Rhave, 4) + dow_t\\ + hod;\\ offset(\log(pop))\end{gathered} \tag{1}$$

City-specific all-cause and subgroup daily mortality counts (μ_{ct}) in

Table 1
Summary statistics of the daily meteorological and mortality of the nine cities, 2002–2008.

City	Average temperature (°C) mean (± SD)	PM$_{2.5}$ concentration ($\mu g/m^3$) mean (± SD)	Relative humidity (%) mean (± SD)	All-cause mortality mean (± SD)	Age-specific mortality mean (± SD)		Sex-specific mortality mean (± SD)		Population[a]	Death rate (per 1000)[a]
					0–64	> 64	Women	Men		
Fukuoka	22(± 12)	17(± 8)	65(± 11)	22(± 5)	4(± 2)	18(± 5)	11(± 3)	12(± 4)	358,103	22.5
Ichikawa	18(± 9)	16(± 8)	69(± 15)	7(± 3)	2(± 1)	5(± 2)	3(± 2)	4(± 2)	466,608	5.37
Kobe	20(± 10)	17(± 8)	65(± 11)	31(± 7)	5(± 2)	26(± 6)	14(± 4)	16(± 5)	1,525,393	7.48
Kurashiki	22(± 11)	17(± 9)	66(± 11)	9(± 3)	1(± 1)	8(± 3)	4(± 2)	5(± 2)	469,377	7.09
Nagoya	19(± 10)	16(± 8)	65(± 12)	43(± 8)	8(± 3)	36(± 8)	20(± 5)	24(± 6)	2,215,031	7.34
Sakai	20(± 10)	17(± 8)	63(± 11)	16(± 4)	3(± 2)	13(± 4)	7(± 3)	8(± 3)	830,966	7.25
Sapporo	12(± 6)	9(± 9)	68(± 10)	33(± 7)	6(± 3)	26(± 6)	15(± 4)	18(± 5)	1,880,863	6.51
Sendai	13(± 7)	13(± 8)	72(± 13)	16(± 4)	3(± 2)	13(± 4)	7(± 3)	9(± 3)	1,025,098	5.66
Tokyo	19(± 9)	17(± 8)	59(± 15)	165(± 21)	30(± 6)	134(± 19)	75(± 12)	89(± 13)	12,587,020	4.86

[a] Population in 2005.

city c on time t follows a Poisson distribution. $\log(\mu_{ct})$ is the expected number of city-specific mortality; α is the intercept; the cross basis term for the PM$_{2.5}$ concentration (cb_{pm}), in the respective lag and exposure dimensions with a maximum lag of 3, and the cross-basis term for temperature (cb_{tave}) with a maximum lag of 7, the natural cubic spline (ns) of date with 7 df per year (for 7 years), and the other covariates of relative humidity, $ns(Rhave, 4)$, smoothed with ns and 4df, categorical variable of day of the week (dow_t), binary variable of holiday (hod), and an offset for the population growth, $offset(\log(pop))$. First stage, city-specific risk coefficient estimates were then pooled via random-effects meta-analysis. The framework of pooling the (DLNM) first-stage, city-specific risk curves is discussed comprehensively in details elsewhere (Gasparrini and Armstrong, 2011, 2013).

2.2. Health impact assessment

The subgroup-specific pooled estimates derived from the risk estimation were utilized in the HIA of the two proposed interventions, namely: i) decrease to Japanese standards (15 $\mu g/m^3$) (MOE, 2009), and ii) decrease to WHO standards (10 $\mu g/m^3$) (WHO, 2006), which were compared with the status quo (18 $\mu g/m^3$; current annual concentration calculated from actual data). Status quo is equivalently referred to as “do-nothing”, while the decrease to Japanese and the WHO standards as the hypothetical alternative interventions. We used the average VSL in Japan from two relevant studies (Itaoka et al., 2007; Kaida et al., 2008), to reflect the trade-off in averting the risks associated with air pollution on health (Hammitt, 2007). VSLs are estimates derived from an individual's willingness-to-pay valuation of how much would he/she is willing to forgo, in terms of monetary resources, to avert a certain proportion of risk in a given period of time (NRC, 2008; Roman et al., 2012). This aggregate estimate depicts the economic benefit from a societal perspective with respect to the reduction of risks brought upon by the intended policy or intervention (NRC, 2008). Likewise, given that an individual may value the delay of the fatality or reduction of risk depending on the available period they have, VSLYs are utilized to account for the expected life years of a given age group, thus assuming that the mortality risk reduction varies proportionally with age (WB and IHME, 2016). We utilized a 3% time discounting for future life years, which reflects a social time preference on a healthy life year at present, compared to the future, with the underlying assumption that the current time has greater value due its certainty, compared to an uncertain future (Gyrd-Hansen and Sogaard, 1998; NRC, 2008). Comprehensive discussions of the empirical and theoretical concepts related to VSL and VSLY are extensively discussed elsewhere (Gyrd-Hansen and Sogaard, 1998; Hammitt, 2007; Roman et al., 2012; Viscusi, 2010; Viscusi and Hersch, 2008). A more detailed methodological specification of the utilization of VSL and VSLY in the study can be found in the Supplementary materials-health impact assessment.

Aside from estimating AN and YLL, we also estimated the EH impact, which serves as an indicator of the economic value of life years lost through the valuation of VSLY combined with YLL. We further calculated aggregate metrics such as 1) economic burden by summing up the EH impact per mortality subgroup in each pollution level, and 2) EH impact as economic benefit brought by each hypothetical alternative intervention. Economic benefit is defined as the reduction of the burden in terms of the difference between the do-nothing, the status quo, and either of the alternative hypothetical pollution levels. We compared the study estimates with the published journal and reports' estimates (Goto et al., 2016; OECD, 2014; WHO, 2016), to establish the validity of the HIA metrics in the study; as shown in Supplementary materials-estimates validation. All analyses were done using R Statistical programming (R Core Team, 2017).

3. Results

All-cause mortality is high in a populated area such as Tokyo, followed by less populated but equally urbanized cities of Nagoya, Sapporo, Kobe, and Fukuoka, as shown in Table 1. There is not much variation in the mean PM$_{2.5}$ concentration levels, except for Sapporo (mean = 9, SD = 9). Variations in the mean temperature are apparent for study areas distant from each other; Sapporo having the lowest year-round mean temperature (12 °C), located in the northern part of Japan, in contrast to the mean temperature of a southern area, in Fukuoka, which is at 22 °C. There are no variations in relative humidity among the cities. While there are more > 64 y.o. mortality than 0–64 y.o., mortality distribution between the sexes are the same.

In calculating the HIA metrics, we either calculated the required estimates (β_{sub} and $YLL_{0,sub}$) using the current data sources, or have extracted these estimates from previous literature (VSL_O and r); as shown in Table 2.

Risk curves in the first stage analysis are not entirely linear, with some cities following non-linear dose-response risk functions. In reference to city-specific lowest concentration, risks are generally increasing, except for Ichikawa and Sakai.

We observe an apparent upward linear risk after pooling the city-specific risk curves. Centering at the across-city minimum concentration at 3 $\mu g/m^3$, a 10-unit increase would increase the risk by 0.52% (95% CI: −0.91% to 1.99%) for all-cause mortality.

In all-cause mortality, AN and YLL are particularly high in the status quo, with decreasing magnitude (of attributable mortality and life years lost) in the hypothetical alternative interventions (Japanese and WHO standards). Both Fig. 4A and B indicate that these alternative interventions will have lower number of attributable mortality and YLL, however, lacks an insight whether enforcement towards these hypothetical interventions will yield monetary economic benefits if compared to status quo. The monetary valuation gap was supplemented

Table 2
Input variables used for HIA.

HIA metric to be estimated	Input variable	Estimates used	References/estimates
Attributable fraction ($AF_{i,sub}$)	β_{sub}	0–64 years old: 0.0030 (95% CI: −0.0210–0.0279) > 64 years old: 0.0074 (95% CI: −0.0037–0.0185) Women: 0.0073 (95% CI: −0.0069–0.0214) Men: 0.0058 (95% CI: −0.0076–0.0192)	(Study estimates from the subgroup-specific pooled risk curve)
Years life lost (YLL_{sub})	$YLL_{0,sub}$	0–64 years old: 15.98 > 64 years old: 5.29 Women: 7.68 Men: 9.34	Study estimates calculated from YLL (from 2002 to 2008) per mortality subgroup
Value of statistical life year ($VSLY_{i,sub}$)	VSL_0	(In Japanese yen): 372.5 × 10^6	Itaoka et al. (2007); Kaida et al. (2008)
	r	3%	Springmann et al. (2016); Viscusi and Hersch (2008)

β_{sub} ≡ mortality subgroup-specific beta coefficient; $YLL_{0,sub}$ ≡ subgroup-specific life expectancy; VSL_0 ≡ average local VSL estimates; r ≡ discount rate.

by the valuation of the three air pollution level scenarios in Fig. 4C, indicating high economic burden in status quo (3.34 trillion yen) and decreased burden in the alternative interventions. In reference to status quo, the enforcement of the alternative interventions will yield monetary economic benefits, which are particularly high in the stricter WHO standard (2.19 trillion yen) (4D).

Between the age groups, the elderly are mostly at risk with higher AN and YLL compared to 0–64 years old (Fig. 5A, B). As for sex, women would account for slightly higher AN and YLL compared to men (Fig. 5E and F, respectively). Patterns of decreasing AN and YLL can be observed in the three air pollution level scenarios, with the lowest in the WHO standard. After the valuation, large proportions of (total) economic burden were estimated in the status quo for either age- or sex-specific mortality subgroups (Fig. 5C and G) (1.90 trillion yen and 4.14 trillion yen, respectively). On the other hand, enforcement of alternative interventions yielded varying levels of economic benefits, with greater benefits in the enforcement to the WHO standard for both mortality subgroups (Fig. 5D and H) (age: 1.25 trillion yen; sex: 2.70 trillion yen). In the mortality subgroups, economic burden is largely concentrated in the elderly (> 64 y.o.), but would eventually yield greater economic benefits if alternative interventions were to be implemented. While for the sexes, although the women have slightly higher $PM_{2.5}$-related economic burden and economic benefits than the men, there is no sufficient evidence which could highlight a substantial difference between the two.

4. Discussion

In this study, we were able to determine the economic losses by three air pollution level scenarios, and two economic benefits brought forth by two hypothetical $PM_{2.5}$-related interventions, utilizing a localized risk estimation and valuation process. Specifically, we used a localized two-stage risk coefficient estimation followed by HIA to determine the associated economic burden/benefit. In the pooled all-cause mortality, a 10-unit increase in $PM_{2.5}$ increased the risk by 0.52% (95% CI: −0.91% to 1.99%). Economic burdens are apparent in status quo for both all-cause and subgroup specific mortality. However, if interventions were to be implemented, such as the enforcement of stricter standards, i.e. WHO standard, we expect high economic benefits.

4.1. Risk coefficient estimation

Estimating the effects of $PM_{2.5}$ on mortality have been assumed to be linear, evident in previous studies (Crouse et al., 2012; Dockery et al., 1993; Pope III et al., 2002). Progressive research have brought forth insightful developments in the exposure-response modeling (Lippmann, 2005), which became more accommodating to other functional risk shapes (Nasari et al., 2016). In this study, we have allowed a more flexible and less arbitrary approach in estimating a risk coefficient, which does not restrict the functional shapes of the risk curves by applying a penalized DLNM. In Fig. 2 the direction of the risk among the majority of the cities was generally upward signifying that the increasing $PM_{2.5}$ concentration would result to an increase in the risks, except for Ichikawa and Sakai. Consequently, after pooling, the overall risk curve in Fig. 3, has a distinct upward linear shape, with lesser uncertainty compared to the city-specific risk curves. Though the approach is less arbitrary compared to the previously used models, there were certain parameters, which should be carefully examined, such as the maximum lag as well as the reference point. We initially set the $PM_{2.5}$ maximum lag at 7, but we have observed that the risks were already depreciating beyond lag 3 (Fig. S3), hence we finally set the maximum lag at 3. Alternatively, risk coefficient interpretation is dependent on the selected reference point, in this case, the pooled pattern was linear and thus the risk coefficient was stable regardless of whatever reference point was used.

4.2. Mortality subgroup analyses

In this study, we further utilized the estimated risk coefficient towards the valuation in the HIA among different mortality subgroups. In most air pollution-related HIA studies (Anenberg et al., 2010; Anenberg et al., 2012), the population structure has been less focused, with most assume an aggregate population, which, in turn, would eventually under- or over-estimate the risks associated with the specific risk population. Effect modification by age and sex have been observed among air pollution-health studies (Bell and Dominici, 2008; Bell et al., 2014). We took into account the effect modification and have addressed it by stratifying all-cause mortality by the subgroups as well as its corresponding YLL in order to facilitate subgroup-specific HIA. Generally, the other two intervention scenarios would deem to have greater economic benefits not just with the decreased number of AN and YLL, but also with reduced magnitude of the EH impact; as in Figs. 4A, B, 5A, B, E and F.

Among age-specific mortality, the elderly population had greater number of AN, which was in concurrence with the increased risk observed in the pooled RR estimate (Table S1). Previous literature have also observed the high risks brought upon by short-term exposure of air pollution among the elderly (Filleul et al., 2003; Gouveia and Fletcher, 2000). Decreased lung functionality as a result of the natural aging process has been one of the few pathways whereby exposure to air pollutants can affect the pool of frail elderly population, which, in most cases, have pre-existing diseases (Simoni et al., 2015). On the other hand, sex-specific analysis showed that women would suffer more from $PM_{2.5}$. Pope III et al. (2011b) observed that the decline in vascular response relative to the elevated ambient air pollution for the previous two days even at low concentration were found to affect women. Contrary to this, Granados-Canal et al. (2005) noted strong short-term associations of air pollution and respiratory hospital admissions among men in Paris. There is no definite risk attribution for the plausible risk

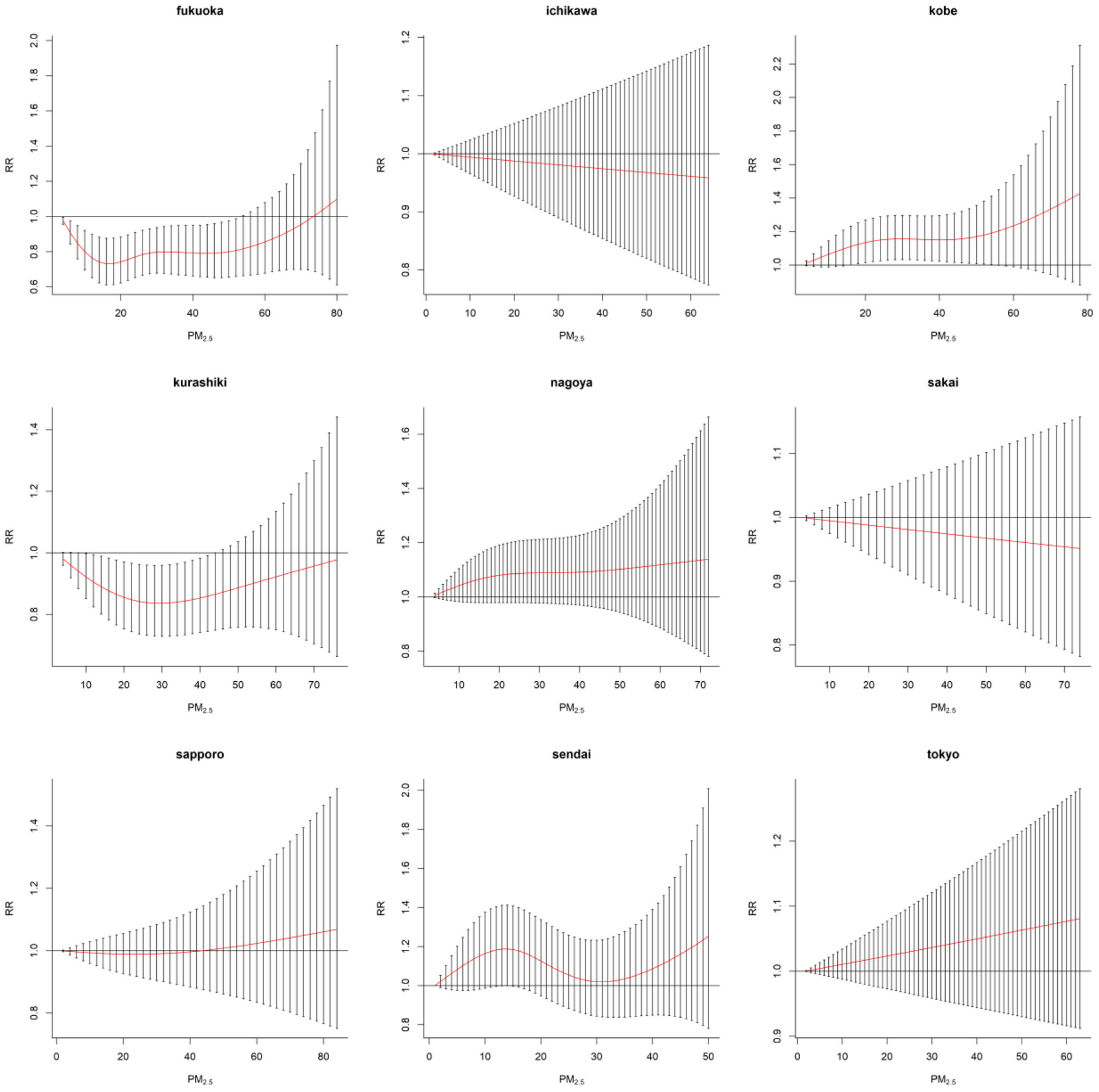

Fig. 2. First stage, city-specific GAM risk curves of the nine Japanese cities.
The red horizontal line (relative risk estimate) of the y-axis, together with its respective confidence intervals (black vertical lines), covers the whole range of the city-specific mean PM2.5 concentration (x-axis). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

difference between the sexes, however, a candidate presupposition may be linked to the biological differences, occupational exposures as well as activity patterns between the sexes (Clougherty, 2011; Son et al., 2013).

4.3. Health impact analysis

If we compare status quo with either pollution levels of the hypothetical alternative interventions, we observe a general pattern of decreasing AN and YLL for both all-cause and mortality subgroups (Figs. 4A–B, 5A–D). Furthermore, Figs. 4C, 5C, and G show the economic burdens associated with the respective air pollution levels, as well as the economic benefits if we were to enforce the alternative hypothetical interventions. Economic burdens were mostly apparent in the status quo, which would simply mean that continued levels of $PM_{2.5}$ would not only be deterrent to health, but would pose a substantial economic burden to society. In a do-nothing, all-cause mortality perspective, economic burden was valued to be at 3.35 trillion yen. In the mortality subgroups, economic burdens varied (age = 1.90 trillion yen; sex = 4.14 trillion yen) (Table S2), which reflects the influence of a combination of factors such as risk population attributable fraction, the exposed population and life expectancy. The difference of the economic burden/benefit between all-cause and subgroup specific mortality reflects the importance of the utilization of the appropriate health

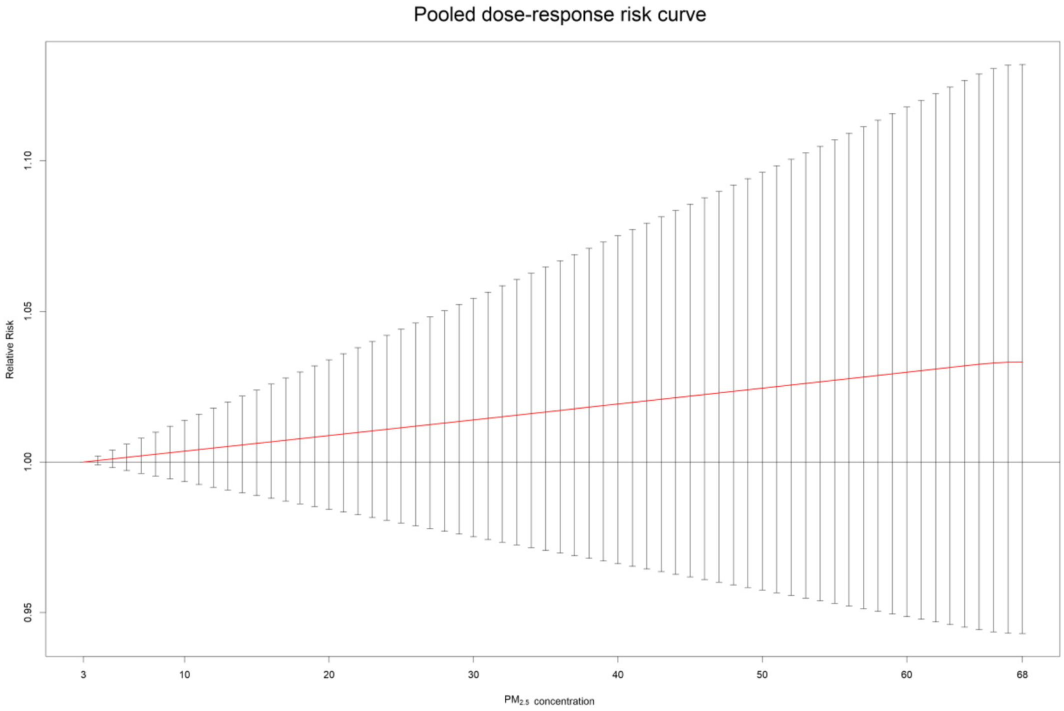

Fig. 3. Second stage, pooled-risk curve of the city-specific risk curves.
The estimated city-specific risk curves were pooled via random-effects meta-analysis with the overall relative risk (horizontal red line) with its 95% confidence interval (vertical black lines) covering the across-city mean PM2.5 concentration range. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

outcome group of interest. In this instance, we observe that the utilization of all-cause mortality, relative to the mortality subgroup, may not only under- or overestimate the risks, but also the associated valuation of the risks. In the hypothetical alternative interventions, we observe reduced economic burdens, with the lowest in the WHO standard. The difference of the burdens observed in the hypothetical alternative interventions and that of the status quo can be assumed as economic benefits; with more favorable results if WHO standards were to be implemented.

The averted mortality and life years lost, and most especially the potential economic benefits of the hypothetical alternative interventions are indicative of the window of opportunities for local, national and international administrative units to utilize as part of a well-informed policy making process. In particular, these hypothetical alternative interventions serve as an encompassing umbrella which may include a multitude of strategies under each intervention, aimed at decreasing the current mean $PM_{2.5}$ concentration, at status quo, to the either of the Japanese and WHO standards. The underpinning strategies may be varied which may focus on the management of specific emission sources (Oka et al., 2007).

Though the opportunities of the implementation of the hypothetical alternative interventions have been overwhelmingly positive with indications of averted mortality and life years lost, as well as the potential economic benefits, we have not fully accounted for the cost of implementing the aforementioned alternative interventions; a limitation of this study worth investigating in the future. The alternative interventions were hypothetically assumed with no associated implementation costs, and may fall short of deciding whether such cost of implementing these alternative implementations would be less than the estimated potential benefit; popularly evaluated through the cost-benefit approach. Nevertheless, a workable framework can be facilitated whereby policymakers can complement by considering policies which include low-cost strategies in relation to the potential economic benefits highlighted in this HIA study. Ultimately, the economic benefits supplement decision making in terms of a rapid assessment of the hypothetical alternative interventions. Each administrative unit would have the opportunity to operate their own HIA to assess the relevant health impact, in terms of losses or gains, which they can mitigate or enhance before implementing an intervention (Fischer et al., 2018).

Each of the metrics highlighted in this study can be utilized for specific policy decisions, and that no gold standard assumes a definite superiority of one metric from the other. The value for the utilization of these metrics lie on the information available, as well as on what the policy needs (Veerman et al., 2005). Intuitively, a decision can only as much depend on the information which is readily available, and can't go beyond what is limited. On the other hand, a certain metric can also be used as a supplementation to the intended policy to be carried out. AN provides an overview of the burden with regard to proportion of cases due to air pollution, while YLL considers the contribution of life expectancy into the valuation. A multitude of factors could affect how a person perceives risk such as the remaining life years due to age, which could eventually affect how risks are valued (Viscusi, 2010). VSLY, calculated by dividing the VSL by the discounted life years for the specific age group, reflects the adjustment on the value of life with respect to age (Robinson and Hammitt, 2009). While combining VSLY with YLL produces a metric which represents the economic burdens in terms of the value of life years lost, through the EH. Eventually, the greater number of metrics, the wider is the array of policy decisions which could be carried out or can be selected upon. However, careful usage of each metric is advised as each metric provides a different information, and a different perspective with regard to policy implications.

5. Limitations

One of the few novelties of this study is the usage of local estimates from the risk coefficient estimation until the HIA, which is reflective of the local scenario. Though generalizations of the results are limited to the Japanese context, this epidemiological/empirical exercise provides a simple overview and application of how local context estimates can be

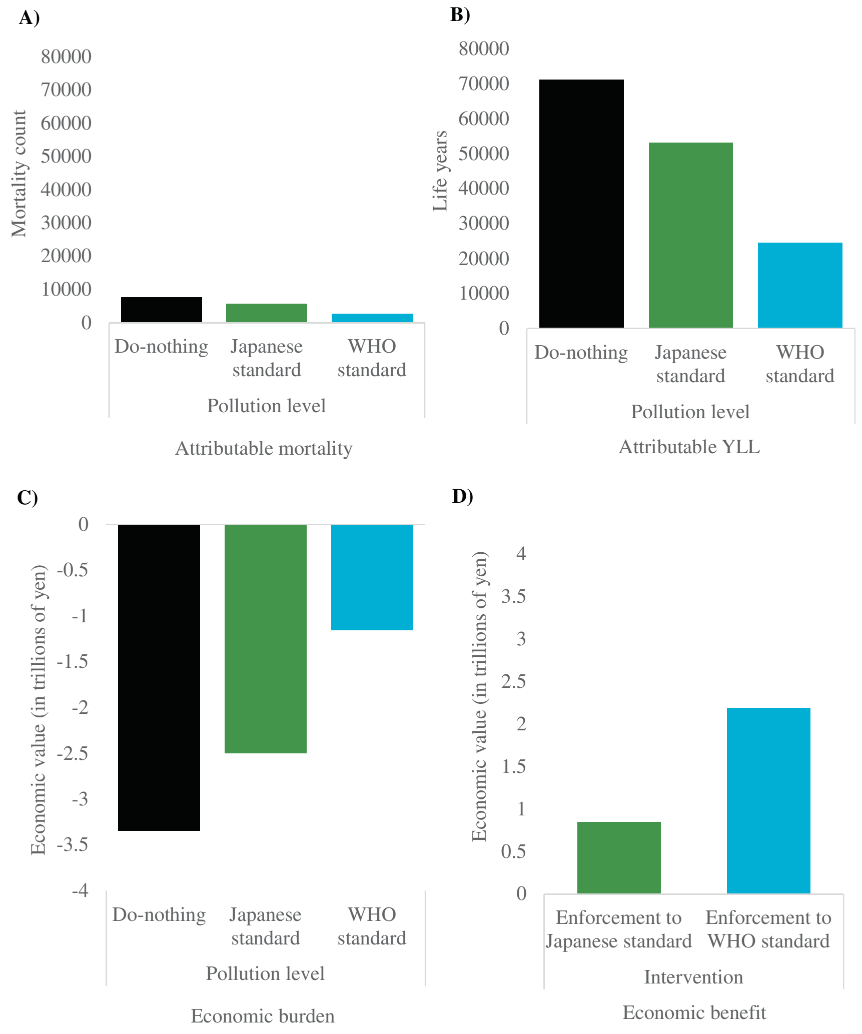

Fig. 4. Health impact of air pollution on all-cause mortality in various HIA metrics.
Changes in the HIA metrics (attributable mortality, attributable YLL, Economic burden and Economic benefit) depend on the pollution level and intervention being considered. Three pollution levels represent varying annual mean PM2.5 concentration levels, namely: do-nothing (otherwise known as status quo with 18 μg/m^3), Japanese standard (15 μg/m^3), and WHO standard (10 μg/m^3). While the remaining two interventions under economic benefit are the benefits in terms of the reduction of the economic burden with reference to the status quo: 1) enforcement to Japanese standard (economic burden of do-nothing minus economic burden of Japanese standard), and 2) enforcement to Japanese standard (economic burden of do-nothing minus economic burden of Japanese standard).

utilized for national valuations in the respective countries.

The risk coefficients estimated in this study are short-term, which we would assume could complement a near future valuation of the health impacts associated with shot-term air pollution exposure. Most of the recent studies would utilize long-term risk estimates, which depict the chronic effects attributable to the exposure. One of the goals of the study, aside from providing an overview of the various HIA metrics, is the process of the utilization of local risk estimates, which could then be used for local HIA valuation. Long-term estimates are a result of cohort studies, which are most of the time from high income/developed countries. The value of using the local risk estimates lies on the access of available data relevant to the specific area, which would then be complemented by socio-demographic characteristics, i.e. life expectancy, and how the population acknowledge and their response through the valuation of risk aversion; i.e. WTP studies.

All-cause mortality was utilized over cause-specific mortality due to its correspondence with the usage of VSL. The nature of the VSL derived from the WTP contingent studies is dependent on the questions of general mortality risk aversion to the risk factor, air pollution, and not on the specific causes of mortality. In the previous WTP contingent studies, though the risk perception did not vary by the cause of mortality or existing illness, these risk perception varied with non-health individual/socio-demographic characteristics, such as sex and particularly age, hence the subgroups. There are other candidate non-health individual/socio-demographic characteristics which can affect risk perception such as education level, income level and race, but were not available in the existing data source.

We utilized hypothetical alternative interventions in order to highlight the specific HIA metrics, which may be seen as an oversimplification of the wide spectrum of strategies eligible within each intervention. However, such exercise can give a hindsight for policymakers of the magnitude of health impact, for losses and benefits, and can be a starting point of valuation for more specific strategies.

6. Conclusions

In this study, we were able to determine the economic burdens by three air pollution level scenarios, and economic benefits from the two hypothetical $PM_{2.5}$-related interventions. If $PM_{2.5}$ concentration levels were not to change, at status quo, we will observe substantial economic burdens. However, if stricter standards were to be enforced, i.e. WHO standard, we can expect greater economic benefits. Using the estimated local risk coefficients complemented with an economic valuation, policymaking entities will have the opportunity to operate their own HIA to assess the relevant air pollution-related health impacts.

Authors' contributions

XS conceptualized and designed the analysis, as well as carried all the statistical and econometrical analyses in the manuscript. MK substantially contributed to the health impact valuation, while KU and TM provided relevant comments in the risk estimation. Meanwhile, YH provided technical insights for the risk estimation. TM, SY, and HN collected the data.

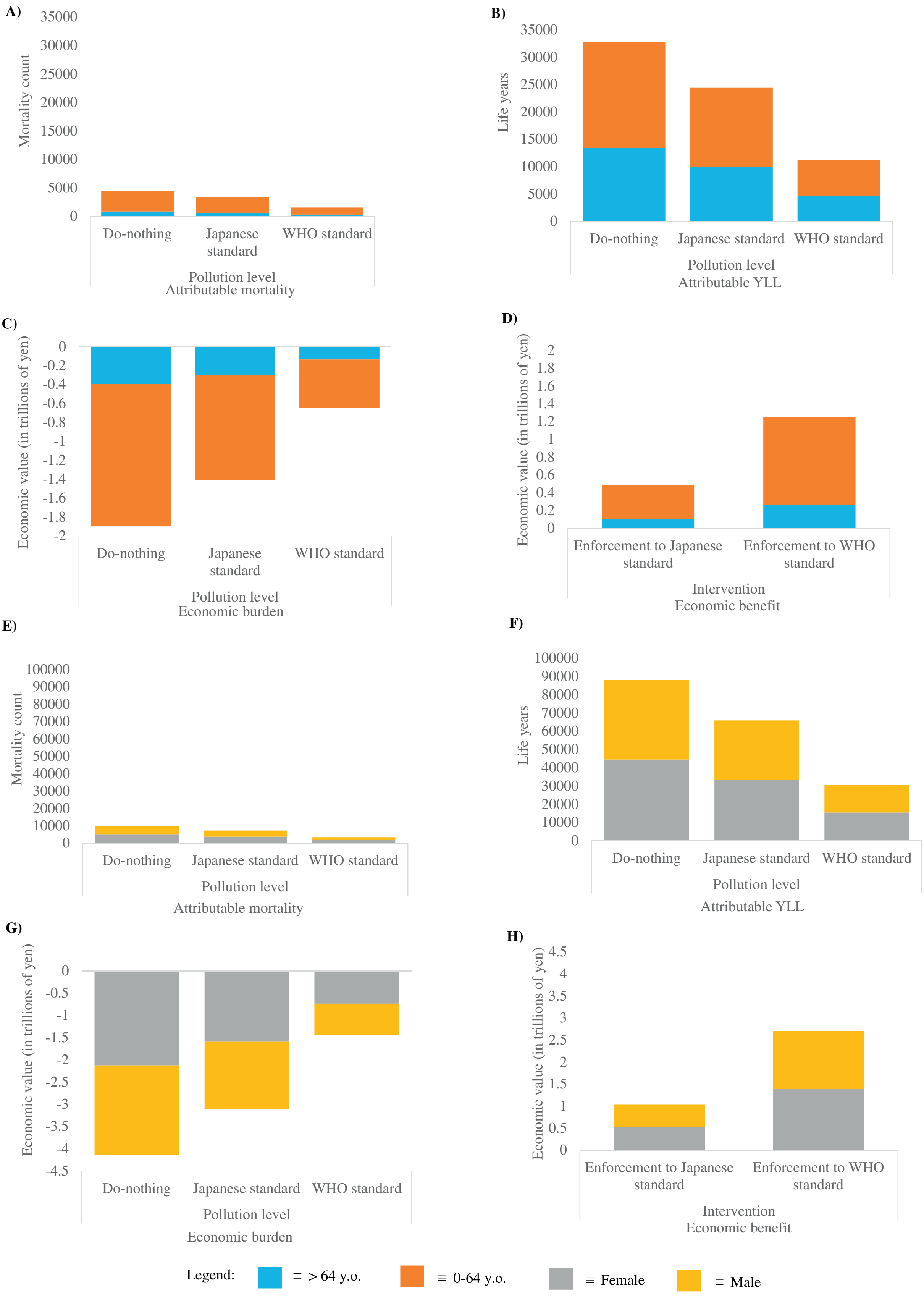

Fig. 5. Health impact of air pollution on age- and sex-specific mortality through the different HIA metrics.
Changes in the HIA metrics sex- (female and male) and age- (0–64, y.o. and > 64 y.o.) specific mortality subgroups subject to the pollution level (do-nothing, Japanese standard, and WHO standard) and intervention (enforcement to Japanese standard and enforcement to WHO standard) being considered.

Declaration of competing financial interests

We hereby declare that there are no pertinent competing financial interests during the conduct of this study.

Role of funding source

None.

Ethics committee approval

This study was approved by the Ethics Committee of the Kyoto University Graduate School of Engineering.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2018.08.037.

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