The co-benefits of climate change mitigation strategies on cardiovascular health: a systematic review

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Summary

Background Climate change is a significant threat to global human health and a leading cause of premature death. Global warming, leading to more extreme weather (in particular extreme heat events), and air pollution has been associated with increased cardiovascular disease (CVD) morbidity and mortality. According to the Global Burden of Disease Study 2019, 62% of the deaths attributable to climate change were from CVD. Climate change mitigation is a slow, steady process, and the concept of co-benefits has arisen to promote climate action. This systematic review examines how numerous mitigation strategies, such as plant-based diets, increasing green spaces, increasing active transport, using renewable energy sources, and smoking cessation, may have the co-benefit of reducing CVD.

Methods A mixed methods systematic review with narrative synthesis was conducted on four databases, according to the PRISMA guidelines. The articles retrieved (published between 2012 and 2022) had a mitigation strategy as the exposure, and CVD related morbidity or mortality reduction as an outcome.

Findings The review found that renewable energy has a stronger association with cardiovascular co-benefits compared to emission reduction targets. Multimodal transport is more beneficial for both the climate and cardiac health than zero emission vehicles. Diet modification, such as Mediterranean and plant-based-diets, is positively associated with CVD reduction. Proximity to green spaces and reducing urbanisation may also improve cardiac health.

Interpretation This systematic review demonstrates that implementing four mitigation strategies - increasing renewable energy use, active transport, green spaces, and plant-based diets; could lead to the co-benefit of reducing CVD morbidity and mortality. Furthermore, it illustrates the importance of plant-based diets and active transport to improve cardiovascular health.

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Keywords: Cardiovascular disease; Climate change; Mitigation; Co-benefits; Mitigation strategies; Cardiac disease; Plant-based diets; Renewable energy; Active transport; Green spaces

Introduction

Climate change is one of the largest threats to the global health of humans.[1,2] The World Health Organisation (WHO) reports that environmental risk factors account for 35% of the global burden of ischaemic heart disease, which is the leading cause of global mortality.[3] Cardiovascular disease (CVD) causes significant morbidity and is the leading cause of mortality globally.[4] The environment is a significant modifiable risk factor for CVD, in particular air pollution and extreme temperatures increase CVD.[5] Energy production in the form of electricity and heat from the burning of fossil fuels is the leading source of direct greenhouse gas emissions (25%), followed closely by agriculture and land use (24%), industry (21%) and transport (14%).[6] Air pollution is a significant cause of mortality, accounting for nearly 7 million deaths worldwide, of which more than half are due to cardiovascular causes.[7] A large, global systematic review and meta-analysis found a 1 °C increase in temperature was associated with a 2.1% increase in CVD mortality and 0.5% increase in CVD morbidity; with heatwaves associated with an 11.7% increase in CVD mortality.[8]

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Research in context

Evidence before this study

Climate change induced increases in the frequency and peak of extremes in air pollution and temperature are associated with increased cardiovascular morbidity and mortality. While the current literature identified various strategies that mitigate climate change, these strategies can also have an impact on health in general. The specific area of reduced cardiovascular risk as an effect of climate change mitigation has not been explored.

Added value of this study

The adverse impacts on cardiovascular health, one of several consequences of climate change, highlights the importance of identifying and implementing climate change reduction strategies Hence, this systematic review endeavours to fill the gap in the literature by linking these two concepts with an investigation into which measures simultaneously reduce climate change and cardiovascular risk.

Implications of all the available evidence

The current evidence combined with the results of this systematic review support the development of policies and programs that incorporate these mitigation strategies to address both climate change and cardiovascular health simultaneously.

Climate change mitigation is a process of slow steady change hence, the effects of mitigation strategies are not apparent in the short term.[12] Therefore, the concept of co-benefits, a directly visualised positive impact resulting from climate change mitigation policies that may also have other benefits, has arisen to aid in the promotion of climate action.[2] Health is commonly used as a measure of the more immediate benefits of mitigation strategies. There are numerous mitigation strategies which are hypothesised to benefit cardiovascular health such as plant-based diets, increasing green spaces, increasing active transport, changing to renewable energy sources, and smoking cessation (Fig. 1).

A study in the United States showed that climate mitigation could prevent 10,000 premature deaths by 2050, which would equate to $US150 billion in value of statistical life (VSL).[13] VSL is the amount a society is willing to pay to reduce the chance of death.[13] The health co-benefits of mitigation strategies involving food and agriculture, transportation, and energy systems have been well investigated.[12] Observational studies have shown that transportation changes, such as increasing the use of active transport, can reduce carbon emissions and improve air pollution, but also have the cardiovascular benefit of increasing physical activity.[2] Furthermore, modelling studies have illustrated that plant-based diets, as opposed to meat-based diets, have less environmental impacts, including lower greenhouse gas emissions, land and water usage, while also having health benefits such as reducing the risk of colorectal cancer and CVD.[12]

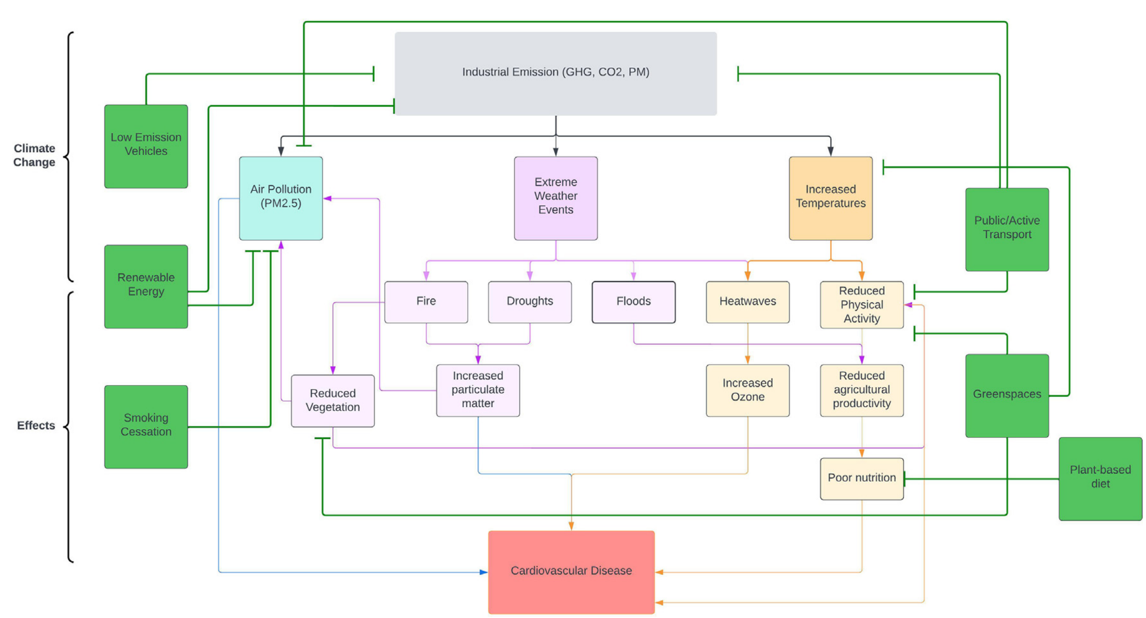

Fig. 1: Pathway of Mitigation Strategies resulting cardiovascular disease.[9–11]

Planetary health literature has progressed in the last decade to increase the discourse surrounding the impact of climate change on CVD and has recently identified that mitigation strategies have health co-benefits. However, to the best of our knowledge, there are no analytical studies which have investigated the literature to identify the co-benefits of mitigation policies which improve cardiovascular health to date. Hence, by linking CVD, climate change and mitigation strategies, this systematic review endeavours to fill this gap in the literature.

This paper aims to systematically review the current evidence of climate change mitigation measures that have cardiac benefits.

Methods

Data sources and search strategy

A comprehensive literature search of peer-reviewed studies, published between January 2012 and September 2022, was conducted using the electronic databases of Medline, Scopus, Lancet Planetary Health, and Google Scholar. The search strategy for Medline used the following search terms: "cardiovascular disease" AND "climate change" AND "mitigation" OR "adaptation" OR "sustainability" OR "reduction" or "action" OR "plant-based diets" OR "greenspaces" OR "smoking" OR "active transport" OR "renewable energy" OR "smoking cessation". These terms were adapted to suit the other databases. The search strategy was based on the SPIDER framework, a research question development tool used as an alternative to PICO used in mixed method or qualitative studies.

Sample: adults >18 years of age.
Phenomenon of Interest climate change mitigation.
Design observational cohort studies, epidemiological studies, cross sectional studies, randomised control trials, modelling studies.
Evaluation: cardiac co-benefits.
Research Method: mixed methods systematic review study.

Inclusion and exclusion criteria

- Types of Studies: original, peer reviewed journal articles were included. Reviews, reports, conference abstracts, books, policy papers, and meta-analyses were excluded.
- Population: human only articles were included. We excluded articles including children or pregnant participants as studies have shown that the environment (eg, heat and air pollution) is a significant modifiable risk factor for cardiovascular disease in particular ischaemic heart disease, the leading cause of death in the world, and this is rarely seen in children.
- Research Factors: At least one mitigation strategy was included in the exposures of interest.
- Target Outcomes: Cardiovascular disease related morbidity, mortality or hospital admissions were analysed as a co-benefit. We excluded studies which examined cerebrovascular disease or hypertension only, as we aimed to focus on mainly cardiovascular disease, which already constitute a huge public health burden, rather than have a broad focus.
- We limited articles to those written in the English language or those with English Language transcripts available.

Screening process

The results from the database were exported to Endnote and duplicate articles were removed. Two authors (PS, FA) independently screened the results for relevance through title and abstract. A third reviewer (SKN) settled disagreements of the preliminary screen. The full texts of each article were assessed against the inclusion and exclusion criteria by two authors (PS, FA) and the third author (SKN) independently screened the full text to reach a majority consensus.

Data extraction

Data were extracted by two authors (PS, FA) from the final selection of articles using a data extraction form which obtained key information including: publication date, study design, study period, study setting, population traits, sample size, industry involved, key definitions, mitigation strategies, comparator, climate benefit, outcome type, cardiovascular co-benefit, adjustments, or confounders. The data were then cross checked, and discrepancies were discussed to come to a consensus. The data extracted are shown in the Supplementary material.

Quality assessment

Critical appraisal of the selected articles was performed by two independent reviewers (PS, FA). The Newcastle Ottawa Scale was selected due to the observational study design of most of the final studies.[14] The NOS Appraisal Tool (See Supplementary material) was used to score the studies. The tool allows for a maximum of one star to be awarded for each quality criteria. These are totalled and a higher NOS score indicates higher quality. Modelling studies were appraised using a pre-made template form (See Supplementary material) based on a modelling study credibility checklist, based on the Critical Appraisal Skills Programme and Van Voorn et al. checklist, developed by Jarmul et al.[15,16]

Data synthesis

Due to clinical heterogeneity, with numerous mitigation strategies used, and the diverse CVD outcomes collected (mortality, morbidity, hospitalisation) a meta-analysis was not appropriate. We reported findings using narrative synthesis. We initially grouped the studies by outcome, which resulted in two groups (CVD mortality and CVD hospital admissions). These studies were synthesised, and harvest plots were used to illustrate the effect of the mitigation strategies on CVD outcomes.[17]

Results

The database search retrieved a total of 292 articles and a further 17 articles were identified through manual searching of references and expert advice. The duplicates were removed, and the remaining articles were screened using their title and abstract. The remaining 110 articles were screened for an examination of the full text and 13 peer-reviewed articles were selected unanimously, as shown in Fig. 2.

Table in the Supplementary material details the 13 articles which were extracted. Overall, the 13 studies analysed were predominantly modelling studies and cohort studies. There was an array of settings across both cities and countries including Australia, Canada, China, Kuala Lumpur, and New York. The studies examined different industries including transport, energy, food & agriculture, and urban planning while investigating the association between climate change mitigation and cardiovascular health co-benefits. The articles were appraised using the NOS and the adapted Jarmul et al. checklist, then their scores were converted to a percentage to unify the two scales. The quality of included articles is visually presented in Fig. 3. The quality appraisal of the articles ranged from 67% to 100% with 9 out of 13 articles having a score >80%, demonstrating a high level of reporting quality. The causes of low quality were mainly due to a lack of precision of measured effects in modelling studies as seen in the Supplementary material.

Energy

Most of the articles that addressed the utilisation of renewable energy, examined the effect of air pollution reduction, via PM 2.5 or PM 10, and examined the

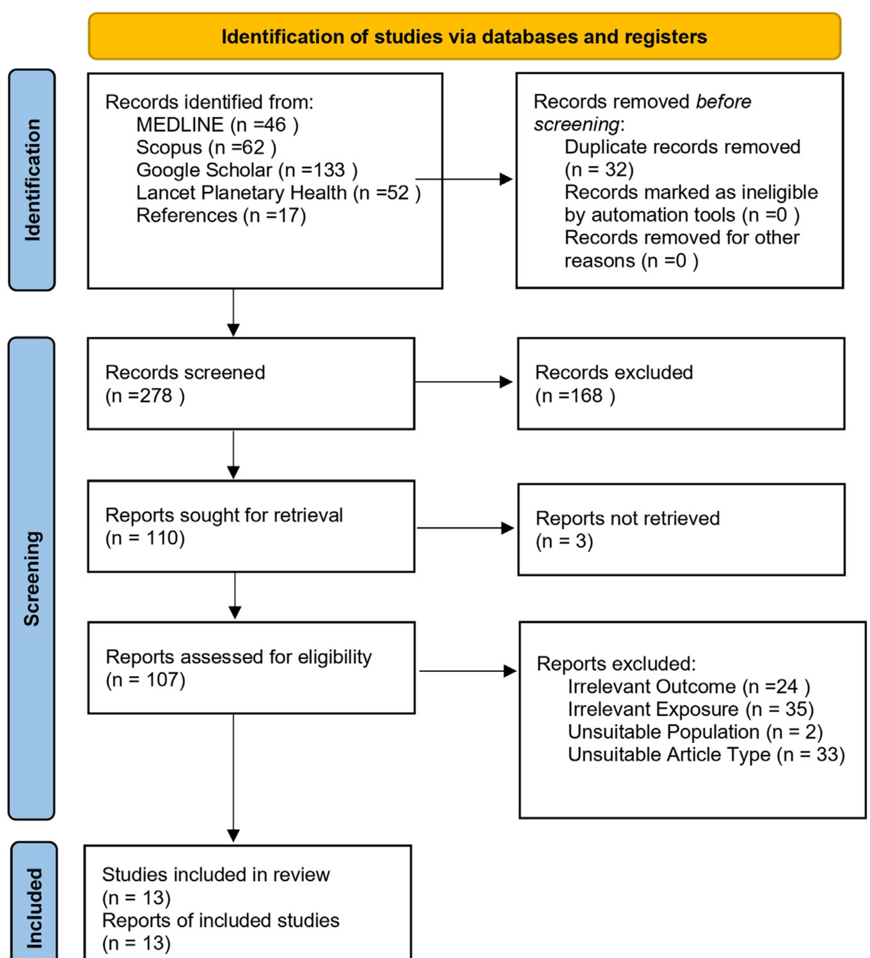

Fig. 2: PRISMA flow diagram of screening process.

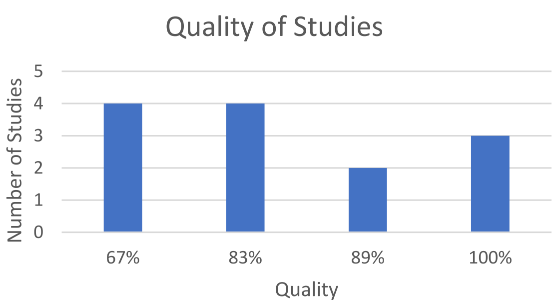

Fig. 3: Results of critical appraisal using Newcastle Ottawa Scale and adapted Jarmul et al. checklist.

co-benefit of reduction in CVD related hospital admissions. A modelling study based in New York (NYC) in 2017 projected four different mitigation scenarios. Three individual scenarios were building specific emission targets, reduction of traffic using increased active and public transport, and an increase of renewable energy to achieve a low carbon energy grid. The fourth scenario combined all three mitigation strategies to reach an 80% Green House Gas (GHG) emission reduction by 2050 (in comparison to 2005).[18] This study predicted that CVD hospitalisations would be most reduced by setting emission targets on large buildings, with an annual decrease of 20 (95% CI 0–30) hospitalisations in NYC per annum.[18] In comparison, a similar modelling study assessing the role of negative emission technology (land usage change, forestry and carbon capture, and storage) compared with renewable energy in reaching China's carbon neutrality target for 2060- has estimated a 43–59% PM 2.5 reduction by 2060.[19] The study estimates a reduction of CVD hospital admissions from 137.10 million with no change to policy, to 84.92 million incidences when using negative emission technology and 77.88 million incidences when using renewable energy.[19] Hence, renewable energy has a stronger association with cardiovascular co-benefits. The beneficial effect of renewable energy in the form of hydropower and wind projects has been linked to a reduction of 3.5 hospital admissions (related to cardiopulmonary or respiratory disease) per project in a 2012 modelling study based in China.[20]

Transport

Studies which investigated changes in transport primarily reported levels of PM 2.5 and cardiovascular morbidity. One study estimated that the increase of green transport (IGT) [active transport and public transport accounting for more than 75% of all transport used in central Beijing] reduced PM 2.5 emissions by 29% in 2050 compared to 2020, whereas more electric vehicles (MEV) reduced PM 2.5 emission by 4%.[21] Simultaneously, the study demonstrated a reduction of ischaemic heart disease (IHD) mortality by 0.41% in the IGT scenario, while the MEV scenario improved IHD morbidity by 0.14%.[21] Hence, public transport resulting in incidental physical activity is more beneficial for both climate and health in comparison to zero emission vehicles. Another modelling study predicting the effect of a new 51 km rail system in Kuala Lumpur found that the shift of 400,000 daily train passengers from car or motorbike users would reduce PM 2.5 emission by 2.2% compared to the average emission for the year of the study, while having the co-benefit of reducing cardiorespiratory deaths by 0.55%.[22] Furthermore, the study showed that the assumed 15 min of increase in physical activity for public transport commuters also reduced cardiovascular morbidity by 5% (Fig. 4).[22] The New York based modelling study revealed a reduction of 10 (95% CI: 0–30) CVD hospitalisations in NYC when more active transport and public transport was used.[18] Therefore, a beneficial association between increased active transport and cardiovascular co-benefits has been established. This appears to be mediated primarily by increased physical activity, with a lesser contribution from reduced emissions.

Plant based diets

The studies which focused on diet as a mitigation strategy predominantly compared the reduction of meat with conventional diets and calculated the GHG emissions which are associated with the production of the foods within these diets.

A modelling study, which focused on the period 2012–2030 using baseline data of the national Italian population in 2005–2006, found that CVD mortality could be reduced by 3.3% if the population followed a diet based on guidelines of the Mediterranean pyramid targets of 150 g/week beef as opposed to the baseline average daily beef consumption of 406 g/week.[23] Similarly, when reducing processed meats from 245 g/week to 50 g/week as recommended in a Mediterranean diet, 6.4% of CVD deaths would be avoided.[23] Furthermore, the shift of beef consumption to the recommended diet was predicted to reduce 8000 GgCO2eq/year (gigagrams of CO2 equivalent gases per year) while a complete dietary shift to a Mediterranean diet scenario with low carbon food substitutions result in 625.6 kgCo2eq/person/year (kilograms of carbon dioxide equivalent gases per person per year).[23] Another study examining different diets used 8 global cohort studies to project future predictions on CVD mortality and GHG emissions through lifecycle analysis of the components of each diet.[24] The study revealed a decrease of relative risk of CVD mortality ranging between 20 and 26% when comparing the conventional omnivorous diet to the alternative diets (Mediterranean, Pescetarian and Vegetarian).[24] The Mediterranean diet had the greatest benefit to CVD health with 26% relative risk reduction.[24] Furthermore, the study forecasts a 32% increase in GHG emissions due to food production using the conventional model in 2050 in contrast to GHG reductions

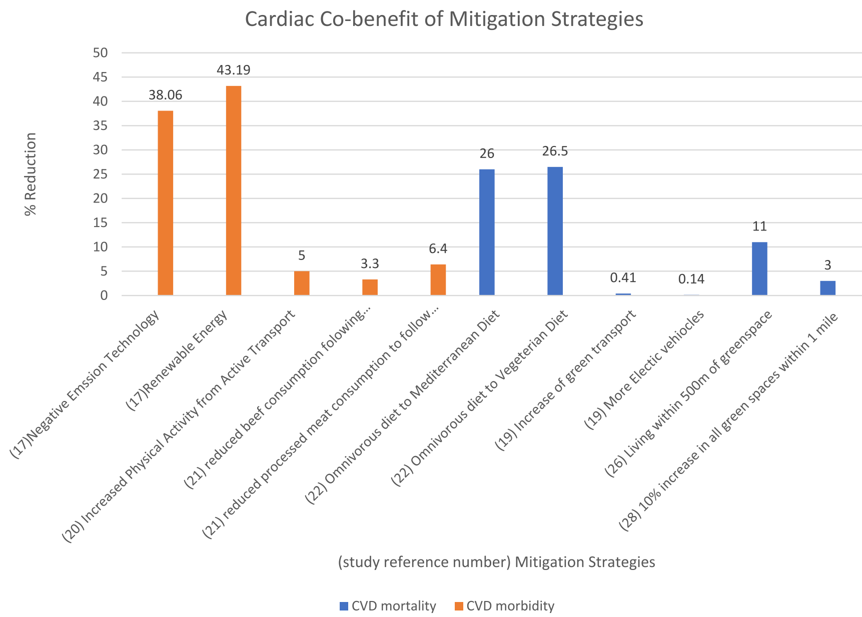

Fig. 4: Reduction of cardiovascular morbidity or mortality rates based on percentage.

of 30%, 45% and 55% based on the Mediterranean, Pescetarian and Vegetarian diets, respectively.[24] Hence, both these studies confirm the planetary co-benefit of the Mediterranean diet, which is a recognised cardioprotective diet.[25]

Multiple studies attempt to compare different sustainability focused diets and their impacts on CVD. In a cohort study of 443,991 participants from the European Perspective Investigation into Cancer and Nutrition (EPIC) study, a hazard ratio (HR) of 0.99 (95% CI: 0.93–1.07) was attributed to sustainable diets that met 13/14 of the EAT-Lancet recommendations (emitted 5 kg CO_2) and diets furthest from the planetary health diet (emitted 8.4 kg CO_2) resulted in a HR of 1.19 (1.10–1.28),[26] in comparison to a diet which met all the 14 categories of EAT-Lancet recommendations (emitting 3.6 kg CO_2). Another modelling study focused on the comparison of different scenarios such as reducing animal product consumption, nutritionally balanced diets and diets based on energy balance.[27] The study, which estimates mortality in 2030, predicts that 24–29% (average of 26.5%) of coronary heart disease related deaths would be reduced through a vegetarian diet.[27] The climate change mitigation strategy of plant-based-diets is therefore positively associated with CVD reduction.

Urban planning

Green spaces were the predominant urban planning mitigation strategy investigated. Two cohort studies, by Tamosiunas et al. and Crouse et al., compared the proximity of the population's residences to areas of greenness with their likelihood of CVD morbidity or mortality. Crouse et al. found that compared with the general population in urban Canada living greater than 500 m away from a green space, participants living within 500 m of green spaces had a 11% lower chance of mortality due to CVD with a HR of 0.890 (95% CI: 0.871–0.910).[28] Similarly, Tamosiunas et al. found that 45–72-year-olds living in a Lithuanian city (Kaunus), followed for a 10-year period, were more likely to develop CVD morbidity based on distance from greenspaces.[29] The study revealed that incidence of non-fatal CVD was greater in people living greater than 347.8 m away from a green space in comparison to the control of people living within 347.8 m from greenness with a HR of 1.66 (95% CI: 1.01–2.73).[29] Furthermore, the study illustrated that total CVD (both mortality and morbidity) was increased when a participant lived greater than 629 m from a green space in comparison to participants living within 347.8 m from a green space with a HR of 1.36 (95% CI: 1.03–1.80).[29] Hence, both these studies conclude that proximity to green spaces can improve CVD. While these studies did recognise the benefits of green spaces in mitigating air pollution and urban heat, they did not specifically measure the climate benefit of green spaces. Crouse et al. did adjust for the effects of PM 2.5, ozone and nitrogen dioxide in the current environment and found that there was an 8.9% decrease in the HR of participants living within 250 m of a green space to CVD mortality when removing these factors.[28]

A third study investigated the relationship between the green space type and housing type on CVD. Feng et al. conducted a longitudinal cohort study following urban New South Wales residents for a 10-year period using data from the 45 and Up Study.[30] This study found that a 10% increase in all green spaces within 1 mile (1.6 km) of a participant residing in houses reduced the risk of CVD mortality by 3%.[30] They found that tree top coverage was the specific greenage type that improved health the most with a reduction of all-cause mortality (HR 0.97, 95% CI 0.95–0.99), CVD mortality (HR 0.96, 95% CI 0.93–0.98) and a reduced risk of fatal and non-fatal acute myocardial infarctions by 7%, with a HR of 0.93 (95% CI 0.89–0.96).[30] In comparison, the associations of increased green space to CVD outcomes were not statistically significant in participants living in apartments.[30] This was hypothesised to be due to factors such as population density per area of greenspace, lack of quality of the spaces available and the potential that communal green spaces do not provide the cardiovascular benefits associated with activities such as gardening.[30]

Another modelling study examined the effects of improving urbanisation levels on temperature related CVD death.[31] Xing et al. projected scenarios with differing socioeconomic pathways for 2020–2099 using data collected in Beijing in 2006–2011.[31] They compared different representative concentration pathways (RCP) which would result from lowering urbanisation levels within Beijing and the effect they have on CVD related mortality.[31] In comparison to the fixed socioeconomic pathway, improvement of urbanisation levels would decrease the cardiovascular mortality rate, defined as the ratio of excess CVD mortality divided by the median population, by 1.0–4.5% in 2020–2039, 2.5–6.1% in 2050–2069, and 3.7–12.5% in 2080–2099.[31] The study also showed that RCP with higher concentrations of GHG were estimated to increase temperature, with RCP of 2.6, 4.5, 7.0, and 8.5 increasing temperatures at the rate of 0.13, 0.28, 0.43, and 0.59 °C every 10 years.[31]

Hence, the effects of improved urban planning through both reduction of urbanisation and increasing incorporation of green spaces in our communities are climate change mitigation measures which improve cardiac health.

Discussion

To the best of our knowledge, this is the first systematic review that has summarised the information known on the cardiovascular co-benefits of mitigation strategies. The 12 studies reported a positive association between the strategy investigated and improvement of cardiovascular health, although the strength of the association varied. The main knowledge base has been explored in the areas of energy, transportation, dietary changes, and urban planning.

We found that renewable energy has a stronger association with cardiovascular co-benefits in comparison to emission reduction targets. However, there was still a strong positive effect of energy-based mitigation strategies, regardless of the method, in comparison to no action. The analysis of the transportation sector revealed that multimodal transport, resulting in incidental physical activity, is more beneficial for both climate and health in comparison to zero emission vehicles. Increased active transport has been established to have a small but beneficial association with cardiovascular co-benefits, which was mainly driven by increased physical activity, with reduced emissions adding a smaller effect. Analysis of the food sector found that switching to more plant-based and low emission diets had a positive effect on reduction of CVD. We found that sustainability focused diets are cardioprotective, while cardioprotective diets also reduce carbon emissions; however, the size of the effect of each type of diet on CVD was inconsistent between studies. Furthermore, our systematic review revealed that proximity to green spaces reduces CVD with the greatest benefit found in increased tree canopy coverage. Furthermore, a reduction of urbanisation of our communities was predicted to improve cardiac health.

Our systematic review did not include studies which explored policies already implemented to mitigate climate change. These studies did not have CVD as their main outcome of interest, hence were removed due to the strict exclusion criteria. An example study which may encourage climate action is one that demonstrated that adding GHG taxes on food items based on their CO_2 emissions could reduce a significant number of deaths annually.[32,33] Furthermore, increased active transportation target policies in Copenhagen (35% cycling) and Paris (50% walking) decreased all-cause mortality and CO_2 emissions.[32,34]

While we initially set out to explore the benefit of tobacco smoking cessation on climate and cardiovascular health, we found a lack of studies which met our criteria. The studies were mainly excluded due to lack of primary studies investigating this relationship, or a lack of contemporary research that fit within our time frame of the last 10 years. However, we do acknowledge the significance of cigarette smoking as a predisposition for ischaemic heart disease.[35] Environmental tobacco smoke produces fine particulate matter (PM), that contributes to air pollution and has been associated with increased CVD mortality in those exposed to it.[36] The environmental impact of smoking involves not only consumption but also has a significant impact during the process of tobacco growing, production and distribution of cigarettes, and post consumption waste.[37] Hence, smoking cessation reduces individual risk of CVD, but also contributes to the mitigation of climate change. This is an area which would benefit from further research to fully quantify the extent of this correlation.

Further gaps in the literature include the lack of data from developing countries. While most of the studies included were based in China or Europe, developing countries were poorly represented in the literature. These developing countries contribute the least to climate change, but will be the most affected by the results of the changing climate such as high air pollution, natural disasters, and malnutrition.[38] Hence, the investigation of mitigation strategies in these areas, which could have an ancillary benefit on cardiovascular health, is essential to reduce the impact of climate change in these areas.

Another challenge faced by the field of planetary health is the lack of observational studies. Multiple subtopics such as energy and transportation were limited to modelling studies, due to the lag before benefits are made apparent. Few cohort studies and other observational studies have been published in this area, perhaps due to the length of the follow-up period required to obtain meaningful results. However, the alternative modelling studies are also flawed due to their lack of ability to anticipate unexpected events and rapid shifts in trends. Due to the uncertain nature of the results of modelling studies, and their reliance on data which may change in the future, it is important to note the limitation of this systematic review in drawing comparisons between multiple modelling studies. The only comparable studies are the urban greenness-based studies.[28,29] It is indicated that proximity to green spaces is the best measure in comparison to increasing greenspaces (Fig. 5).

This study is the first to fill the gap in the literature by linking the concepts of mitigation of climate change with the cardiovascular co-benefits that are concurrently present. This study will help inform policy makers and encourage them to implement strategies that protect from climate change, with the additional incentive of improving one of the most common forms of disease in our populations, cardiovascular disease. As this systematic review has summarised multiple studies, it provides information in a synthesised manner which will allow for effective decision-making. Strengths of this study include the use of multiple independent reviewers who screened through the texts and the defined inclusion and exclusion criteria used to remove chances of selection bias.

However, this study does have numerous limitations, firstly the restriction of the English language and exclusion of children-based studies limits the populations which were investigated. Studies which may have explored more developing countries were excluded, hence providing a view restricted to developed countries. Our initial search did result in 278 articles to be screened, however, as we aimed to discuss articles which examined a very specific topic, we were unable to include many articles. For example, an article regarding air pollution co-benefits of carbon pricing by Xie et al., would be excluded using our criteria due to cardiovascular morbidity and mortality or hospital admissions due to CVD not having been the main outcome of the study.[39] While these articles do discuss co-benefits of climate mitigation strategies, they do not discuss CVD particularly, which is the research gap that initiated this study Furthermore, the restriction of study designs to include primary articles, eliminated important documents such as reports, policy papers and books from the WHO, the United Nations, and multiple national

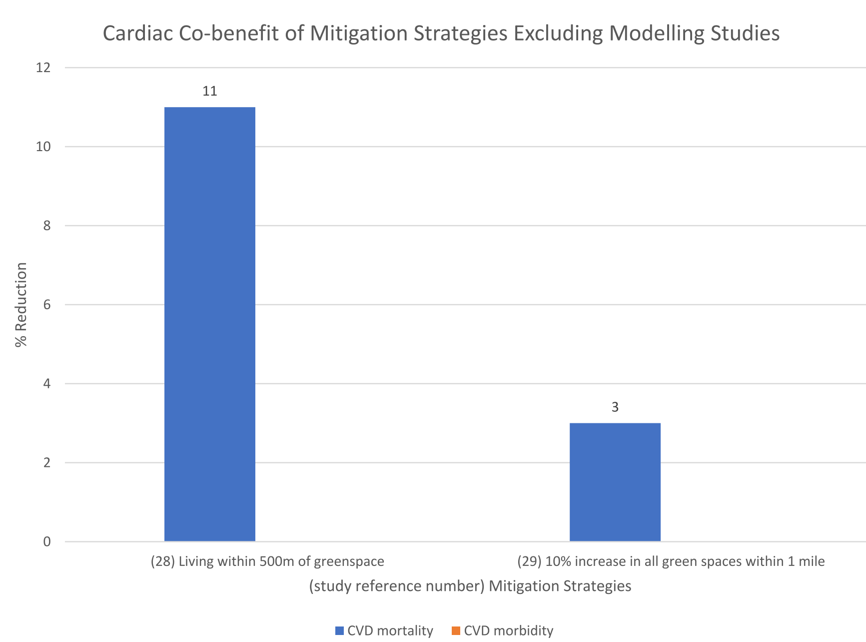

Fig. 5: Reduction of cardiovascular morbidity or mortality rates based on percentage excluding modelling studies.

policies. Furthermore, the literature search may not have retrieved all the available studies due to the restriction of only using four available databases, and publication bias could not be removed. Publication bias may have reduced the publication of studies which found no effect, causing an overstatement of the effect of climate mitigation strategies in the published literature.

Conclusion

This paper synthesised and summarised the available evidence regarding the effects of multiple climate change mitigation strategies in reducing CVD. The results suggest that there are cardiovascular co-benefits in most of the mitigation strategies we have identified, including change to renewable energy, increased active transport, plant-based diets, increasing greenspaces, and reducing urbanisation. Hence, this systematic review raises awareness within the scientific community and further to the public, of mitigation strategies which can be implemented at an individual and community level to city, national and global level. This review may inform policy makers in deciding the most resource-effective mitigation strategies in the battle against climate change.

Contributors

F.F. conceived the original idea. P.S. and F.F. detailed the research questions. F.I., S.K. and P.S. executed the literature search, screening, and extraction of articles. Data extraction and analysis was done by P.S. and F.I. with the support of T.B.P. Raw data was accessed by P.S., S.K.N. and F.I., data was verified by T.B.P. P.S. wrote the manuscript with support from S.K., T.B.P., F.I. and F.F. F.F. and T.B.P. helped supervise the project. The final decision to publish was made by F.F. and P.S.

Data sharing statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

Declaration of interests

No conflicts of interests to declare.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2024.101098.

References

1 Kotcher J, Maibach E, Miller J, et al. Views of health professionals on climate change and health: a multinational survey study. *Lancet Planet Health*. 2021;5(5):e316–e323.
2 Shaw C, Hales S, Howden-Chapman P, Edwards R. Health co-benefits of climate change mitigation policies in the transport sector. *Nat Clim Change*. 2014;4(6):427–433.
3 Prüss-Üstün A, Wolf J, Corvalán C, Bos R, Neira M. *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks*. World Health Organization; 2016.
4 Harikrishnan S, Jeemon P, Mini G, Thankappan K, Sylaja P, GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980-2017: a systematic analysis for the global burden of disease study 2017. *Lancet*. 2018;392(10159):1736–1788.
5 Vaduganathan M, Mensah GA, Turco JV, Fuster V, Roth GA. *The global burden of cardiovascular diseases and risk: a compass for future health*. Washington, DC: American College of Cardiology Foundation; 2022:2361–2371.
6 Pachauri RK, Gomez-Echeverri L, Riahi K. *Synthesis report*. 2014.
7 Al-Kindi SG, Brook RD, Biswal S, Rajagopalan S. Environmental determinants of cardiovascular disease: lessons learned from air pollution. *Nat Rev Cardiol*. 2020;17(10):656–672.
8 Liu J, Varghese BM, Hansen A, et al. Heat exposure and cardiovascular health outcomes: a systematic review and meta-analysis. *Lancet Planet Health*. 2022;6(6):e484–e495.
9 Watts N, Adger WN, Ayeb-Karlsson S, et al. The Lancet Countdown: tracking progress on health and climate change. *Lancet*. 2017;389(10074):1151–1164.
10 Khraishah H, Alahmad B, Ostergard RL Jr, et al. Climate change and cardiovascular disease: implications for global health. *Nat Rev Cardiol*. 2022;19(12):798–812.
11 Smith KR, Chafe Z, Woodward A, et al. *Human health: impacts, adaptation, and co-benefits. Climate change 2014 impacts, adaptation and vulnerability: part A: global and sectoral aspects*. 2015:709–754.
12 Carlton EJ, Khan AS, Remais JV. *Health co-benefits of climate mitigation strategies. Global climate change and human health: from science to practice*. 2021:343.
13 Xie Y, Dai H, Xu X, et al. Co-benefits of climate mitigation on air quality and human health in Asian countries. *Environ Int*. 2018;119:309–318.
14 Peterson J, Welch V, Losos M, Tugwell P. *The Newcastle-Ottawa scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses*. vol. 22011;vol. 2. Ottawa: Ottawa Hospital Research Institute; 2011;2(1):1–12.
15 Van Voorn G, Verburg R, Kunseler E-M, Vader J, Janssen PH. A checklist for model credibility, salience, and legitimacy to improve information transfer in environmental policy assessments. *Environ Model Softw*. 2016;83:224–236.
16 Jarmul S, Liew Z, Haines A, Scheelbeek P. Climate change mitigation in food systems: the environmental and health impacts of shifting towards sustainable diets, a systematic review protocol. *Wellcome Open Res*. 2019;4:205.
17 Ogilvie D, Fayter D, Petticrew M, et al. The harvest plot: a method for synthesising evidence about the differential effects of interventions. *BMC Med Res Methodol*. 2008;8:1–7.
18 Johnson S, Haney J, Cairone L, Huskey C, Kheirbek I. Assessing air quality and public health benefits of New York City's climate action plans. *Environ Sci Technol*. 2020;54(16):9804–9813.
19 Zhang S, An K, Li J, et al. Incorporating health co-benefits into technology pathways to achieve China's 2060 carbon neutrality goal: a modelling study. *Lancet Planet Health*. 2021;5(11):e808–e817.
20 Partridge I, Gamkhar S. A methodology for estimating health benefits of electricity generation using renewable technologies. *Environ Int*. 2012;39(1):103–110.
21 Lu C, Adger WN, Morrissey K, et al. Scenarios of demographic distributional aspects of health co-benefits from decarbonising urban transport. *Lancet Planet Health*. 2022;6(6):e461–e474.
22 Kwan SC, Tainio M, Woodcock J, Hashim JH. Health co-benefits in mortality avoidance from implementation of the mass rapid transit (MRT) system in Kuala Lumpur, Malaysia. *Rev Environ Health*. 2016;31(1):179–183.
23 Farchi S, De Sario M, Lapucci E, Davoli M, Michelozzi P. Meat consumption reduction in Italian regions: health co-benefits and decreases in GHG emissions. *PLoS One*. 2017;12(8):e0182960.
24 Tilman D, Clark M. Global diets link environmental sustainability and human health. *Nature*. 2014;515(7528):518–522.
25 Battino M, Forbes-Hernández TY, Gasparrini M, et al. Relevance of functional foods in the Mediterranean diet: the role of olive oil, berries and honey in the prevention of cancer and cardiovascular diseases. *Crit Rev Food Sci Nutr*. 2019;59(6):893–920.
26 Laine JE, Huybrechts I, Gunter MJ, et al. Co-benefits from sustainable dietary shifts for population and environmental health: an assessment from a large European cohort study. *Lancet Planet Health*. 2021;5(11):e786–e796.
27 Springmann M, Wiebe K, Mason-D'Croz D, Sulser TB, Rayner M, Scarborough P. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet Health*. 2018;2(10):e451–e461.
28 Crouse DL, Pinault L, Balram A, et al. Urban greenness and mortality in Canada's largest cities: a national cohort study. *Lancet Planet Health*. 2017;1(7):e289–e297.

29 Tamosiunas A, Grazuleviciene R, Luksiene D, et al. Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. *Environ Health*. 2014;13:1–11.
30 Feng X, Navakatikyan MA, Toms R, Astell-Burt T. Leafier communities, healthier hearts: an Australian cohort study of 104,725 adults tracking cardiovascular events and mortality across 10 years of linked health data. *Heart Lung Circ*. 2023;32(1):105–113.
31 Xing Q, Sun Z, Tao Y, et al. Projections of future temperature-related cardiovascular mortality under climate change, urbanization and population aging in Beijing, China. *Environ Int*. 2022;163:107231.
32 Hadley MB, Vedanthan R, Ebi KL, Fuster V. Climate cardiology. *BMJ Glob Health*. 2022;7(6):e008860.
33 Springmann M, Mason-D'Croz D, Robinson S, et al. Mitigation potential and global health impacts from emissions pricing of food commodities. *Nat Clim Change*. 2017;7(1):69–74.
34 Rojas-Rueda D, De Nazelle A, Andersen ZJ, et al. Health impacts of active transportation in Europe. *PLoS One*. 2016;11(3):e0149990.
35 Barnett E, Anderson T, Blosnich J, Halverson J, Novak J. Promoting cardiovascular health: from individual goals to social environmental change. *Am J Prev Med*. 2005;29(5):107–112.
36 Invernizzi G, Ruprecht A, Mazza R, et al. Particulate matter from tobacco versus diesel car exhaust: an educational perspective. *Tob Control*. 2004;13(3):219–221.
37 Novotny TE, Bialous SA, Burt L, et al. The environmental and health impacts of tobacco agriculture, cigarette manufacture and consumption. *Bull World Health Organ*. 2015;93:877–880.
38 Gao J, Kovats S, Vardoulakis S, et al. Public health co-benefits of greenhouse gas emissions reduction: a systematic review. *Sci Total Environ*. 2018;627:388–402.
39 Li M, Zhang D, Li C-T, Mulvaney KM, Selin NE, Karplus VJ. Air quality co-benefits of carbon pricing in China. *Nat Clim Change*. 2018;8(5):398–403.