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Reduction Potential of Anthropogenic Mercury Release in Malaysia

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Anthropogenic release of mercury, human exposure and environmental health are important and mercury management policies are required to effect significant change in Malaysia. To provide a useful information to facilitate the creation of strategic management policies for mercury as the Minamata Convention on Mercury is implemented in Malaysia, there is an urgent need to estimate the potential to reduce mercury release by applying different control measures, i.e. simple electrostatic precipitator and mercury-specific filter. Equally urgent is the need to clarify the alleviated environmental burdens from the reduced mercury releases by applying different control measures. Many researches have explored issues in terms of the mercury' toxicity and the harm of mercury compounds worldwide. A lack of surveys to evaluate both on the reduction potentials and alleviated environmental burdens of mercury releases resulted in anthropogenic sources under different control measures has been observed. This study estimated the potential reduction and alleviation of the environmental burden of anthropogenic mercury released into the natural environment (air, water and land) in Malaysia under three emission control scenarios and identified the potential reductions. A life cycle impact assessment was applied to estimate an alleviated environmental impact under these scenarios. As a result, the environmental burden can be reduced by 77 % by applying the multipollutant emission control measures such as applying mercury-specific filter for coal combustion compared to no emission control measures. At this maximum, the harm to human health can be reduced by 3,730 disability-adjusted loss of life years and the harm to ecosystems can be reduced by 0.16 species/year. This study will assist decision makers to understand the magnitude of changes resulting from different emission control measures.

1. Introduction

Mercury is a global pollutant that has serious effects on human health and the natural environment (Habuer et al., 2021a). Minamata Disease caused by methylmercury is one of the typical case of health damage from mercury. Methylmercury and its compounds are bioaccumulative environmental toxicants, which exposure to sunlight enabling their detoxification (Praveena et al., 2013). Mercury can enter the environment through several routes, such as from natural sources, anthropogenic activities and re-emission from previous disposal in nature (Habuer et al., 2021b). Streets et al. (2018) reported that the fraction of mercury released to the air as metal mercury has increased steadily. About 2.2 × 10^6 kg of mercury released to the air in 2015 from anthropogenic sources (UNEP, 2019). Asia is the region with not only the fastest growth of mercury production and consumption but also the largest mercury emissions and releases. Malaysia is potentially at risk of mercury pollution (Jeevanaraj et al., 2016), with high mercury concentrations reported in West Port, the Malacca Straits, Prai and West Johor (Rahman et al., 2016). Possible sources of mercury release are industrial discharge (rubber glove factories), agriculture chemical use (palm oil plantations), cargo ships and fishing vessels (in the Malacca Strait) and a coal-fired power plant (Wolswijk et al., 2020). It was estimated that the total potential emission in Malaysia in 2012 were 7,600-59,090 kg (Habuer et al., 2016). Anthropogenic releases of mercury, human exposure and environmental health are important within the framework and policies outlined in the Minamata Convention on Mercury (MCM) (Bank, 2020). The MCM, which entered into force on 16 August 2017, is a global treaty with the goal of protecting human health and the environment from anthropogenic activities that requires mercury management policies. Malaysia signed the MCM on 24 September 2014 (Habuer et al., 2021a).

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Countries that sign the MCM must take measures that combine multiple transformative technologies and systems to replace or update outdated technologies and systems to avoid mercury pollution. To provide information to facilitate the creation of strategic management policies for mercury as the MCM is implemented in Malaysia, there is an urgent need to estimate the potential to reduce mercury release by applying different control measures. Equally urgent is the need to clarify the alleviated environmental burdens from the reduced mercury releases by applying different control measures. Many researches have explored issues in terms of the mercury' toxicity and the harm of mercury compounds worldwide. Gavilan-Garcia et al. (2015) evaluated the impact of policy alternatives for the sound management of mercury released from used thermometers using a life cycle assessment approach. Studies have used model prediction and substance flow analysis to estimate anthropogenic releases in China (Habuer et al., 2021b) and Malaysia (Habuer et al., 2016). Habuer et al. (2021a) also used a life cycle impact assessment (LCIA) approach to estimate the environmental burden arising from anthropogenic sources in Malaysia under an assumption of no emission control (EC) measures applied. EC data are important for relatively accurate quantifying the mercury release rather than assuming the situation as that no control measure applied, as in the previous study (Habuer et al., 2021a). The Ministry of the Environment and Water of Malaysia (2021) released the Minamata Convention Initial Assessment Report, which examined the total release under EC scenarios without exploring either different mediums or the environmental burden. A lack of surveys to evaluate both on the reduction potentials and environmental burdens of mercury releases resulted in anthropogenic sources under different control measures has been observed. This study estimated the potential reduction and alleviation of the environmental burden of anthropogenic mercury release into the natural environment (air, water and land) in Malaysia under three EC scenarios. The potential reductions were identified. A LCIA was applied to estimate the alleviated environmental burden under these scenarios.

2. Methodology

According to Habuer et al. (2021a), the anthropogenic mercury release sources in Malaysia can be divided into five categories: extraction and combustion; mineral production (including production of primary metal, and production of other minerals and materials with mercury impurities); secondary metal production; waste treatment; and crematoria and cemeteries. These can be subdivided in 21 subcategories. The detailed classification for release sources is reported elsewhere (Habuer et al., 2021a).

2.1 Potential mercury release to the natural environment as inventories

According to Habuer et al. (2021b), the potential mercury distribution in the natural environment is calculated using Eq(1):

$$PR_{Hg\to i} = \sum_{i=(1)}^{(3)} \sum_{c=1}^{21} \sum_{j=1}^{3} [I_{Hg,c} * S_j * DF_{c,j\to i}] \quad (1)$$

where $PR_{Hg\to i}$ is the potential mercury release into different sinks (the i values) in 2019. The sinks include (1) air, (2) water and (3) land. $I_{Hg,c}$ is the mercury input by subcategory *C* which refer to different subsources. The mercury input $I_{Hg,c}$ was reported elsewhere (Habuer et al., 2021a). The values of S_j are the output scenarios, which number j. The scenarios, *S*, run from the worst to the best control measure for each subcategory, where S_1 indicates the worst, i.e. no EC measure applied, S_2 indicates the least EC measures applied, and S_3 indicates the greatest EC measures applied from an environmental perspective. Note that these scenarios are hypothetical and future technology transformations are dependent on the development of legislation and the economic situation. The subcategories with technology transformations were listed up in Table 1, which gives details of the EC measures applied for each scenario. EC devices were not applied in all scenarios for none mentioned subcategories (C3 and C5) in Table 1. For example, in subcategory C1.1 (coal combustion), it was defined as that No EC device was applied in S_1 (S_{1_noEC}); Simple air pollution control was applied in S_2 ($S_{2\_lowestEC}$); Mercury-specific filter was applied in S_3 ($S_{3\_highest\ EC}$). The technical background of treatment processes was referred from UNEP (2019). The distribution factor (*DF*) reflects how the estimated mercury input from a subcategory is distributed to different environmental media (Civancik and Yetis, 2015). The *DF* values of the UNEP Toolkit Level 2 (UNEP Chemicals, 2017) were applied in this study.

2.2 LCIA methods

LCIA is a common method for assessing the environmental impact of a product (Gavilan-Garcia et al., 2015), process or activity (Habuer et al., 2021a). The impact assessment method ReCiPe Endpoint (H) V1.13 (RIVM, 2017) was selected as the LCIA here. The ReCiPe method is the most authoritative method, which cover all stages of LCIA including classification, characterization, damage assessment, normalization and weighting. The calculation results from section 2.1 were used as inventories of LCIA. The sum of total releases of all subcategories in each sink and each scenario was used for LCIA. The LCIA results in this study, such as characterization, damage assessment, and single score were obtained using the World ReCiPe H/A indicators, and an average weighting set provided in the software Simapro 9.3.0. The results are described using the impact and damage categories defined in ReCiPe 2016 (Table 2). The impact categories here include human toxicity (HT), terrestrial ecotoxicity (TET), freshwater ecotoxicity (FET), and marine ecotoxicity (MET). The damage categories include damage to human health and ecosystem diversity. The harms to human health appears as a sum on years of life lost and years with disability (Disability-adjusted loss of life years, DALY). The harms to ecosystem diversity appear as number of species lost over time (Time-integrated species loss, species/y). The release to the natural environment (air, water and land) was defined as the system boundary for LCIA. The metal mercury release amount in kilograms under the three scenarios in 1 year (2019) was the functional unit. Habuer et al. (2021a) explains data transparency in detail.

Table 1: EC measures applied in the subcategories in different scenarios

Category	Subcategory	Scenarios		
		S_{1_noEC}	$S_{2\_lowestEC}$	$S_{3\_highestEC}$
C1. Extraction and combustion	C1.1 Coal combustion	No EC devices	Simple air pollution control: ESP / PS / cyclones	Mercury-specific filter
	C1.2.3 Combustion / Use of heavy oil and petroleum coke	No EC devices	PM control using an ESP or scrubber	Power plants with cESP and FGD
	C1.2.4 Combustion / Use of gasoline, diesel, light fuel oil, kerosene, LPG and other light to medium distillates	No EC devices	PM control using an ESP or scrubber	Power plants with cESP and FGD
	C1.3.1 Natural gas extraction	No EC devices	No mercury removal	Mercury removal
C2. Mineral Production	C2.3 Cement	No EC devices	Simple particle control (ESP / PS / FF)	Very efficient mercury release control (wetFGD + ACI / FF + scrubber + SNCR)
	C2.5 Pulp and paper	No EC devices	No mercury removal filter	PM control with general ESP or PS
C4. Waste treatment	C4.1 Incineration of municipal solid waste	No EC devices	PM reduced, simple ESP, or similar	Mercury-specific absorbents (and downstream FF)
	C4.2 Incineration of medical waste	No EC devices	PM reduced, simple ESP, or similar	Mercury-specific absorbents (and downstream FF)
	C4.3 Incineration of hazardous waste	No EC devices	PM reduced, simple ESP, or similar	Mercury-specific absorbents (and downstream FF)

Abbreviations: ESP, electrostatic precipitator; PM, particulate matter; FF, fabric filter; FGD, flue gas de-sulphurisation; LPG, liquefied petroleum gas; SNCR, selective non-catalytic reduction; ACI, activated carbon injection; cESP, cold-site ESP; PS, particle scrubber

Table 2: Impact and damage categories considered in this study (RIVM, 2017)

Area of protection	Impact categories	Damage categories	Units
Human health	Human toxicity (HT)	Damage to human health	Disability-adjusted loss of life years (DALY) [1)]
Natural environment	Terrestrial ecotoxicity (TET) Freshwater ecotoxicity (FET) Marine ecotoxicity (MET)	Damage to ecosystem diversity	Time-integrated species loss (species/y) [2)]

[1)] Sum on years of life lost and years with disability; [2)] Number of species lost over time

3. Results and discussion

3.1 Potential mercury releases by scenarios and reduction potentials

According to Habuer et al. (2021a), the total mercury release in Malaysia in 2019 was estimated to be 36,400 kg, including 1,071 kg to general and specific treatment/disposal waste as well as 4,507 kg to stock. The total respective releases to air, water and land were 12,847, 1,783 and 15,874 kg in S_{1_noEC}, 10,745, 1,783 and 15,874 kg in $S_{2\_lowestEC}$, and 2,571, 1,783 and 15,874 kg in $S_{3\_highestEC}$. The potential reduction was 7 % (2,100 kg) by $S_{2\_lowestEC}$ and 34 % (10,280 kg) by $S_{3\_highestEC}$ when compared to S_{1_noEC} in which the total release amount to the natural environment was estimated to 30,500 kg. The total release amount to water and land in the three scenarios did not change because the EC measures mostly were the control measures for air pollution, but not that for controlling releases to water and land. The EC measures applied in $S_{2\_lowestEC}$ were all air pollution control measures which benefit with the reduction of mercury emission, such as simple air pollution control using electrostatic precipitator (ESP), particle scrubber (PS), cyclones, particulate matter (PM) control using an ESP or scrubber. The EC measures applied in $S_{3\_highestEC}$ were multipollutant control measures including both air pollution control measures and mercury-specific filters, i.e. very efficient mercury pollution control measures which apply wet flue gas de-sulphurisation (FGD), activated carbon injection (ACI) / fabric filter (FF), scrubber, selective non-catalytic reduction (SNCR). $S_{2\_lowestEC}$ can potentially reduce the mercury emit to the air by 16 % and $S_{3\_highestEC}$ can potentially reduce the mercury emit to the air by 80 % when compared to S_{1_noEC} (Figure 1). For categories C3 (secondary metal production) and C5 (crematoria and cemeteries), there were no mercury reduction potential. Because EC devices were not applied in all scenarios for categories C3 and C5. The obvious air emission of mercury can be attributed to the categories C1 (extraction and combustion) and C4 (waste treatment). It also can be reduced through applying the multipollutant control measure such as those in $S_{3\_highestEC}$. For example, the potential respective reduction of mercury to the air was 87 % by $S_{3\_highestEC}$ compared to S_{1_noEC} in category C1 (extraction and combustion), and 90 % in category C4 (waste treatment). The simple air pollution measures also can benefit with the reduction of mercury. The potential reduction of mercury to the air was 20 % by $S_{2\_lowestEC}$ compared to S_{1_noEC} in category C1 (extraction and combustion). (Figure 1).

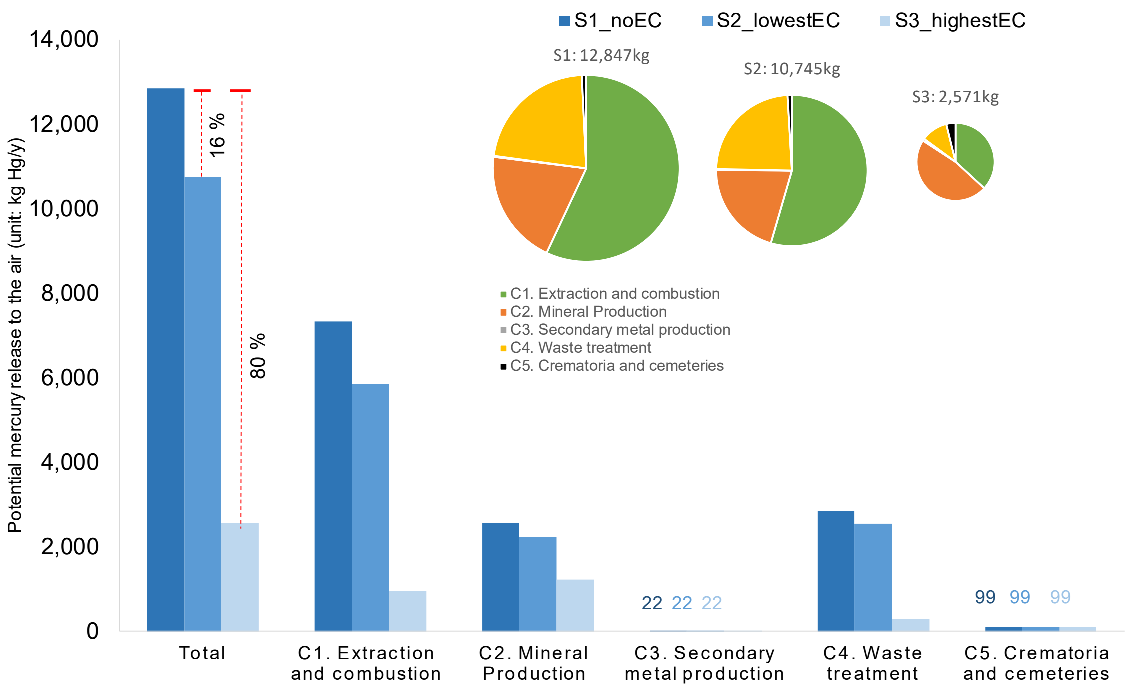

Figure 1: Potential mercury release to the air in Malaysia in 2019 under three scenarios

3.2 Alleviated environment burden reflected in impact and damage categories

Figure 2 summarises the environmental burden caused by mercury release to the air, water and land in the three scenarios. The potential harm to HT can be reduced as 16 % by $S_{2\_lowestEC}$ and 77 % by $S_{3\_highestEC}$

compared to S_{1_noEC}. The potential harm to MET can be reduced as 15 % and 74 % (Figure 2(a)). The harms to human health can be reduced as 16 % and 77 %. The harms to ecosystem diversity can be reduced as 4 % and 20 % by applying $S_{2\_lowestEC}$ and $S_{3\_highestEC}$ (Figure 2(b)). It can be said that implementation of the multipollutant control measures ($S_{3\_highestEC}$) can obviously reduce the harms to human health and marine ecosystem. The alleviated environmental impact, as reflected in damage categories, shown as harm to human health and ecosystem diversity based on normalisation of the eco point (Pt) in ReCiPe 2016. The total harm to human health was 142, 119 and 32 MPt (1 MPt = 1 × 10^3 Pt) in S_{1_noEC}, $S_{2\_lowestEC}$ and $S_{3\_highestEC}$. The total harm to ecosystem diversity in was 0.37, 0.36 and 0.30 MPt (Figure 3), implying that the environmental burden on human health caused by mercury release is much larger than that on ecosystem diversity. At most, the environmental burden can be reduced 77 % (109 MPt) by applying the multipollutant control measures ($S_{3\_highestEC}$) compared to no EC measures (S_{1_noEC}). The harm to human health was 4,830, 4,070 and 1,100 DALY in S_{1_noEC}, $S_{2\_lowestEC}$ and $S_{3\_highestEC}$, while the harm to ecosystem diversity was 0.85, 0.82 and 0.69 species/y. At most, the harm to human health can be reduced by 3,730 DALY and the harm to ecosystem diversity by 0.16 species/y. It indicates that mercury reduction potential in Malaysia contributed 3,730 DALY for world population in 2019, and alleviated health impact is 0.011 % of Malaria impact to human health and 0.005 % of traffic accidents.

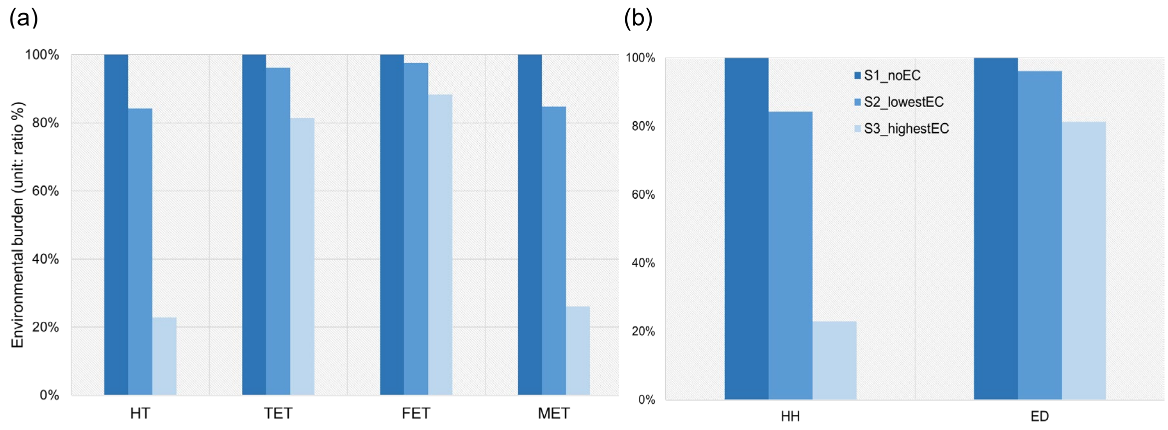

Figure 2: The reduction potential of environmental burden caused by mercury release in the scenarios reflected as (a) impact and (b) the damage categories human health (HH) and ecosystem diversity (ED)

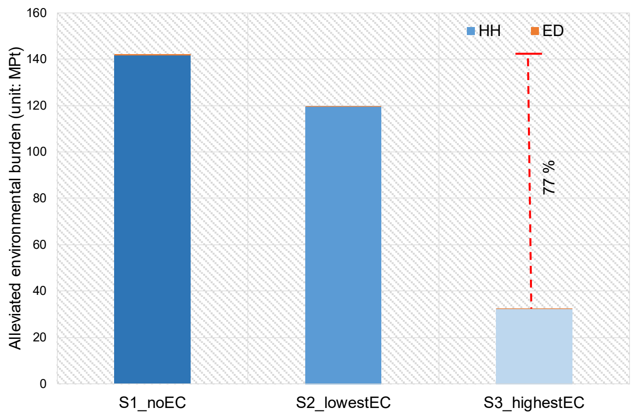

Figure 3: The alleviated environmental burden reflected in the damage categories human health (HH) and ecosystem diversity (ED)

4. Conclusion

This study estimated the potential reduction and alleviated environmental burden of anthropogenic mercury release in Malaysia under three EC scenarios. Most of the mercury emitted to the air was from category C1 (extraction and combustion). The multipollutant control measure seems to be the best available technology if inconsideration of social and economic situation, that can reduce 80 % of mercury emission to air. At most, the environmental burden can be reduced by 77 % by applying the multipollutant control measure compared to no EC measures. The harm to human health can be reduced by 3,730 DALY, which is 0.011 % of alleviated Malaria impact to human health and 0.005 % of traffic accidents. The harm to ecosystem diversity can be reduced by 0.16 species/y. The environmental burden on human health caused by mercury release is much larger than that on ecosystem diversity. This study will assist decision makers to capture the magnitude of changes imposed by the use of different EC measures, aiding the selection of EC measures, where appropriate. A study limitation is that only metal mercury was targeted for LCIA due to a lack of data for other mercury compounds. Future work should focus on the economic/financial and technical capabilities of the relevant stakeholders to apply EC measures.

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