Protecting Europe's hearts in a changing climate: Addressing cardiovascular health impacts of air pollution and temperature changes

Funded by the European Union
This project has received funding from the European Union under grant agreement nº 101057739.

climate-health cluster

SUMMARY

Cardiovascular diseases (CVDs) are a leading cause of death in the EU. Climate change exacerbates CVD risks through rising temperatures and air pollution, contributing to a significant health burden. While some EU initiatives address CVD prevention, it is crucial to develop policies based on evidence about the environmental CVD risks related to climate change. This policy brief draws on a recent report from the EU climate-health research project TRIGGER to summarize the evidence on the adverse effects of air pollution and temperature changes on CVDs in Europe. Special attention is given to vulnerable groups and socio-economic risk factors. We recommend a better integration of climate-health objectives into EU policies, implementation of a range of measures to reduce environmental CVD risks, and ensuring equitable health outcomes.

KEY RECOMMENDATIONS

1. Better address climate-related cardiovascular health challenges in EU policies
2. Strengthen air quality regulations and health action planning for heat and cold
3. Expand early warning systems for air pollution and climate hazards
4. Ensure climate-resilient health infrastructure in urban planning and design
5. Support vulnerable groups
6. Promote research on cardiovascular health risks of climate change
7. Raise awareness and capacity building

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INTRODUCTION

The burden of cardiovascular diseases in Europe: prevention is key

Cardiovascular diseases (CVDs) are diseases that affect the heart or blood vessels (veins and arteries), including heart disease and stroke. CVDs represent a significant health burden across the EU. In 2021, they accounted for 1.71 million deaths[1] – which is 32.4% of all recorded fatalities – and an estimated economic cost of €282 billion, including 55% healthcare costs, 28% informal care costs, and 17% of costs due to productivity losses.[2] Although improved screening, treatment and prevention have reduced CVD-related disability and deaths in most EU countries, CVDs **remain the leading cause of death in Europe**.[1]

According to the **World Heart Federation**, **80% of CVDs are preventable**. Crucial risk factors of CVDs that can be influenced are lifestyle habits: an unhealthy diet, physical inactivity, tobacco use, excessive alcohol use, stress and poor sleep. These lifestyle behaviours can contribute to raised blood pressure and cholesterol levels, overweight and diabetes, which are clinical risk factors of CVDs.[3] On top of these lifestyle factors, there is increasing attention to environmental risk factors.[3,4]

Climate change: a growing driver of CVDs

Climate change is emerging as a significant driver of cardiovascular issues. Global warming has led to record-breaking heat and temperature changes, increasing deaths across Europe, including from CVDs.[3] Climate change also exacerbates air pollution, which accounts for 7% of CVD-related deaths in Europe (i.e., EU, Iceland, Switzerland and Norway).[3] In total, **environmental factors account for over 18% of preventable CVD-related deaths in Europe**, according to the European Environmental Agency.[3] The environmental burden of preventable CVD deaths is especially high in **Eastern and South-eastern Europe.**[5] These regions are home to many of Europe's most polluted cities, where coal is still used in industry, outdated power plants, and residential heating.[6] Heat-related CVD deaths are also more prevalent in Eastern Europe and Mediterranean climate zones.[7,8]

Current EU efforts: the need for action on environmental risks

Although the EU has several initiatives targeting CVDs, such as the **Healthier Together Initiative** and the **EU4Health Programme 2021-2017**, **environmental risks tied to climate change remain largely unaddressed.**[3] Climate-related policies often overlook the connection between climate change and cardiovascular health.[4] To effectively reduce the burden of CVDs, it is crucial to address environmental risk factors, as they are largely preventable and can be mitigated through targeted policies that benefit entire populations.[3] Policy intervention is particularly important given the limited ability of individuals to protect themselves against environmental CVD risks and the increased vulnerability of Europe due to its aging and urbanizing population.[3,4] To ensure **equitable health outcomes,** policies should pay special attention to vulnerable groups and socioeconomic risk factors of CVDs.[4] The **EU Horizon Project TRIGGER** – a member of the European **Climate-Health Cluster** – aims to support evidence-based policymaking on climate-related CVD risks.

Focus of this policy brief

This policy brief summarizes current evidence on the adverse effects of two major climate-related environmental exposures on cardiovascular health in Europe – **air pollution** and **temperature changes** – building on a review of observational studies.[4] Special attention is given to the effects on **vulnerable groups** and the role of socio-economic factors. The **recommendations** derived aim to contribute to the development of comprehensive climate-health policies.

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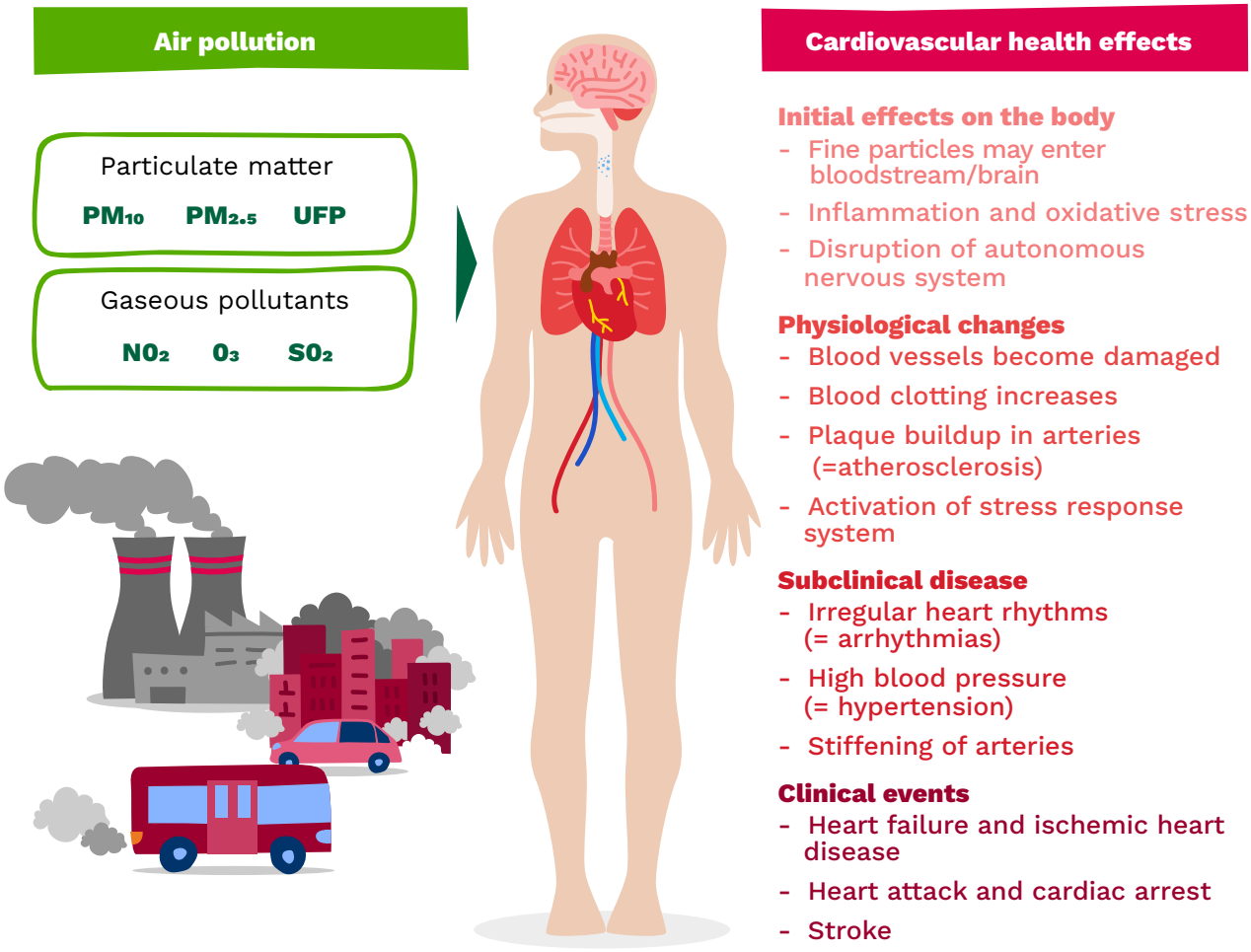
AIR POLLUTION AND CARDIOVASCULAR HEALTH

Air pollution refers to chemical, physical, or biological contaminants in the air that harm people and the environment. Air pollution and climate change are closely interconnected, primarily because air pollution and greenhouse gases share many of the same sources.[9] These include the combustion of fossil fuels and biomass (for heating, power generation, transportation and industrial processes), as well as animal agriculture, which emits ammonia-forming particulate matter pollution and greenhouse gases such as methane.[9] Some air pollutants are also potent greenhouse gases, such as black carbon smoke and ground-level ozone.[9] Rising temperatures, in turn, can worsen air pollution, for example by increasing the formation of ground-level ozone and the risk of wildfires.[10]

Impact of air pollution on cardiovascular health

Air pollution is a **major risk factor for CVDs (Figure 1)**. When inhaled, air pollutants can trigger inflammation and oxidative stress in the body, disrupt the autonomic nervous system and activate the stress response system.[11] However, the effects on cardiovascular health typically build up gradually over the long term, contributing to increased blood pressure, irregular heart rhythms and stiffening of the arteries. This, in turn, can increase the risk of clinical CVDs, including ischemic heart disease, cardiac arrest, heart failure, heart attack, stroke and premature death. The effect of air pollution on cardiovascular health outcomes ultimately depends on the dose and duration of exposure, an individual's health status or risk factors (e.g., age, pre-existing conditions), and the type of air pollutant.[11]

Figure 1 – How air pollution affects cardiovascular health (based on Bont et al., 2022)[11]



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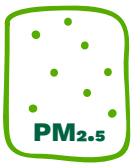
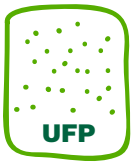
Types of air pollutants and their impacts on cardiovascular health

Air pollutants with strongest evidence for public health concern include particulate matter (PM_{10}, $PM_{2.5}$, ultrafine particles or UFP) and gaseous pollutants (e.g., NO_2, O_3, SO_2).[4,12] These pollutants stem from various sources and are associated with both short- and long-term cardiovascular risks (**Table 1**).[4,9–13]

Table 1 – Sources of major pollutants and short- and long-term cardiovascular risks[4,9]

Particulate matter (PM)	Sources	Short-term risks (minutes, days)	Long-term risks (months, years)
	- Wind-blown dust - Traffic, mining - Agriculture (ammonia) - Pollen, sea spray - $PM_{2.5}$ and UFP sources	- High blood pressure - Irregular heart rhythm - Heart attack/failure - Cardiac arrest - Stroke	- Arterial stiffness - Ischemic heart disease - Heart attack [11] - Stroke
	- Fossil fuel combustion: traffic, industry, power generation - Chemical reactions in air - Black carbon from incomplete combustion of biomass from wildfires or burning wood, coal or fuel - Indoors: heating	- High blood pressure - Irregular heart rhythm - Cardiac arrest - Heart attack/failure - Stroke - Cardiovascular death	- Arterial stiffness - Ischemic heart disease - Heart attack - Stroke
		- High blood pressure - Angina problems - Heart attack	- Heart attack - Stroke
Gaseous pollutants	**Sources**	**Short-term risks**	**Long-term risks**
	- Fossil fuel combustion: heating, traffic, industry, power generation - Indoors: fire places, gas stoves, ovens, furnaces	- Irregular heart rhythm - Heart attack - Cardiovascular death - Stroke [11]	- Arterial stiffness - Ischemic heart disease - Heart attack - Stroke [10]
	- Ground-level ozone in smog is formed by sunlight that interacts with NO_x, CO and volatile organic compounds (VOCs) from traffic and industry	- Cardiac arrest [13] - Cardiovascular death	- Cardiovascular death
	- Fossil fuel combustion: heating, industry, power generation - Disinfectants, refrigerants, reducing agents, bleach, food preservatives	- Heart attack/failure [10]	- Cardiovascular death

Note. Cardiovascular risks mentioned are based on available evidence and not conclusive.

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- **Particulate matter (PM)** refers to dust particles classified by size, with PM_{10} referring to particles with an aerodynamic diameter of ≤10 µm, $PM_{2.5}$ to fine particles of ≤2.5 µm, and $PM_{0.1}$ to ultrafine particles (UFP) of ≤0.1 µm.[12] **Finer particles tend to be more harmful** as they can penetrate deeper into the lungs, enter the bloodstream and reach the heart and other organs.[11] Although the number of deaths in the EU due to **$PM_{2.5}$** pollution has fallen substantially in recent decades (41% between 2005 and 2021), it **remains the deadliest pollutant.** In 2022, at least 239,000 deaths in the EU were attributable to $PM_{2.5}$ pollution above the WHO guideline level of 5 µg/m³. Most of these deaths were from ischemic heart disease and stroke.[3,14] Unlike $PM_{2.5}$ and PM_{10}, UFP are not regulated within the EU and available evidence on their health effects is more limited.

- **Nitrogen dioxide (NO_2)** is a reddish-brown gaseous pollutant with a pungent odour.[12] In 2022, NO_2 pollution above the WHO guideline level of 10 µg/m³ was associated with at least 48,000 deaths in the EU, mainly from diabetes mellitus (a risk factor of CVDs) and stroke.[3] NO_2 plays an important role in forming PM pollution and ground-level ozone (O_3), a major smog component.

- **Ground-level or tropospheric ozone (O_3),** as opposed to stratospheric ozone in the upper atmosphere, is a harmful pollutant. Both short- and long-term exposure to ground-level ozone have been shown to increase the risk of cardiovascular death, although death from respiratory illnesses, such as chronic obstructive pulmonary disease, remains a higher risk.[15]

- **Sulphur dioxide (SO_2)** can also have adverse cardiovascular effects (**Table 1**).

TEMPERATURE AND CARDIOVASCULAR HEALTH

Changes in atmospheric temperatures, both hot and cold, make it more difficult for the body to maintain its normal temperature around 37°C and can adversely affect cardiovascular health (Figure 2). Each European region has a specific temperature range where the daily deaths are lowest. Deviations from this optimal temperature increase mortality, following a U-, J- or V-shaped curve. Colder regions have lower optimal temperatures than warmer regions. While extreme temperatures are usually more deadly, moderate deviations from the optimum result in more deaths overall because of their higher frequency, with moderate cold accounting for most of these deaths. Cardiovascular health impacts of heat and cold depend on the timing, intensity and duration of exposure, as well as the population's level of adaptation to temperature changes.

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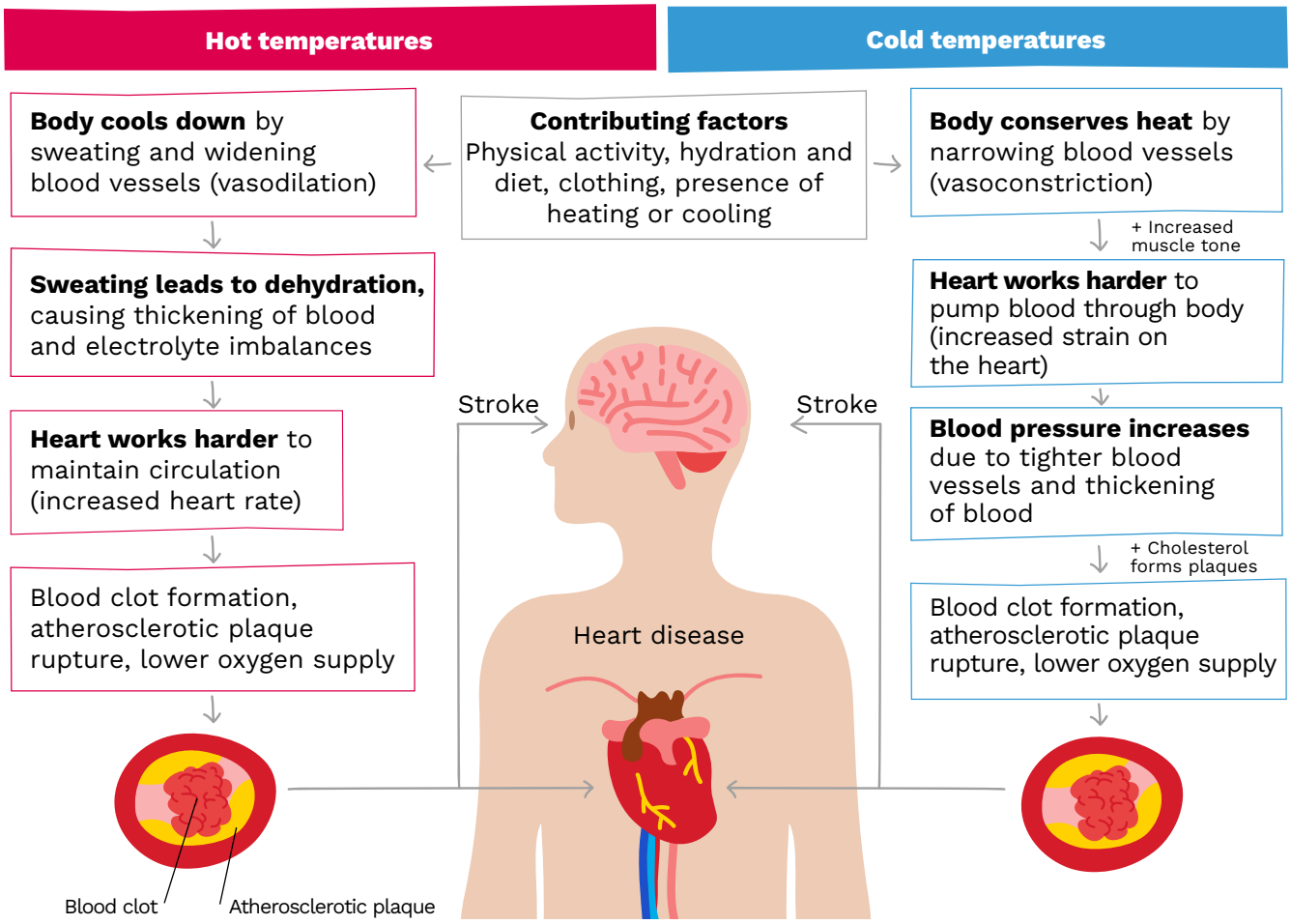
Figure 2 – Effect of hot and cold temperatures on cardiovascular health (by Khraishah et al., 2022)[10]



Note. Especially people with pre-existing CVD are susceptible to clinical events.

Impact of heat on cardiovascular health

- **Higher temperatures lead to more health care visits and cardiovascular deaths.**
  - For every 1°C rise in temperature there is an associated 2.1% increase of cardiovascular deaths (mostly due to stroke and ischemic heart disease) and 2.6% increase of health care visits due to irregular heart beating (arrhythmias) and cardiac arrest.[7]
  - Cardiovascular clinical effects of extreme heat often take place with a time lag of 2-3 days.[10] Heart failure is the most common cause of death when exposed to extreme heat.[16]

- **Heatwaves are particularly deadly.**
  - Heatwaves – prolonged periods of high temperature – increase the risk of cardiovascular death by 11.7%, with heatwave intensity and duration further increasing the risk.[7]
  - Early summer heatwaves are particularly problematic, possibly because people are less prepared or because of the so-called harvesting effect, where the frail population is at higher risk of dying when temperatures change.[17]

- **Hot nights are a significant risk.**
  - Poor sleep, dehydration and blood circulation issues increase the risk of stroke.[10]
  - Night-time temperatures are rising due to climate change.[18]

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Impact of cold on cardiovascular health

- **Cold weather causes more cardiovascular deaths than hot weather.**
  - In Europe, 17.3% of all deaths are related to cold, 0.79% to heat.[8] Most cold-related cardiovascular deaths occur in Eastern Europe.[8]
  - Cardiovascular clinical effects of extreme cold often take place with a time lag of 2 weeks or more.[10] Heart failure is the most common cause of death related to extreme cold.[16]
  - More strokes, heart failures and heart attacks occur with rapid changes in daily temperature, relative humidity and atmospheric pressure.[19,20]
- **Cold waves are more deadly.**
  - Cold waves – prolonged periods of cold – increase CVD hospitalizations, out-of-hospital cardiac arrests and deaths.[19]
  - The risk of these deaths increases when the cold season starts early and lasts longer, and decreases when cardioprotective medications are used.[21]
- **Cold air, wind and air pollution form a dangerous mix.**
  - Strong winds during cold days make it harder for the body to stay warm ("wind chills").[4]
  - During winter months, a layer of dense cold air in the atmosphere may prevent air circulation and trap air pollution near the cold surface. A combination of cold and NO^2 pollution has been shown to increase CVD hospitalizations.[4,10]

INTERPLAY BETWEEN RISING TEMPERATURES AND AIR POLLUTION UNDER CLIMATE CHANGE

Anthropogenic climate change is estimated to have caused 37% of heat-related deaths in the warm season in recent decades.[22] While heat-related deaths are projected to further increase, it is not clear whether cold-related deaths will decrease at the same rate in Europe. Rising temperatures and air pollution may interact under climate change to exacerbate CVDs:

Climate change increases the frequency and severity of heatwaves. During these events, especially in humid conditions, the body's ability to regulate internal temperature through sweating is reduced, making it harder for the body to cool down and placing strain on the cardiovascular system.[4,10,23]

Climate change can worsen air pollution by reducing air clearance. Disruptions in wind circulation (e.g., reduced wind speed, vertical mixing) can impair the dilution and removal of air pollutants.[24] Higher temperatures, regionally or temporarily reduced precipitation, and prolonged droughts can also cause air pollutants to accumulate.[10,24]

Climate penalty refers to the formation of secondary pollutants due to rising temperatures and altered weather conditions.[24] For example, solar radiation during hot, dry and windless conditions promotes the formation of ground-level ozone, increasing CVD risks.[10,23] A similar "climate penalty" has been observed for $PM_{2.5}$, although the relation is less straightforward due to the diversity of particle types.[10,24]

Dust storms are expected to become more frequent as climate change causes drought and desertification. Dust storms exposes people to PM pollution and has been associated with increased CVD hospitalizations and deaths, particularly among vulnerable populations.[24]

Wildfires are another growing concern, with climate change increasing their frequency and severity. Wildfire smoke contains toxic air pollutants, including PM, that contribute to the burden of cardiovascular disease and mortality.[10,24]

Extreme weather events can also disrupt healthcare services, making it harder for patients with cardiovascular conditions to access medical care.[10]

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VULNERABLE GROUPS

Some groups are at higher risk of CVDs due to air pollution and sub-optimal temperatures:

Children's lungs and airways are still developing, and they are more exposed to pollutants because of their lower height. Their bodies also have less effective temperature regulation, making them more vulnerable to heat and cold. Cold temperatures can put extra strain on the heart, especially in children with pre-existing heart defects or asthma.[4]

Older people face age-related declines in temperature regulation, cardiovascular capacity and resilience to air pollution.[7,11] Pre-existing cardiovascular health problems, such as high blood pressure or ischemic heart disease, are also more common and increase their vulnerability.[7]

Although CVD is more common in men[25], **women** are generally more vulnerable to CVD caused by environmental stressors. Women tend to have smaller lungs and airways, making them more susceptible to air pollution.[4] Women also have a reduced ability to sweat, making it more difficult to cool themselves in hot weather.[4] During heatwaves, women have a higher risk of CVD-related death.[7,23] In addition, diagnosis of CVD in women is often more difficult.[26]

Pregnant women face altered thermoregulation during pregnancy. Heat stress can cause dehydration and reduce blood flow to the uterus and placenta, which both reduce oxygen and nutrient supply to the baby. This increases the risk of preterm births, low birth weight, or stillbirth. Cold stress can reduce blood flow to the placenta, increasing the risk of pre-eclampsia and restricted foetal growth.

Outdoor workers are directly exposed to heat, cold and air pollution.[4,10] Hot and cold temperatures push the heart to work harder, especially during physical labour.[27] Prolonged exposure to cold also increases the risk of hypothermia, which can contribute to cardiovascular issues.

People with disabilities are more likely affected by extreme temperatures and face higher risks of CVDs and post-stroke complications from prolonged exposure to air pollution. People with more severe disabilities are typically less able to cope with disruptions in healthcare access and with extreme weather events, such as finding shelter or staying hydrated during heatwaves.[28]

Pre-existing cardiovascular conditions increase vulnerability to clinical events from air pollution and temperature changes. Some medications can exacerbate the adverse effects of heat.[10,11,23]

People with lower socioeconomic status (SES) are more likely to live in urban areas with heavy traffic and limited green space, which tend to have higher pollution and heat risks.[4,10] Low-income populations also often live in poorly insulated homes or lack access to proper heating or cooling, which increases CVD risks. Limited social support and access to healthcare services, a lack of health literacy or pre-existing conditions can also increase risks.[10,29] Refugees and immigrants are often at increased risk due to socioeconomic disparities, poor living or working conditions and language barriers.[10]

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RECOMMENDATIONS

The following policy recommendations outline an integrated approach to protecting cardiovascular health in the face of increasing climate change impacts in Europe.

1. Better address climate-related cardiovascular health risks in EU policies

- **Embed cardiovascular health into EU Green Deal policies** such as the Climate Law and the Zero Pollution Action Plan to ensure that cardiovascular health risks from climate change are adequately addressed.[30] Likewise, cardiovascular health risks should be covered more consistently in national adaptation strategies in Europe.[31]

- **Strengthen the European Health Union by integrating environmental stressors and climate adaptation in EU health policy.** The EU Global Health Strategy (2022) highlights the need for better coordination and integration of EU and Member States policies in the context of climate change.

2. Strengthen air quality regulations and health action planning for heat and cold

- **Align EU air quality regulations** for key pollutants ($PM_{2.5}$, PM_{10}, NO_2, O_3, SO_2) with WHO guidelines and follow WHO's good practices to reduce UFP pollution.[4,12] These recommendations support the EU's ambition to speed up the transition to clean energy and climate neutrality.

- **Improve international collaboration** and capacity building to reduce transboundary pollution.[4]

- **Expand and evaluate heat-health action plans** at national, regional and local levels. Over a quarter of European countries lack these plans, which may negatively impact their preparedness to heat. Existing action plans need to be evaluated for effectiveness and revised.[32]

- **Develop cold-health action plans** to reduce cold-related deaths by incorporating real-time monitoring and early warning systems, timely public and medical advice, protections for vulnerable populations, improved urban planning and prepared health and social care systems. Align with energy poverty initiatives, such as the EU Social Climate Fund and Renovation Wave.

3. Expand early warning systems for air pollution and climate hazards

- **Implement real-time air pollution warning systems** that provide mobile alerts, public health advisories, and urban digital displays in high-pollution areas.

- **Strengthen early warning systems** for heatwaves, cold spells, and other climate hazards to help at-risk populations prepare and protect themselves.

- **Support the UN Early Warnings for All initiative** by expanding access to climate and air pollution alerts, emergency preparedness programs, and community-based risk communication strategies.

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4. Support vulnerable groups

- **Provide targeted support for vulnerable groups** (e.g., children, the elderly, outdoor workers, women, people with disabilities or low socioeconomic status), such as climate adaptation tools in schools, elderly homes, care centres, and workplaces, and timely public health information.[4]

- **Improve healthcare access** for people with disabilities and marginalized communities.

- **Engage local communities in urban design decisions** (e.g., urban greening projects, low-emission zones) to ensure social equity in climate-health adaptation.[4]

5. Ensure climate-resilient health infrastructure in urban planning and design

- **Transform healthcare systems** to substantially decrease greenhouse gas emissions and increase preparedness against climate stressors to protect vulnerable groups.[10,13]

- **Retrofit buildings to improve energy efficiency and resilience to climate stressors** by adding insulation, replacing inefficient heating/cooling systems and improving ventilation and air purification/filtering, mitigating climate-related cardiovascular health risks.[13]

- **Expand walking and cycling infrastructure and introduce low-emission, low-traffic, and car-free zones** to encourage active, low-carbon transportation.[13,33] Compact city models (e.g., Barcelona's Superblocks, Paris' 15-minute city), where essential services are within walking and cycling distance, can support physical health while reducing car dependency and pollution.[13,33]

- **Expand green infrastructure** such as urban forests, green roofs, and parks to enhance air quality, mitigate urban heat island effects and promote cardiovascular health by encouraging physical activity and social interaction.[4,13,33]

- **Promote healthy, balanced, plant-rich diets in public institutions,** including hospitals, to reduce emissions and air pollution from agriculture, and to support cardiovascular health.[33]

- **Support entrepreneurs** who produce products and services with climate-health co-benefits, and make co-beneficial consumer choices accessible and affordable.

6. Promote research on cardiovascular health risks of climate change

- **Prioritize research on vulnerable populations,** including people with low socio-economic status (e.g., migrants, low-income communities), as these groups are often underrepresented.[4] Socio-economic factors should be properly considered **to ensure inclusive scientific evidence** on climate-related health risks **and enable the development of targeted interventions.**[4] States in the (south)east of Europe are more vulnerable to environmentally induced cardiovascular disease, yet high-quality studies are relatively scarce. More research is also needed to compare the vulnerability of **urban versus rural populations,** as most studies focus on urban areas.[4]

- **Promote "multi-exposure" research** to acquire a more comprehensive understanding on how multiple environmental exposures (e.g., air pollution, suboptimal temperatures) simultaneously affect cardiovascular health.[4] Current research often focuses on single exposures.

- **Assess the impact of policy interventions.** Support research on the effectiveness of climate adaptation strategies, such as urban cooling measures and air quality improvements, in reducing cardiovascular health risks.[4]

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- **Develop a standardized framework at the EU level** for analysing climate change and health to enable cross-study comparisons.[4] A coordinated, international effort is needed to standardize exposure definitions and a list of confounders in data collection.[4] The use of standardized personal wearables and agent-based modelling can also improve exposure assessments by capturing real-time individual-level data and reducing bias from indirect exposure proxies.[4]

7. Raise awareness and capacity building

- **Launch public education campaigns** on the cardiovascular risks of air pollution and temperature extremes, and on protective measures (e.g., staying hydrated, filtering the air, avoiding exercise during pollution peaks or temperature extremes).[10,30] Encourage climate change mitigation strategies with health co-benefits.[33]

- **Train health professionals** to recognize and address climate-related cardiovascular risks through specialized education.[10] Equip them with skills to educate the public and vulnerable groups on prevention and adaptation strategies.[10]

CONCLUSIONS

Cardiovascular diseases remain a leading health burden in Europe, exacerbated by air pollution and temperature changes within the context of climate change. To reduce these environmental risks, the EU and its Member States need to integrate climate-related cardiovascular health challenges in EU and national policies, strengthen air quality regulations and action plans to deal with heat and cold, expand early warning systems, and invest in climate-resilient infrastructure. Targeted interventions for vulnerable groups and increased research, awareness-raising and capacity-building are crucial for ensuring equitable health outcomes. An integrated approach to climate-health policymaking will help mitigate climate-related cardiovascular health risks and protect public health across Europe. Clinical studies and stakeholder engagement activities within TRIGGER will help to further refine policy recommendations.

ACKNOWLEDGEMENTS

This policy brief builds on findings from the report *The impact of climate change on cardiovascular and respiratory health in Europe: A systematic review*, produced as part of the **TRIGGER** project (*Solutions for Mitigating Climate-Induced Health Threats;* https://project-trigger.eu). TRIGGER is funded by the European Union under the Horizon Europe Funding Programme for Research and Innovation and is one of six member projects of the European Climate-Health Cluster (https://climate-health.eu). This policy brief is part of a broader series, complementing policy briefs on respiratory and mental health impacts of air pollution and climate change.

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Funded by the European Union

This project has received funding from the European Union under grant agreement n° 101057739.

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Funded by the European Union

This project has received funding from the European Union under grant agreement n° 101057739.

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