Summary Report: Review and Assessment of the Evidence on Health Impacts of Low-Level Pollution in Countries with Levels of Ambient Air Pollution Comparable to Scotland

October 2023

Scottish Government
Riaghaltas na h-Alba

Report reference

RESAS/020/20 – Summary Report, version 1.2

Contract Details

Scottish Government – Reference: RESAS/020/20 – Invitation to Tender: Provision of Review and Assessment of the Evidence on Health Impacts of Low-Level Pollution in Countries with Levels of Ambient Air Pollution Comparable to Scotland

Presented by

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1 Background

The scope of the work commissioned under this specific request arises from the Cleaner Air for Scotland 2 (CAFS2) Strategy. One of the actions from the CAFS2 Strategy is to assess the evidence on health impacts of low-level air pollution in countries with levels of ambient concentrations comparable to Scotland. To review and assess the evidence of health impacts in such countries, a robust, rapid semi-systematic literature review was undertaken. This review aims to collate and discuss the evidence on:

- The health impacts of air pollution at low levels comparable to Scotland
- Reasons for an absence of association between air pollution and cardiovascular disease in Scottish studies.

This review covers research published between 1 January 2020 and 1 January 2024[1] and builds on a mapping review by Dominski *et al.* (2021) '*Effects of air pollution on health: A mapping review of systematic reviews and meta-analyses'*, herein referred to as the Dominski review. To define countries as comparable to Scotland, data on the population-weighted mean exposure in either 2017, 2018 or 2019 (pre-COVID-19) was collected with a $PM_{2.5}$ annual mean threshold of 12 µg/m^3, as the United Kingdom (including Scotland) mean is approximately 10.2 µg/m^3 (based on the State of Global Air 2017-2019 data) (Health Effects Institute, 2020).

This report presents a summary of the research findings from this review. For further detail on the methodology, including the search terms and limits, please see RESAS/020/20 – Final Report.

2 Results summary

A total of 333 studies were found using Scopus. The titles and abstracts were screened for relevance; 54 potentially relevant papers were identified, and full copies were obtained for detailed assessment. Of these, 46 papers were assessed as relevant and 8 were rejected due to reasons outlined in the main report. In addition to the Dominski review, supplementary searches identified three studies from the Health Effects Institute (HEI) report '*Assessing Health Effects of Long-Term Exposure to Low Levels of Ambient Air Pollution'*, which looked at all-cause mortality, cause-specific mortality and morbidity endpoints (Health Effects Institute, 2014), and three papers (published before 1 January 2020) in Scotland (Yap *et al.*, 2012; Willocks *et al.*, 2012; Lee *et al.*, 2019).

[1] Although the last search date in the review by the Dominski review is 18 June 2020, the search strategy used in this study was from 1 January 2020 to ensure all relevant papers were collated, including those that may have been accepted in early 2020 but not published until after 18 June 2020, due to the timescales associated with academic publishing. An end date of 1 January 2024 was used to capture any pre-dated early release publications.

Half of the 46 included papers (24) were from European countries, most commonly the UK (or England), Sweden, Denmark and the Netherlands. Around two-thirds of papers (31) assessed health outcome in adults, with one third on health outcomes in children. The most evaluated health outcomes were mental health and well-being (11), dementia (6) and cognition (5), with most papers (39) focussing on long-term outcomes.

The prevalence of papers on mental health and well-being is reflective of the search strategy timescale. The evidence on the physiological health impacts of air pollution has been established for several years. Therefore most of these papers would have been published prior to 1 December 2020, and were captured by the mapping review by Dominski *et al.* (2020) and the three HEI reports. Of all pollutants $PM_{2.5}$ (41) was the most evaluated, followed by NO_2 (23) and PM_{10} (19) (N.B. Studies evaluated one or more pollutants).

Within the HEI reports, the ELAPSE study found significant associations between $PM_{2.5}$, Black Carbon (BC), and NO_2 exposure and natural-cause, cardiovascular, respiratory, and lung cancer mortality, as well as stroke, asthma, and COPD hospital admissions, at concentrations below the European Union limit values for $PM_{2.5}$ (25 µg/m^3) and NO_2 (40 µg/m^3)[2]. The study also reported significant associations between NO_2 and acute coronary heart disease and between $PM_{2.5}$ and lung cancer incidence. The shape of the associations between exposure and natural-cause mortality showed steeper slopes at lower exposures, indicating increased risks for mortality at even the lowest observed concentrations; furthermore there were no concentration levels where associations were not found for $PM_{2.5}$, BC, and NO_2 (Brunekreef *et al.*, 2021).

The MAPLE study found long-term outdoor $PM_{2.5}$ exposures as low as 2.5 µg/m^3 were linked to an increased risk of death in a large representative sample of Canadian adults, with variation across different geographical regions and with smaller effects when adjusted for O_3 concentrations (Brauer *et al.*, 2022).

Dominici *et al.* (2019) found that $PM_{2.5}$ was associated with an increased risk of all-cause mortality of 6% to 8% per 10 µg/m^3 in 68.5 million older Americans (aged 65 and over). The effect estimates were larger in a low-exposure sub-cohort. The consistency of the associations across the methods suggests that long-term exposure to $PM_{2.5}$ is likely to have a causal effect on mortality, providing stronger evidence than previous studies.

From the Dominski review (Dominski *et al.*, 2021), 75% of reviews (180/240) showed a positive association, 53/240 (22%) studies were classified as ambiguous and only seven (3%) showed a negative association or no harmful effect(s). Of these seven the health outcomes they analysed were: asthma, childhood cancer, congenital heart defects, pneumonia, stroke, telomere length, and venous thrombosis. Overall, their review found that even low levels of PM exposure can increase the risk of respiratory and cardiovascular disease (CVD), cancer, and premature death. Exposure to $PM_{2.5}$ was the most widely studied pollutant and an

[2] The annual mean Air Quality Objectives for the protection of public health in Scotland are 10 µg/m^3 for $PM_{2.5}$ and 40 µg/m^3 for NO_2 (https://www.scottishairquality.scot/air-quality/standards)

association was found with 8/10 health outcomes evaluated. The most frequently studied health outcome was CVD (32 reviews).

3 Discussion

This section discusses the evidence identified by the search strategy as well as the by the preliminary and supplementary searches.

3.1.1 Cardiovascular disease (CVD)

The three HEI reports, the Dominski review, and the single study identified by this review that focused on CVD (So *et al.*, 2023), all provide significant evidence for the association and impact of air pollution on cardiovascular health globally. One of the Scottish studies (Yap *et al.*, 2012) also found significant associations with all-cause mortality, cardiovascular mortality, ischaemic heart disease and respiratory mortality. Conversely, Willocks *et al.* (2012) and Lee *et al.* (2019) found no association between air pollution and CVD in Scotland.

The absence of an association found by Willocks *et al.* (2012) does not prove that there is no association, and may be due to several limitations in their methodology. Firstly, they only collected data on $PM_{10,}$ rather than $PM_{2.5}$, BC, NO_2, or O_3, which have all been strongly associated with adverse health outcomes including CVD. The authors also discuss the possibility that the study design did not provide enough statistical power to detect a pollution-health relationship as the number of CVD admissions was relatively low. The study also only analysed short-term exposure to particulate matter (PM_{10}) and hospital admissions due to CVD and not the long-term effects of air quality on CVD (Willocks *et al.*, 2012).

Lee *et al.* (2019) found no evidence that CVD or total non-accidental mortality are associated with any of the four pollutants (PM_{10}, $PM_{2.5}$, NO_2, and NOx), however, it is possible that the adjustment for confounders may be oversensitive due to the historic data used to quantify the association between deprivation and smoking.

In conclusion, whilst Willocks *et al.* (2012) and Lee *et al.* (2019) did not find an association between air pollution and CVD, this is likely an artefact of the study design and data. These limitations explain in part why the results are different from the earlier research by Yap *et al.* (2012) and the vast consensus of global research and data.

3.1.2 Mental health and well-being

The majority of studies reviewed focused on mental health and well-being, which is likely to be due to the recent focus in this area relative to more established links between air pollution and other health effects including CVD, respiratory and cancers. While causality cannot be assumed, the evidence clearly indicates an association between air pollution and negative effects on mental health and well-being in a wide variety of populations and settings.

3.1.3 Dementia

Multiple studies identified in this review provide consistent evidence linking air pollution, particularly $PM_{2.5}$, to an increased risk of dementia and potentially the exacerbation of Parkinson's disease symptoms.

3.1.4 Cognition

The papers identified support the harmful effects of air pollution on cognition across various populations, including adults, children, and individuals exposed prenatally. Studies consistently demonstrate associations between air pollution exposure and cognitive impairments, including attention, memory, language skills, and academic performance.

3.1.5 Neurological

This review provides further evidence of the link between air pollution and Parkinson's disease, dementia and stroke, and evidence of an association with other neurological outcomes including multiple sclerosis, emergency department visits for nervous system disorders, autism spectrum disorder and attention-deficit/hyperactivity disorder in children. These findings highlight the detrimental effects of air pollution on neurological health, both in terms of mortality and the incidence and severity of neurodevelopmental and neurological disorders.

3.1.6 Respiratory

The Dominski review provided a strong evidence base for the harmful effects of air pollution on respiratory health. The studies reviewed here are consistent with previous findings.

3.1.7 Development

The effects of prenatal exposure to air pollution on prenatal and childhood development presented in these studies is inconclusive and more comprehensive studies are needed to better understand the complex relationship.

3.1.8 Mortality

Three studies provide evidence for the association between air pollution and mortality. Bai *et al.* (2022) found a significant relationship between $PM_{2.5}$ exposure and mortality, with a substantial proportion of deaths attributable to diabetes and major cardiovascular events. The Danish study by So *et al*. (2022) revealed that long-term exposure to $PM_{2.5}$, NO_2, and BC was associated with increased mortality from various causes, while O_3 showed a generally negative association. Furthermore, So *et al*. (2023) identified significant positive associations between mortality and exposure to specific $PM_{2.5}$ elemental components. These findings highlight the adverse health effects of air pollution on mortality, in addition to the specific health outcomes discussed in this report.

3.1.9 Cancer

The association between air pollution and cancers is evidenced in the literature, however the strength of the association is not as well established as it is for other health outcomes. Furthermore, the relationship more specifically with childhood cancers has limited evidence and needs further assessment.

3.1.10 Neonatal

Recent studies have shed light on the concerning impact of air pollution, particularly $PM_{2.5}$, on neonatal health, however further evidence is needed to understand the extent of this impact and the underlying biological mechanisms.

3.1.11 Type-2 Diabetes

The Dominski review, as well as the evidence discussed, supports a significant association between air pollution, specifically $PM_{2.5}$, and the incidence and prevalence of type-2 diabetes.

3.1.12 Ocular

Only one study from the search analysed the effects of air pollution on ocular outcomes such as visual impairment and age-related eye disease and observed associations between $PM_{2.5}$ and ocular outcomes, suggesting the need for further studies to confirm these associations and explore potential mechanisms (Grant et al., 2021).

3.1.13 Primary care healthcare service use

One study analysed the effects of air pollution on short term primary and pharmaceutical care usage which highlighted the potential health effects of $PM_{2.5}$ exposure during critical developmental periods and the importance of considering sex differences in susceptibility (Ziou *et al*., 2023).

3.1.14 Contradictory evidence

This report identified two studies (Cortes *et al.* 2023; Kusters *et al.* 2022) which did not report any positive association between air pollution and the studies' health outcome. These studies do not negate the level of evidence for the negative health impacts of air pollution; however, they do highlight the need for further research using more robust methodologies and comprehensive confounding adjustments to better understand the complex relationship between air pollution and health outcomes and importantly the best way of evaluating the associations and potential causality.

4 Conclusion

This review explored the existing evidence on the health effects associated with low-level pollution in countries that have levels of ambient air pollution similar to Scotland. It also considered the inconclusive evidence from Scotland regarding the association of air pollution with cardiovascular disease, as well as the potential contributing factors to this variation.

The evidence from global studies and reviews consistently supports the association between air pollution and various health outcomes, including CVD, respiratory health, mortality, cancer, neonatal health, type-2 diabetes, ocular outcomes, primary care healthcare service use, cognition, and neurological health. The studies also highlight the association between air pollution and mental health, including self-harm, psychopathology, major depressive disorder, and cognitive impairments. Furthermore, air pollution contributes to the

development and exacerbation of dementias and is associated with neurological diseases such as Parkinson's disease, stroke, multiple sclerosis, and nervous system disorders.

While the global evidence is robust, the specific evidence regarding air pollution and health outcomes in Scotland is limited and inconclusive. When specifically considering CVD, some studies in Scottish cohorts support the global consensus, showing associations between air pollution and CVD, while others did not find significant associations, possibly due to methodological limitations and challenges in adjusting for confounding factors. Further research in the Scottish context, considering multiple pollutants and addressing data limitations, is necessary to provide more conclusive insights into the relationship between air pollution and health outcomes in Scotland.

Overall, the Dominski review, three HEI reports and recent evidence identified and discussed in this review emphasis the broad range of impacts from air pollution and the necessity to mitigate the harmful health effects of air pollution, promoting public health and well-being. As these harmful effects have been extensively evidenced at concentrations below national and international air quality standards, effective policies and interventions are necessary to reduce air pollution levels. In addition, further research is needed to better understand the underlying mechanisms behind these impacts and, explore potential associations in specific health outcomes, allowing the development of prevention and targeted interventions populations, particularly those most vulnerable.

References

(N.B. Full references list in the main report.)

Brauer, M., Brook, J.R., Christidis, T., Chu, Y., Crouse, D.L., Erickson, A., Hystad, P., Li, C., Martin, R.V., Meng, J., Pappin, J., Pinault, L.L., Tjepkema, M., van Donkelaar, A., Weichenthal, S., Burnett, R.T., 2022. Mortality–Air Pollution Associations in Low Exposure Environments (MAPLE): Phase 2.

Brunekreef, B., Strak, M., Chen, J., Andersen, Z.J., Atkinson, R., Carey, I., Cesaroni, G., Forastiere, F., Fecht, D., Gulliver, J., Hertel, O., Hoffmann, B., de Hoogh, K., Houthuijs, D., Hvidtfeldt, U., Klompmaker, J., Krog, N.H., Liu, S., Ljungman, P., Mehta, A., Renzi, M., Rodopoulou, S., Samoli, E., Schwarze, P., Sigsgaard, T., Stafoggia, M., Vienneau, D., Weinmayr, G., Wolf, K., Hoek, G., 2021. Mortality and Morbidity Effects of Long-Term Exposure to Low-Level PM2.5, BC, NO2, and O3: An Analysis of European Cohorts in the ELAPSE Project.

Cortes, T.R., I.H. Silveira, B.F.A. de Oliveira, M.L. Bell, and W.L. Junger. 'Short-Term Association between Ambient Air Pollution and Cardio-Respiratory Mortality in Rio de Janeiro, Brazil'. *PLoS ONE* 18, no. 2 February (2023). https://doi.org/10.1371/journal.pone.0281499.

Dominici, F., Zanobetti, A., Schwartz, J., Braun, D., Sabath, B., Wu, X., 2019. Assessing Adverse Health Effects of Long- Term Exposure to Low Levels of Ambient Air Pollution: Implementation of Causal Inference Methods.

Dominski, F.H., Lorenzetti Branco, J.H., Buonanno, G., Stabile, L., Gameiro da Silva, M., Andrade, A., 2021. Effects of air pollution on health: A mapping review of systematic reviews and meta-analyses. Environ. Res. 201, 111487. https://doi.org/10.1016/j.envres.2021.111487

Grant, A., Leung, G., Aubin, M.-J., Kergoat, M.-J., Li, G., Freeman, E.E., 2021. Fine Particulate Matter and Age-Related Eye Disease: The Canadian Longitudinal Study on Aging. Invest. Ophthalmol. Vis. Sci. 62, 7. https://doi.org/10.1167/iovs.62.10.7

Health Effects Institute. 2020. State of Global Air 2020. Data source: Global Burden of Disease Study 2019. IHME, 2020. https://www.stateofglobalair.org/data/#/air/table

Health Effects Institute, 2014. 14-3 Assessing Health Effects of Long-term Exposure to Low Levels of Ambient Air Pollution [WWW Document]. Health Eff. Inst. URL https://www.healtheffects.org/research/funding/rfa/14-3-assessing-health-effects-long-term-exposure-low-levels-ambient-air-pollution (accessed 4.14.23).

Kusters, M.S.W., E. Essers, R. Muetzel, A. Ambrós, H. Tiemeier, and M. Guxens. 'Air Pollution Exposure during Pregnancy and Childhood, Cognitive Function, and Emotional and Behavioral Problems in Adolescents'. Environmental Research 214 (2022). https://doi.org/10.1016/j.envres.2022.113891.

Lee, D., Robertson, C., Ramsay, C., Gillespie, C., Napier, G., 2019. Estimating the health impact of air pollution in Scotland, and the resulting benefits of reducing concentrations in city centres. Spat. Spatio-Temporal Epidemiol. 29, 85–96. https://doi.org/10.1016/j.sste.2019.02.003

So, R., Andersen, Z.J., Chen, J., Stafoggia, M., de Hoogh, K., Katsouyanni, K., Vienneau, D., Rodopoulou, S., Samoli, E., Lim, Y.-H., Jørgensen, J.T., Amini, H., Cole-Hunter, T., Mahmood Taghavi Shahri, S., Maric, M., Bergmann, M., Liu, S., Azam, S., Loft, S., Westendorp, R.G.J., Mortensen, L.H., Bauwelinck, M., Klompmaker, J.O., Atkinson, R., Janssen, N.A.H., Oftedal, B., Renzi, M., Forastiere, F., Strak, M., Thygesen, L.C., Brunekreef, B., Hoek, G., Mehta, A.J., 2022. Long-term exposure to air pollution and mortality in a Danish nationwide administrative cohort study: Beyond mortality from cardiopulmonary disease and lung cancer. Environ. Int. 164, 107241. https://doi.org/10.1016/j.envint.2022.107241

So, R., Chen, J., Stafoggia, M., de Hoogh, K., Katsouyanni, K., Vienneau, D., Samoli, E., Rodopoulou, S., Loft, S., Lim, Y.-H., Westendorp, R.G.J., Amini, H., Cole-Hunter, T., Bergmann, M., Shahri, S.M.T., Zhang, J., Maric, M., Mortensen, L.H., Bauwelinck, M., Klompmaker, J.O., Atkinson, R.W., Janssen, N.A.H., Oftedal, B., Renzi, M., Forastiere, F., Strak, M., Brunekreef, B., Hoek, G., Andersen, Z.J., 2023. Long-term exposure to elemental components of fine particulate matter and all-natural and cause-specific mortality in a Danish nationwide administrative cohort study. Environ. Res. 224, 115552. https://doi.org/10.1016/j.envres.2023.115552

Willocks, L.J., Bhaskar, A., Ramsay, C.N., Lee, D., Brewster, D.H., Fischbacher, C.M., Chalmers, J., Morris, G., Scott, E.M., 2012. Cardiovascular disease and air pollution in

Scotland: no association or insufficient data and study design? BMC Public Health 12, 227. https://doi.org/10.1186/1471-2458-12-227

Yap, Christina, Iain J. Beverland, Mathew R. Heal, Geoffrey R. Cohen, Chris Robertson, Deborah E. J. Henderson, Neil S. Ferguson, Carole L. Hart, George Morris, and Raymond M. Agius. 'Association between Long-Term Exposure to Air Pollution and Specific Causes of Mortality in Scotland'. *Occupational and Environmental Medicine* 69, no. 12 (1 December 2012): 916–24. https://doi.org/10.1136/oemed-2011-100600.

Ziou, M., Gao, C.X., Wheeler, A.J., Zosky, G.R., Stephens, N., Knibbs, L.D., Williamson, G.J., Melody, S.M., Venn, A.J., Dalton, M.F., Dharmage, S.C., Johnston, F.H., 2023. Primary and pharmaceutical care usage concurrent associations with a severe smoke episode and low ambient air pollution in early life. Sci. Total Environ. 883, 163580. https://doi.org/10.1016/j.scitotenv.2023.163580

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The Scottish Government
St Andrew's House
Edinburgh
EH1 3DG

ISBN: 978-1-83521-488-6 (web only)

Published by The Scottish Government, October 2023

Produced for The Scottish Government by APS Group Scotland, 21 Tennant Street, Edinburgh EH6 5NA
PPDAS1370354 (10/23)

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