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# Mitigation of climate change and health prevention in Italy: the co-benefits policy

Edited by P. Vineis, R. Alfano, C. Ancona, L. Carra, F. de' Donato, I. Iavarone, L. Mangone, M. Martuzzi, P. Michelozzi, L. Petiti, A. Ranzi, M. Romanello, A. Silenzi, M. Stafoggia

AMBIENTE E SALUTE

# ISTITUTO SUPERIORE DI SANITÀ

# Mitigation of climate change and health prevention in Italy: the co-benefits policy


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**Mitigation of climate change and health prevention in Italy: the co-benefits policy.**
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2021, iii, 64 p. Rapporti ISTISAN 21/20

An undisputable body of evidence shows that man-made climate change, mainly driven by fossil fuel combustion, is underway and accelerating. Changes are being recorded at the global level, and Italy is no exception. Projections show that, unless drastic reduction of emissions is achieved, average global temperatures will increase by more than 2 degrees compared to pre-industrial levels. Italy is particularly vulnerable to these changes. To prevent such a catastrophic scenario urgent action is necessary. Considering the human health implications of different policy scenarios can help identify and implement policies for climate change mitigation and adaptation, at global and local level. Policies and interventions in some areas can achieve multiple health benefits while reducing emissions. In particular, action on urban design and transport, green spaces and air quality, food production and consumption, including dietary habits, can mitigate climate change and result in substantial health co-benefits.

*Key words*: Climate change; Co-benefits; Global health; Heat; Pollution; Diet

Istituto Superiore di Sanità
**Mitigazione del cambiamento climatico e prevenzione sanitaria in Italia: la politica dei co-benefici.**
A cura di Paolo Vineis, Rossella Alfano, Carla Ancona, Luca Carra, Francesca de' Donato, Ivano Iavarone, Lorenzo Mangone, Marco Martuzzi, Paola Michelozzi, Luca Petiti, Andrea Ranzi, Marina Romanello, Andrea Silenzi, Massimo Stafoggia
2021, iii, 64 p. Rapporti ISTISAN 21/20 (in inglese)

Le evidenze scientifiche dimostrano che il cambiamento climatico, principalmente dovuto alla combustione di combustibili fossili, sta accelerando. Trend negativi si registrano a livello globale e l'Italia non fa eccezione. Le proiezioni mostrano che, senza una drastica riduzione delle emissioni, le temperature medie globali aumenteranno di oltre 2 gradi rispetto ai livelli preindustriali. L'Italia presenta una serie di vulnerabilità particolarmente critiche. Per prevenire questo catastrofico scenario è necessaria una risposta urgente. Considerare le implicazioni per la salute può aiutare a identificare e attuare politiche per la mitigazione e l'adattamento ai cambiamenti climatici, a livello globale e locale. Alcune politiche possono determinare molteplici benefici per la salute, al contempo riducendo le emissioni. In particolare, azioni di pianificazione urbana e dei trasporti, ampliamento degli spazi verdi, miglioramento della qualità dell'aria, cambiamenti nella produzione e nel consumo del cibo possono mitigare i cambiamenti climatici e portare a sostanziali co-benefici per la salute.

*Parole chiave*: Cambiamenti climatici; Co-benefici; Salute globale; Calore; Inquinamento; Dieta

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# FOREWORD

The changing climate, the loss of biodiversity, the disruption of many natural cycles, the ubiquitous pollution of air, water, soil – in short, the fast deterioration of the environment and of many life-support systems, represent a phenomenal challenge for public health. The challenge is of global nature and Italy is no exception. While Italian citizens have the invaluable privilege of having a solid and dependable national health system, the country has also some important vulnerabilities to climate change, for example due to known hydro-geological weaknesses of its territory, or the expected early desertification of some Mediterranean regions, due to rising temperatures.

The far-reaching nature of the environmental factors affecting human health and the high level of interconnectedness of many types of health determinants has been known for long, but the urgency of the matter has been widely recognized only recently. Much precious time has been wasted unfortunately since the Club of Rome published its *Limits to Growth* in 1972. The extent of the crisis is now clear and it is time governments and societies adopted the necessary, proportionate actions as a response. These actions are by no means "business as usual" as they require progressive profound adjustments in the workings of our societies, our economies, our lifestyles. While such policies are often described and understood as unsustainable and unwelcome, they do not need to be so. On the contrary, they can bring immediate benefits and improve the quality of life of everyone on the planet. The public health community has an important role to play to make it happen, and a great responsibility, because the health argument is both powerful for supporting political action and essential for its governance, including for the identification of policies that maximize returns in terms of health, wellbeing, quality of life, equity and justice at local as well as global level. The health argument, that because of the Pandemic SARS-CoV-2 is now perceived as strictly linked to wealth, can reinforce the notion that policies may indeed be costly, but returns are far greater and many of these policies are a great deal. It turns out, in fact, that adopting the human health point of view, and considering our own health as well as that of our children and future generations, many actions designed to benefit some specific environmental or health outcome carry countless positive "side effects", best known as co-benefits. The opportunities for health of people to go hand-in-hand with the health of the planet are indeed remarkable. We are in a position to take advantage of the strong evidence base that underpins environment and health interactions, while at the same time recognizing the many unknowns. We know that the complexity of the systems we are dealing with involves possible "unknown unknowns", i.e., surprises due to the non-linear nature of some phenomena occurring at the interface of the ecosphere and human societies – surprises we must be prepared for.

In the face of these very complex challenges, it is encouraging to see these points reflected in mainstream political conversations. The recent meeting of the G20 health ministers, held in Rome on 5-6 September 2021 under Italy's presidency, gave strong indications in that respect. At the time of writing this text, there is a high level of anticipation of the COP26, where decisions will be made that have the chance of turning the course of events for the better. We are experiencing a unique opportunity to orient immediately our future, due to the extraordinary amount of resources available in the next years for environment, climate change and health. It is essential that public health professionals are now proactive in the challenging action that is required. We, the health community, have a clear responsibility to support and join the efforts for the preservation of a liveable, hospitable and fair planet, for ourselves and the generations to come.

Silvio Brusaferro
*President of the Istituto Superiore di Sanità*

# BRIEF OVERVIEW

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As the climate crisis accelerates, it has become widely recognised that action against climate change is primarily taken via energy choices, limiting the use of fossil fuels and promoting renewable sources. At the same time, an effective complementary strategy consists in applying interventions designed to prevent diseases and jointly mitigate climate change, the so-called policy of co-benefits. For example, policies promoting active transport (cycling, walking) have the triple effect of mitigating greenhouse gas emissions, preventing diseases related to atmospheric pollution, and increasing physical activity, thus preventing diseases like obesity and diabetes, and providing benefits to mental health.

The role of basic and applied research in identifying and adopting such policies needs to be emphasized. The present report contains a first chapter that describes health-related climate change indicators for Italy, mainly derived from the Lancet Countdown initiative. They show that Italy is particularly vulnerable to climate change for its geographic position, its built environment and population distribution. The second chapter of the document refers to the effects on health of air pollution and changes in temperature (including heat waves), with estimates of the burden of preventable deaths. The third chapter is focused on food and shows the double advantage of limiting meat consumption and promoting intakes of vegetables and legumes, as also suggested by guidelines such as the EAT-Lancet commission, that include health and environmental impacts.

In line with the Paris Agreement objectives, Italy developed both short (1) and, more recently, long term policies (2) aimed at contrasting climate changes via measures that include reducing green gas emissions, increasing the use of renewable energies, and increasing energy efficiency. These measures were reinforced in response to the COVID-19 crisis, through the Italian Recovery and Resilience Plan that devoted 37% of its total expenditure (~70 billions of euros, making Italy the largest recipient of NextGenerationEU funds) to measures that support climate objectives – with large investments in promoting sustainable urban mobility, the use of renewable energy sources and energy efficiency of buildings (3). Despite this, however, health is still underrepresented in climate-related policies in Italy – as is the case in most of Europe – and climate change is addressed almost exclusively from an emissions perspective by ministers of environment and environmental organizations, often without inclusion of health considerations in the design of policy actions. A positive note is represented by the proposal of the Italian Ministry for Ecological Transition plan released in August 2021, in which for the first time co-benefits were officially mentioned as follows: "[…] the strategic development of joint policies of mitigation of climate changes and prevention of diseases requires collaboration between the different Ministries and sectors of Public Administration, for example creating an office and a joint fund for co-benefits and the promotion of the 'health for all policies' principle" (4). Further, in terms of adaptation to climate change, the Ministry of Health's 5 year National Prevention Plan, approved in 2020, specifically addresses climate and health among its core objectives (5).

The confluence of climate change mitigation policies with those related to disease prevention can also lead to substantial economic benefits. Even taking into account exclusively the anthropogenic $PM_{2.5}$ and using the lower bound estimate for Value of a Life Year suggested by the European Union, the exposure to $PM_{2.5}$ at 2018 levels would result in a monetized cost equivalent to 4.2% of the Italian GDP that year (taking into consideration Part III of the 2009 European Union Impact Assessment Guidelines, i.e., €50,000 for all countries, for all population cohorts) (6).

A significant reduction (up to 30-40%) in the incidence of chronic diseases like tumours, diabetes, cardiovascular, respiratory and neurological diseases, can be achieved with prevention policies unrelated to provision of health services, such as policies related to food, transport and agriculture (7). For both traditional Non Communicable Disease (NCD) prevention measures and wider climate change mitigation interventions, the cost of inaction far outweighs the cost of action, as it is clearly stated in the report produced by the World Health Organization (WHO) for COP24 and in the latest country profiles for NCD (8, 9, 10).

It is important to focus on this topic since the negative externalities associated with greenhouse gas emissions are not currently reflected in market values, as it can be seen in the fact that in Italy carbon emissions received in 2018 a net subsidy of 28.0 US$/tCO2e (with the net carbon price accounting for the contribution of the EU Emissions Trading System, budgetary transfers and tax expenditures) (6). The direct consequence of these non-costed externalities is resulting in a sustainability debt, which will be borne by future generations, and which is currently not reflected in common economic or financial indicators like GDP.

For policies capable of producing relevant co-benefits three categories of interventions are of special importance: those focused on urban planning, on diet and on transport. Those that follow are only examples, since many more intersectoral policies that match the concept of co-benefits can be made:

**Urban Planning.** The Italian territory is particularly vulnerable to climate change from several points of view. The country's ageing and fragile housing stock is among the factors that increase the vulnerability of the population to heatwaves. Throughout the country, hydrogeological frailty is also a factor. Floods have caused very serious damage to infrastructures, but also to people, with a significant direct health impact, both quantified in terms of loss of lives as well as unquantified (distress from relocation, loss of property). Such types of damage are expected to increase with climate change. Interactions between the health and safety of populations can emerge from the widespread application of local climate adaptation and mitigation strategies, that can be included in urban, spatial and sectoral planning. For example, the increasingly frequent exposure to extreme heat negatively impacts health leading to greater risks of heat stroke, acute kidney injury and congestive heart failure while contributing to worsen air quality and increasing energy demand. Adverse health effects are further exacerbated in urban settings, where the heat island phenomenon increases the concentration of heat within the urban fabric. This effect can be exacerbated by the shape and distribution of developed and undeveloped areas, by the absence of green spaces, and by the quality of the materials that cover the waterproofed surfaces. Therefore, urban areas tend to be warmer than rural areas, with variable estimates that reach up to 10°C. A cost-effective way of reducing the urban heat island effect is by increasing green space coverage in urban areas, which also helps diminish air pollution, contributes to climate change mitigation by absorbing atmospheric carbon dioxide, and reduces demand of energy for cooling (11). In addition, the increase of green spaces would offer significant health co-benefits: their presence is associated with higher levels of physical activity and reduced obesity, improved mental health and wellbeing, lower rates of cardiovascular disease, improved pregnancy outcomes, and lower risk of overall mortality.

**Diet.** Promoting nutrition styles similar to the Mediterranean diet, and in particular reducing the consumption of meat, can help to prevent many non-communicable and infectious (zoonotic) diseases. Agriculture contributes a large share of total man-made greenhouse gas emissions of which the majority is due to animal breeding. The main greenhouse gas emitted from farming is methane, with higher global warming potential than carbon dioxide, largely due to ruminating animals as a result of fermentation of the rumen. Furthermore, the water consumption associated with the meat industry is very high: a significant portion of global water usage in food production is actually related to farming. In many regions in Italy, especially in the Po Valley, manure spreading practices are the main source of ammonia pollution and consequently of its transformation into particulate matter ($PM_{2.5}$). Although meat is an important source of protein and contains different essential nutrients (including vitamins and iron), a high consumption of red meat contributes to the burden of chronic diseases, particularly cardiovascular diseases. There are many alternative sources of protein, such as legumes, of which production is less impactful on the environment and which could partially and gradually replace meat. It is therefore essential to work with the agricultural and food sectors to reduce greenhouse gas emissions and air pollution, taking into account the added health benefits while prioritizing the conservation of jobs, and traditional values in Italian culture. Italy can greatly contribute to the Farm-to-Fork strategy of the EU. The country still has a large network of farmers with a food system that is less industrialized than in other countries. The Italian food system may be developed into a model that is respectful for people’s livelihoods, the landscape, the environment, the quality of produce and with shorter distribution chains and larger biodiversity than in the current worldwide industrialized food system.

**Transport.** Another sector which also offers the possibility of health and climate change mitigation co-benefits is the transport sector. Policies promoting urban active transport (cycling, walking) have the triple effect of mitigating greenhouse gas emissions, preventing diseases related to atmospheric pollution (pulmonary diseases, lung tumours, cardiovascular diseases, possibly neurological diseases), and increasing physical activity, which is in turn associated with numerous health benefits including mental health. The implementation of ‘Piani Urbani per la Mobilità Sostenibile’ (Urban Planning for Sustainable Mobility) in Italy is urgent, particularly for medium sized and large cities. Analytical models on the combined effects of low emission transport and an increase in active transport in cities such as London have shown significant potential benefits, with a reduction in the risk of diabetes, ischaemic heart disease, heart attacks and other diseases related to a sedentary lifestyle, as well as reduced air pollution. To that end it is desirable that more Italian cities join the C40, a network of cities that combine health targets with climate change mitigation targets (https://www.c40.org; Milan, Rome and Venice are already members).

In the wake of the COVID-19 pandemic, Italy faces the opportunity of rapidly transitioning towards the development of a healthy, sustainable, and equitable economy – deploying the US$650 billion allocated to fiscal stimulus measures in line with the WHO's prescriptions for a healthy, green recovery (12). It is essential that these resources are allocated to counter future climate-related health hazards. At this pivotal moment, urgent political commitment is crucial.

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# LANCET COUNTDOWN INDICATORS FOR ITALY: TRACKING PROGRESS ON CLIMATE CHANGE AND HEALTH

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## Introduction

As a result of the ever-increasing emission of greenhouse gases, the world is now 1.2°C warmer than in the pre-industrial period, and 2020 tied with 2016 as the hottest year on record (1-3). This climatic change is already having profound impacts on the physical and social determinants of health around the world, with more frequent and extreme weather events, increased wildfire risk, sea level rise, changes to environmental suitability for infectious disease transmission, and impairments to the natural systems which human health depends on. In order to prevent the most catastrophic impacts of accelerated warming, countries committed to limiting global warming to "well below 2°C" by the end of the century in the 2015 landmark Paris Agreement. However, six years on, little progress has been made, and current climate change commitments would bound the world to 1.9-3.0°C of warming by the end of the century (4). With predicted local temperatures rising faster than global average, the Mediterranean is especially at risk. In particular, Italy's intrinsic hydro-geological vulnerability, its high proportion of elderly and urban populations, and its high ecological footprint, makes it vulnerable to the impacts of climate change and puts the health of its populations at risk.

Ambitious climate change mitigation holds the potential to deliver enormous health dividends if health is prioritised in all policies. This is not only due to the reduction in climate-related health risks, but especially due to the immediate health co-benefits that climate action could provide: some examples can be how shifting to low-carbon diets would improve health by increasing plant-based food consumption and reducing that of red meat (5) while increasing urban greenspace coverage would reduce urban temperatures, improve urban air quality, and provide spaces for social interaction and outdoor recreation (6, 7). Indeed, putting health at the centre of all climate change policies could result in millions of lives saved annually around the world, by 2040 (8). For all these benefits, the Word Health Organization (WHO) labelled the 2015 the landmark Paris Agreement as "the most important public health agreement of the century" (9, 10).

## Aim and methods

This chapter aims to provide evidence of the health impacts of climate change in Italy and of the implications of the Country's response on the health of its inhabitants by adapting and refining the indicators soon to be published in the 2021 global Lancet Countdown report, to provide data relevant to Italy. *The Lancet Countdown: Tracking Progress on Health and Climate Change* is an international research collaboration created to monitor the health dimensions of climate change and provide sound, scientific evidence to inform policy discussions that keep health at their centre. It draws on the expertise of leading experts from academic and UN institutions around the world, and annually reports its findings through indicators published in the medical journal *The Lancet*. While the collaboration reports findings primarily at a global level, national-level data is also available. Therefore, in this report, out of the 44 indicators in the 2021 global Lancet Countdown report (11), we present 17 indicators for Italy, organized within five sections that mirror those of the Lancet Countdown: 1. climate change impacts, exposures, and vulnerabilities; 2. adaptation, planning, and resilience for health; 3. mitigation actions and health co-benefits; 4. economics and finance; 5. public and political engagement. Wherever possible, data from the Lancet Countdown is enhanced and refined through the use of national statistics, and other sources of improved data available for Italy.

# Results

Main findings are reported below, while a detailed description of each indicator can be found in Appendix A.

## Climate change impacts, exposures, and vulnerabilities

Climate change is already affecting the health of Italian populations, with a yearly average of almost 100 million more person-days of heatwave exposure in people over 65 years of age in 2010-2020 compared to 1986-2005, and 2.3% of the total annual deaths observed in 2015 in Italy being attributable to heat exposure.

In 2020, twice the land surface was affected by at least one health month of drought than in 1950, putting food and water security at risk. The changes in climatic conditions are also affecting the environmental suitability for infectious disease transmission, with the basic reproduction potential ($R_0$) of dengue transmitted by *Aedes albopictus* mosquitoes having increased by 31% in 2020 with respect to the 1950-1954 baseline.

## Adaptation, planning, and resilience for health

Despite clear evidence on the growing health risks, the implementation of adaptation measures to protect the health of Italian populations from climate change hazards has been slow: in September 2021, Italy had still not approved its National Adaptation Plan, submitted to public consultation in 2017. Engagement with international standards on climate change adaptation and risk assessment has also been slow: in 2020, only 18 urban centres in Italy reported the status of their climate change risk assessment plans to the CDP (Carbon Disclosure Project), and until November 2020, Italy had not reported to the World Meteorological Organisation whether its national meteorological and hydrological services provide information to the health sector, which could help inform public health measures that protect health from climate hazards.

### Mitigation actions and health co-benefits

Italy's mitigation response has been insufficient to meet commitments under the Paris Agreement, and the delay may adversely impact human health. The continued use of fossil fuels is still contributing to high levels of air pollution, which made Italy the second country in the EU with the highest number of deaths attributable to $PM_{2.5}$ exposure in 2019, only after Germany. Italy was still sourcing 6% of its electricity from coal in 2018, and fossil fuels still accounted for 96% of all the energy used for road travel in 2017. At the average annual decarbonisation rate observed between 2015-2020, it would take Italy several decades to decarbonise its energy system fully. Estimates from the Lancet Countdown suggest that, in 2018, greenhouse gas emissions related to consumption of animal products represented 82% of all emissions coming from the agricultural products consumed in Italy. According to the Lancet Countdown's modelling, the associated red meat consumption might result in more than 16000 premature deaths.

### Economics and finance

Partly responsible for the slow progress toward decarbonisation is the continued use of public funds to subsidise health-harming fossil fuel burning. In 2018, Italy dedicated the equivalent to 4.77% of its national health budget to this purpose. This not only results in the price of fossil fuels not reflecting their negative health and environmental externalities, but also in effective economic incentives for their continued use, hampering the transition towards a low-carbon economy

### Public and political engagement

Despite the discouraging trends described above, indicators tracking public and political engagement on health and climate change as interconnected issues provide glimpses of hope. Italy has recently begun addressing the link between climate change and health in the UN General Debate, exposing this is becoming a priority in its agenda. The first mention to the link between climate change and health was made in 2016, followed by three mentions in its 2020 speech. The Italian scientific community is also increasingly addressing the climate change and health issue, with original research on the topic led by researchers in Italy growing from 3 articles in 2007 to 29 articles in 2020.

## Discussion

The overall picture depicted by the analysis of the 17 indicators reveals two key findings.

The first finding is that climate change is already having negative impacts on the health of Italian populations. Importantly, these effects are not being felt uniformly across the Country or by different populations, with the most vulnerable groups being disproportionately at risk.

The second key finding is that, through accelerated action on climate change mitigation, Italy has the opportunity of delivering major and immediate health benefits to its population. Accelerated climate change mitigation through energy system decarbonisation and shifts to more sustainable modes of transport could offer major benefits to health from cleaner air and more active lifestyles. The decarbonisation of agricultural systems would similarly offer health co-benefits to Italian populations. If developed keeping people's health and livelihoods at their centre, policies to reduce greenhouse gas emissions from the agricultural and energy sectors could therefore deliver major co-benefits to health.

As respected and reliable voices, scientific leaders can foster knowledge, increase the understanding on the health dimensions of climate change, and produce evidence to help inform the development of climate policies that maximise human health and wellbeing.

However, time is running up. Unless urgent action is taken to tackle climate change, and protect the health of Italian populations, the rapidly changing climate would have catastrophic consequences on the health of Italian populations. In the upcoming UN Climate Change 26$^{th}$ Conference of Parties (COP26) Italy will have the opportunity of shifting the tide, and ensure it delivers a healthy, sustainable system for present and future populations.

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# HEALTH IMPACT OF TEMPERATURE AND AIR POLLUTION IN ITALY

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## Mortality impact of heat in Italy

The short-term effects of temperatures and extreme events have been extensively studied in environmental epidemiology (1, 2).

Heat has been related to an increase in total and cause-specific mortality as well as non-fatal outcomes such as hospital admissions, emergency room visits and ambulance calls (1-3). In particular, a non-linear association between temperature and mortality has been identified, specific to each geographic location with increases in the risk of mortality as temperatures rise above or go below a specific value (4).

The purpose of this study is to quantify the short-term impact of heat on mortality in Italy in the summer of 2015.

### Estimate of mean temperature exposure

Daily mean air temperature with a spatial resolution of 1 km$^2$ (years 2001-2015) was derived using satellite Land Surface Temperature (LST); for observed temperature data and spatio-temporal land use and land cover predictors (5) see Appendix A for details.

Figure 1 shows the geographical distribution of average summer (June-August) daily mean air temperature in the study period (2003-2015).

### Short-term effects of air temperature on all-cause mortality

#### Health data

Mortality data for 8,092 municipalities in Italy for the period 2003-2015 was collected. Individual all-cause mortality records with information on the municipality and the 110 provinces were retrieved from the National Institute of Statistics (Istituto Nazionale di Statistica, ISTAT).

#### Statistical analysis

A time series study was carried out to estimate the association between daily mean air temperature and all-cause mortality.

Firstly, we modelled municipality specific daily time-series within each province by applying the Distributed Lag Nonlinear model (DLNM) approach, a flexible technique that simultaneously considers the non-linear and lag structure of the association (4,6). Details of the model are described in Appendix B.

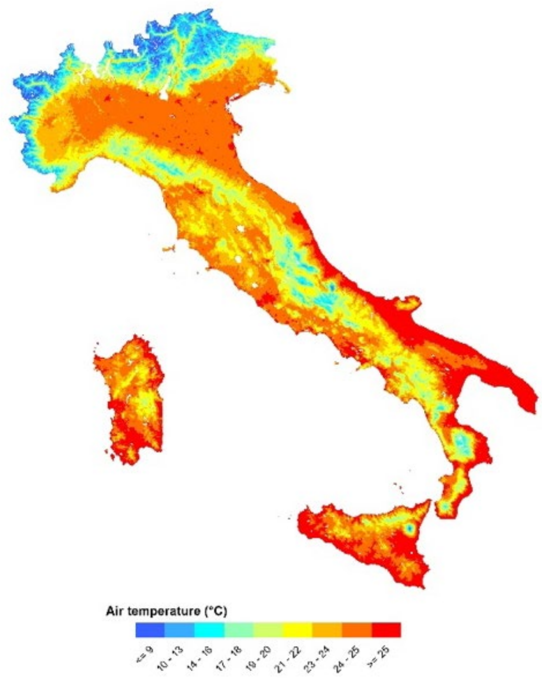


**Figure 1. Average mean air temperature in Italy, Summer 2003-2015**

Secondly, we pooled the reduced coefficients in a multivariate meta-regression to derive an overall national dose-response curve and the Best Linear Unbiased Prediction (BLUP) of the dose-response association in each province. Figure 2 shows the mean temperature-mortality curve for Italy with grey lines representing province specific curves and the bold coloured line the overall estimated curve (red heat effects, blue cold effects). The effect of heat was defined as the Relative Risk (RR), with 95% Confidence Intervals (95%CI) for temperature increases between the 75th and the 99th percentile.

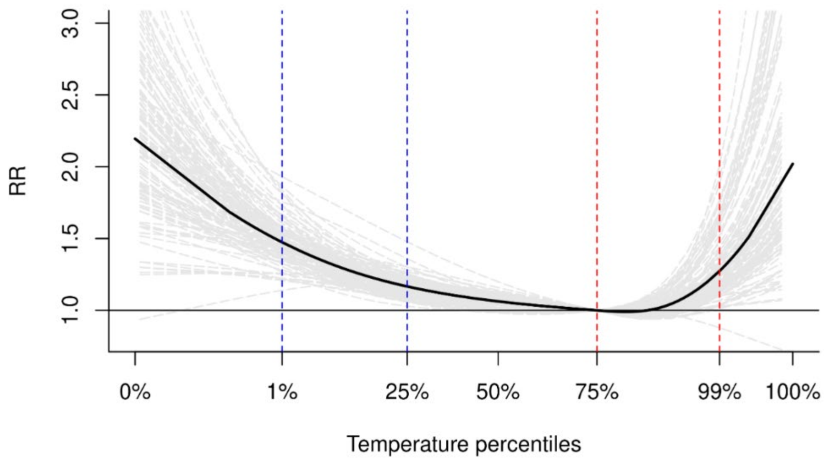


**Figure 2. Mean temperature-mortality association for Italian provinces (grey curves) and overall curve for Italy (black line)**

### Heat attributable deaths in Italy

We used pooled associations to quantify the numbers of all-cause deaths attributable to heat during 2015. Specifically, on the same range of temperatures (75$^{th}$ to 95$^{th}$ percentile) we estimated the deaths attributable to heat, together with the attributable fraction (attributable deaths divided by the total number of observed deaths) and we calculated empirical 95%CI using Monte Carlo simulations. For 2015, a total of 14,521 deaths attributable to heat (temperatures between the 75$^{th}$ to 95$^{th}$ percentile) were estimated in Italy, corresponding to an attributable fraction of 2.3% of the total number of annual deaths (Table 1).

**Table 1. Heat attributable deaths and fraction of total deaths in Italy in 2015**

| 2015 | Estimate | 95%CI |
|---|---|---|
| Attributable deaths (number) | **14,521** | 9,870 - 18,975 |
| Attributable fraction of total deaths (%) | **2.3** | 1.5 - 2.9 |

This work is ongoing and aims to provide exposure and impact estimates for more recent years. Attributable deaths will also be reports by month, geographical area, age group and gender for each year to assess temporal variations in response to exposure and adaptation measures put in place from published literature showing a reduction in heat attributable deaths in Italy (7-9).

## Health impact of particulate matter (PM) air pollution in Italy

The health risks associated long-term exposure to $PM_{10}$ and $PM_{2.5}$ are of particular public health relevance. Both $PM_{2.5}$ and $PM_{10}$ are capable of penetrating deep into the lungs but $PM_{2.5}$ can even enter the bloodstream, primarily resulting in cardiovascular and respiratory impacts, and also affecting other organs (10). The WHO has published several volumes of Air Quality Guidelines (AQGs) to provide guidance to the public, especially to policy and other decision makers, on the health risks of air pollution. The new version was released on September 22, 2021 (11). In the guideline update, recommendations on AQG levels are formulated, together with interim targets. The WHO halved the recommended limits for average annual $PM_{2.5}$ levels from 10 micrograms per cubic meter to 5. It also lowered the recommended limit for $PM_{10}$ from 20 to 15 micrograms. In Table 2, 2021 WHO AQG recommended level for PM are reported.

**Table 2. 2021 WHO AQG recommended level and interim targets for $PM_{2.5}$ and $PM_{10}$**

| Pollutant (μg/m$^3$) | Averaging time | Interim target | | | | AQG level |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| $PM_{2.5}$ | Annual | 35 | 25 | 15 | 10 | **5** |
| $PM_{10}$ | Annual | 70 | 50 | 30 | 20 | **15** |

We aimed to quantify the short- and long-term impact of $PM_{10}$ and $PM_{2.5}$ on the health of the Italian population. The short-term impact on mortality is already largely accounted for in the long-term impact on mortality and the two impact should not be added together. However, the information remains interesting in order to present what could be a quick benefit of the decrease in AP concentration. A 2013 assessment by WHO's International Agency for Research on Cancer (IARC) concluded that outdoor air pollution is carcinogenic to humans, with the PM component of air pollution most closely associated with increased cancer incidence, especially lung cancer and secondarily with cancer of the urinary tract/bladder (12).

## Estimate of particulate matter (PM) air pollution exposure

Estimates of daily mean concentrations of $PM_{10}$ (2006-2015) and $PM_{2.5}$ (2013-2015) for each squared kilometre of Italy were obtained using a machine learning approach, the Random Forest, which leverages information from space-time predictors, satellite data, and air quality monitoring data. Details can be found in Stafoggia *et al.* 2019 (13). Figure 3 displays the annual average concentrations of $PM_{10}$ and $PM_{2.5}$ for the year 2015.

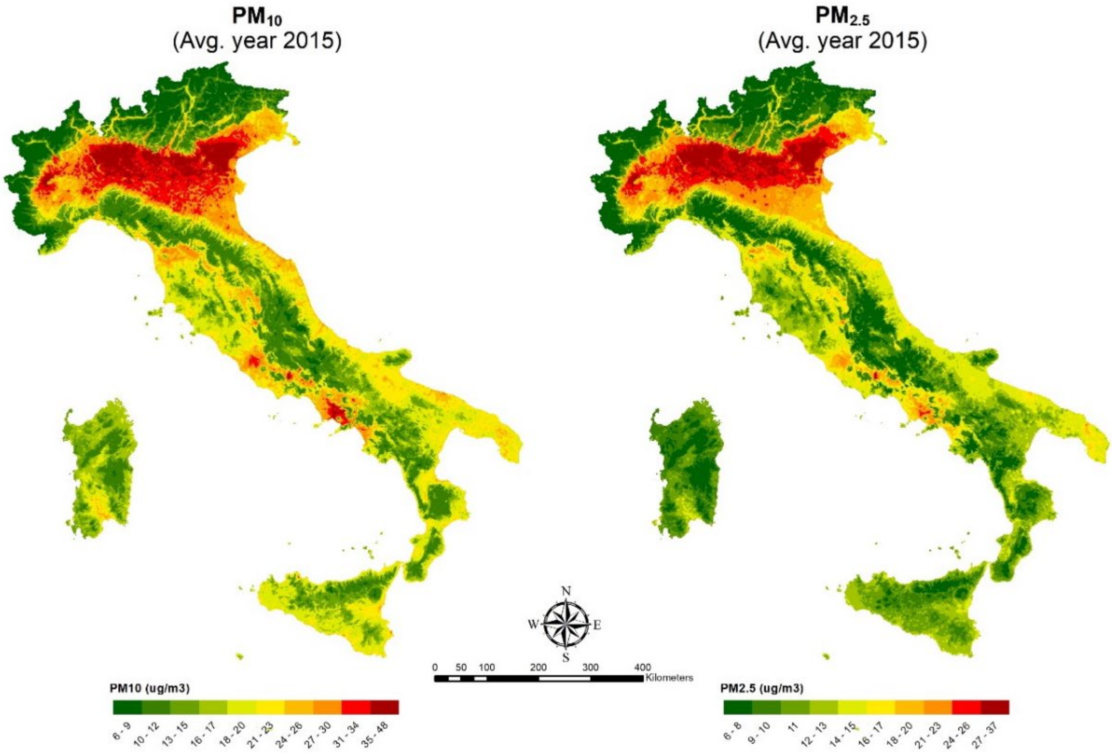


**Figure 3. Annual average concentrations of $PM_{10}$ (left) and $PM_{2.5}$ (right), Italy 2015**

## Short-term effects and impacts of particulate matter air pollution in Italy

### Estimate of short-term effects of $PM_{10}$ and $PM_{2.5}$ on all-cause mortality

In order to evaluate the association between short-term (e.g., daily) exposure to either $PM_{10}$ or $PM_{2.5}$, and all-cause mortality we adopted a multi-stage approach, consisting of mortality data collection, production of municipality-specific time series, fitting of Poisson regression multivariable model in each Italian province, and meta-analysis of the province-specific regression coefficients. We obtained from ISTAT daily counts of mortality (all causes, both sexes, all ages) for each one of the 8,092 municipalities of Italy, for the period 2006-2015.

Daily mean concentrations of $PM_{10}$ (2006-2015) and $PM_{2.5}$ (2013-2015) at the municipality level were derived by averaging, for each municipality, values of all the squared kilometre grid cells intersecting the municipality. Municipality-specific daily time series of potential confounders such as daily mean air temperature, weekly regional flu epidemics, bank holidays and summer population decrements were also collected. We fitted province-specific Poisson regression models, so obtaining, for each of the 110 Italian provinces, estimates of RR and 95% CI of all-cause mortality per unit increment of $PM_{10}$ (for the period 2006-2015) or $PM_{2.5}$ (for the period 2013-2015), in turn. Finally, we ran random-effects meta-analytical techniques on the province-specific estimates and derived a national estimate of the association between short-term exposure to $PM_{10}$ and $PM_{2.5}$ with all-cause mortality.

Table 3 reports the association between daily concentrations of $PM_{10}$ and $PM_{2.5}$ (at different lags) and all-cause mortality, in Italy.

**Table 3. Association* between daily mean PM concentrations (at different lags) and all-cause daily mortality in Italy: percent increases of risk (%IR), and 95% confidence intervals (95%CI) for 10 mg/m$^3$ increment in the pollutant**

| Pollutant | Study period | Lag | IR% | 95%CI | |
|---|---|---|---|---|---|
| $PM_{10}$ | 2006-2015 | 0 | 0.71 | 0.53 | 0.88 |
| | | 0-1 | 0.76 | 0.61 | 0.91 |
| | | 2-5 | 0.45 | 0.26 | 0.64 |
| | | 0-5 | 0.80 | 0.58 | 1.01 |
| $PM_{2.5}$ | 2013-2015 | 0 | 1.17 | 0.77 | 1.56 |
| | | 0-1 | 0.86 | 0.60 | 1.12 |
| | | 2-5 | 0.29 | 0.02 | 0.55 |
| | | 0-5 | 0.72 | 0.34 | 1.09 |

* Boxes around lag 0 estimates, i.e., those used for short-term impact assessment estimation

## Short-term impacts of $PM_{10}$ and $PM_{2.5}$ on all-cause mortality

The estimated pooled associations were used to quantify the numbers of all-cause deaths attributable to daily exceedances in $PM_{10}$ and $PM_{2.5}$ above predefined thresholds during 2015. Methodological details are reported in Appendix C.

Table 4 reports the numbers of all-cause deaths attributable to PM levels exceeding predefined 24-hour thresholds in Italy during 2015: the thresholds internationally recognized as standards for $PM_{10}$ and $PM_{2.5}$ are reported in grey (WHO AQG 2005) and in in blue (WHO AQG 2021).

Exceedances of the threshold of 15 μg/m$^3$ for $PM_{2.5}$ occurred on 35.6% of the days and were responsible for an extremely high impact: an intervention able to contain daily $PM_{2.5}$ levels below 15 μg/m$^3$ would have prevented 4.773 deaths – 95%CI 3.183-6.345. Similarly, had daily $PM_{10}$ concentrations always been below 45 μg/m$^3$, 1.021 (769-1.272) deaths would have been prevented.

**Table 4. All-cause deaths attributable to PM levels exceeding predefined thresholds, Italy 2015**

| Pollutant | Threshold ($\mu g/m^3$) | % days ≥ threshold | n. deaths | AD | 95%CI | | AF (%) |
|---|---|---|---|---|---|---|---|
| $PM_{10}$ | 50 | 5.7 | 63,655 | 772 | 581 | 961 | 1.2 |
| | 45 | 7.4 | 80,183 | 1,021 | 769 | 1,272 | 1.3 |
| | 40 | 9.6 | 102,405 | 1,336 | 1,007 | 1,664 | 1.3 |
| | 35 | 12.8 | 134,344 | 1,743 | 1,313 | 2,170 | 1.3 |
| | 30 | 18.1 | 190,699 | 2,298 | 1,732 | 2,862 | 1.2 |
| | 25 | 27.8 | 286,130 | 3,117 | 2,348 | 3,881 | 1.1 |
| | 20 | 44.3 | 414,707 | 4,333 | 3,265 | 5,396 | 1.0 |
| $PM_{2.5}$ | 25 | 14.1 | 132,299 | 2,460 | 1,641 | 3,270 | 1.9 |
| | 20 | 21.1 | 192,413 | 3,367 | 2,246 | 4,476 | 1.8 |
| | 15 | 35.6 | 316,583 | 4,773 | 3,183 | 6,345 | 1.5 |
| | 10 | 67.6 | 521,715 | 7,146 | 4,764 | 9,503 | 1.4 |

In grey WHO AQG 2005; in blue WHO AQG 2021
**95%CI** 95% Confidence Interval; **AD** Attributable Deaths; **AF** Attributable Fraction

## Long-term health effects of $PM_{10}$ and $PM_{2.5}$ from the epidemiological literature

A systematic review of evidence of associations between long-term exposure to $PM_{2.5}$ in relation to all-cause and cause-specific mortality found a combined Risk Ratio for $PM_{2.5}$ and natural-cause mortality equal to 1.08 (95%CI 1.06-1.09) per 10 $\mu g/m^3$ (14).

The combined effect estimate was larger for cardiovascular (particularly ischemic heart disease) than for natural-cause mortality associated with exposure to $PM_{2.5}$.

The European multicentre study ESCAPE (European Study of Cohorts for Air Pollution Effects, www.escapeproject.eu) studied the chronic effects of air pollution in cohorts of adult subjects. ESCAPE results highlighted the existence of an association between chronic exposure to air pollutants and natural mortality and cardiovascular events (15-18) and cancer of the lung, brain, breast and digestive system (19-21).

Table 5 reports the estimates of association between long-term exposure to PM and cause-specific mortality from the literature.

**Table 5. Association between exposure to $PM_{2.5}$ and $PM_{10}$ and cause specific mortality from literature: relative risk (RR) and 95%CI for increments of 10 $\mu g/m^3$**

| Cause specific mortality | ICD9 | ICD10 | Age in years | $PM_{2.5}$ RR | 95% CI | | $PM_{10}$ RR | 95%CI | |
|---|---|---|---|---|---|---|---|---|---|
| Natural mortality | 001-629; 677-799 | | 30+ | 1.08 | 1.06 | 1.09 | 1.04 | 1.03 | 1.06 |
| Lung cancer | 162 | C33 C34 | 30+ | 1.12 | 1.07 | 1.16 | 1.08 | 1.04 | 1.13 |
| Cardiovascular diseases | 390-459 | I | 30+ | 1.11 | 1.09 | 1.14 | 1.04 | 0.99 | 1.10 |
| Respiratory diseases | 460-519 | J | 30+ | 1.10 | 1.03 | 1.18 | 1.12 | 1.06 | 1.19 |

## Long-term impacts of PM10 and $PM_{2.5}$ on all-cause mortality

The impact of long-term exposure to $PM_{2.5}$ was estimated according to the Integrated Environmental Health Impact Assessment (IEHIA, www.integrated-assessment.eu) methodology which involves the definition of target population, the estimation of the Population Weighted Exposure, the choice of adequate Concentration-Response Functions (FCR) and a basic understanding of the disease and mortality rates of the population.

The population data (people aged 30 and over) used for the IEHIA of $PM_{2.5}$ and $PM_{10}$ were referred to 2020 and provided by ISTAT at census block level. Population exposure was obtained using the 4-stage Random Forest (13).

The cause specific mortality rates were provided by the Statistics Service of the Istituto Superiore di Sanità based on official data of ISTAT, in compliance with the Regulation (EU) 2016/679 for General Data Protection (GDPR).

The model was updated to the most recent years (2016-2019), in collaboration with the Italian Institute for Environmental Protection and Research (ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale) with a spatial resolution of 1x1 km.

The concentration-response functions for mortality (natural, respiratory and cardiovascular) and lung cancer were taken from the last publication from the WHO working group (14). Thresholds of 10 $\mu g/m^3$ for $PM_{2.5}$, 20 for $PM_{10}$, were applied in the assessment, following WHO recommendations on the HIA procedure. Further evaluation was provided for the just published updated thresholds for pollutants (11).

The estimates of the long-term impacts of $PM_{2.5}$ and $PM_{10}$ on cause-specific mortality in Italy (2016-2019) are reported in Tables 6 and 7, respectively.

**Table 6. $PM_{2.5}$ long-term exposure attributable deaths, Italy (2016-2019)**

| Area | Population | PWE | Threshold: 10 mg/m³ | | | | Threshold: 5 mg/m³ | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30+ | (mg/m³) | AD | 95% CI | | AF (%) | AD | 95% CI | | AF (%) |
| **Natural causes** | | | | | | | | | | |
| Italy | 42 952 673 | 16.5 | 28906 | 22083 | 32225 | 4.69 | 50856 | 38974 | 56608 | 8.26 |
| North | 19 354 371 | 20.5 | 20841 | 15952 | 23213 | 7.45 | 30589 | 23507 | 34003 | 10.93 |
| Central | 8 664 082 | 14.5 | 3916 | 2979 | 4375 | 3.10 | 8511 | 6501 | 9489 | 6.75 |
| South | 14 934 220 | 12.6 | 4149 | 3152 | 4637 | 1.98 | 11755 | 8966 | 13115 | 5.60 |
| **CVD** | | | | | | | | | | |
| Italy | 42 952 673 | 16.5 | 13536 | 11273 | 16785 | 2.20 | 24125 | 20152 | 29788 | 3.92 |
| North | 19 354 371 | 20.5 | 9484 | 7914 | 11727 | 3.38 | 13884 | 11630 | 17073 | 4.95 |
| Central | 8 664 082 | 14.5 | 1911 | 1586 | 2384 | 1.52 | 4145 | 3452 | 5140 | 3.30 |
| South | 14 934 220 | 12.6 | 2141 | 1774 | 2674 | 1.02 | 6096 | 5070 | 7575 | 2.91 |
| **RESP** | | | | | | | | | | |
| Italy | 42 952 673 | 16.5 | 2662 | 852 | 4471 | 0.43 | 4638 | 1502 | 7701 | 0.75 |
| North | 19 354 371 | 20.5 | 1945 | 627 | 3244 | 0.69 | 2853 | 932 | 4692 | 1.01 |
| Central | 8 664 082 | 14.5 | 371 | 117 | 634 | 0.30 | 799 | 256 | 1344 | 0.64 |
| South | 14 934 220 | 12.6 | 346 | 109 | 593 | 0.17 | 986 | 314 | 1665 | 0.47 |

**PWE** Population Weighted Exposure
**CVD** CardioVascular Diseases
**RESP** Respiratory diseases
**AD** Attributable Deaths
**AF** Attributable Fraction

**Table 7. $PM_{10}$ long-term exposure attributable deaths, Italy (2016-2019)**

| Area | Population 30+ | PWE (mg/m³) | Threshold: 10 mg/m³ AD | 95% CI | | AF (%) | Threshold: 5 mg/m³ AD | 95% CI | | AF (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| **Natural causes** | | | | | | | | | | |
| Italy | 42 952 673 | 24.9 | 12291 | 9307 | 18091 | 2.00 | 22745 | 17248 | 33385 | 3.70 |
| North | 19 354 371 | 28.2 | 9010 | 6828 | 13242 | 3.22 | 13954 | 10594 | 20430 | 4.98 |
| Central | 8 664 082 | 22.4 | 1337 | 1010 | 1977 | 1.09 | 3503 | 2651 | 5162 | 2.85 |
| South | 14 934 220 | 21.7 | 1943 | 1468 | 2872 | 0.93 | 5288 | 4002 | 7792 | 2.53 |
| **CVD** | | | | | | | | | | |
| Italy | 42 952 673 | 24.9 | 4270 | 0 | 10102 | 0.69 | 8034 | 0 | 18855 | 1.31 |
| North | 19 354 371 | 28.2 | 3056 | 0 | 7197 | 1.08 | 4754 | 0 | 11073 | 1.67 |
| Central | 8 664 082 | 22.4 | 479 | 0 | 1148 | 0.39 | 1268 | 0 | 3008 | 1.04 |
| South | 14 934 220 | 21.7 | 735 | 0 | 1757 | 0.35 | 2012 | 0 | 4774 | 0.96 |
| **RESP** | | | | | | | | | | |
| Italy | 42 952 673 | 24.9 | 2561 | 1353 | 3818 | 0.42 | 4658 | 2480 | 6887 | 0.76 |
| North | 19 354 371 | 28.2 | 1898 | 1007 | 2817 | 0.67 | 2905 | 1557 | 4264 | 1.02 |
| Central | 8 664 082 | 22.4 | 295 | 154 | 445 | 0.24 | 754 | 397 | 1127 | 0.62 |
| South | 14 934 220 | 21.7 | 368 | 192 | 556 | 0.18 | 999 | 526 | 1495 | 0.48 |

**PWE** Population Weighted Exposure
**CVD** CardioVascular Diseases
**RESP** Respiratory diseases
**AD** Attributable Deaths
**AF** Attributable Fraction

$PM_{2.5}$ Population Weighted Exposure in Italy in the period 2016-2019 is equal to 16.5 mg/m³ (20.5 in North Italy and 12.6 in South Italy). This value is under the EU law limit (25 mg/m³ as annual mean) but it exceeds the 2021 WHO AQG recommended value by more than three times (more than 4 in the North of Italy).

According to the 2021 WHO limits every year $PM_{2.5}$ is responsible of 50,856 deaths in Italy (8.3% of national mortality for all natural causes, with higher values (11%) in the Northern part of Italy.

Every year 22,745 deaths are attributable to $PM_{10}$, 3.7% of mortality for all natural causes, with higher values (5%) in the Northern part of Italy. These deaths would not occur if the levels of concentrations of these pollutants did not exceed the values set by 2021 WHO AQG to protect health.

Most of the deaths attributable to air pollution in Italy are due to cardiovascular diseases.

Data on lung cancer mortality are underestimated, due to limited availability of municipality data by age classes only for privacy rules. Available data indicate 13% as a fraction attributable to $PM_{2.5}$ exposure for lung cancer mortality when the 2021 WHO AQG threshold is considered.

Results confirm that ambient air pollution is the environmental risk factor causing the largest measurable health impact. As such, the leverage of preventive action is substantial: most, if not all, climate change mitigation policies in transport, energy, industry, agriculture etc would entail reductions in concentrations of air pollutants, in turn resulting in preventing large numbers of premature deaths and disease.

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# FOOD, HEALTH AND MITIGATION OF CLIMATE CHANGE IN ITALY

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Intervention on food systems is a central component of climate change mitigation policies. The food industry as a whole, and animal breeding in particular, is estimated to be responsible for up to a third of anthropogenic GreenHouse Gas (GHG) emissions worldwide (1), with the largest contribution deriving from agriculture and land use (LU) / land use change activities (2).

Agriculture in particular is responsible for the largest share in methane emissions and is one of the main contributors to $N_2O$ emissions.

Despite a slight downward trend in agricultural emissions in Italy over the last 20 years, as described in the last report by Italian Institute for Environmental Protection and Research (Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA) (3), emissions remain substantial and the relevance of dietary habits in climate change mitigation strategies is undisputable.

To address this issue, most recent dietary guidelines, such as the EAT-Lancet diet, increasingly consider factors such as GHG emissions, water use and LU as parameters that must be evaluated in addition to effects on human health, as well as animal health, adopting a "One Health" approach (4).

## Dietary habits and health outcomes in EPIC cohort

The present chapter is mainly based on the European EPIC (European Prospective Investigation into Cancer and Nutrition) cohort, comprising a very well characterized population in terms of food intake and followed-up for more than 25 years for health outcomes. Overall, the cohort includes 500,000 participants from all over Europe.

A paper analysing the relationship between diet and GHG emissions and LU across the entire European cohort is in press by Laine *et al.* (5).

In this document further analyses based on 10,604 participants of the Torino cohort of EPIC are presented.

The aims of this chapter are:

- to investigate the associations between dietary habits and cancer incidence, cardiovascular diseases, diabetes, obesity, blood pressure and mortality by cause;
- to assess the planetary impact (GHG and land use) of different dietary patterns;
- to investigate jointly the planetary and the health impacts.

### Population

EPIC is a multi-centre prospective cohort study that was designed to investigate the relationships between nutrition and cancer, among other diseases.

A detailed description of the EPIC cohort, including study populations and data collection, has been previously reported elsewhere.

The most recent version can be found in Laine *et al.* (5). A description of the cohort is reported also in Appendix D. The population here under study includes only the EPIC-Torino component (N=10,604).

# Greenhouse gas and land use calculations from food frequency data

GHG and LU were estimated from the detailed standardized country-specific food frequency questionnaires, using the SHARP-ID (Strategic Healthcare Analysis and Research Platform - Indicators Database), a European-wide database for estimating environmental impacts that result from food production, packaging, transport and home preparation (6).

The total food list for EPIC included 11,858 food items. Specific food items were matched between the EPIC database and the SHARP database, based on their FoodEx2 from the Exposure Hierarchy of the European Food Safety Authority.

Most items were matched exactly by their FoodEx2 values; however, for 1,985 (16.7%) items we used a proxy as the exact match was not available in the SHARP database. There were 298 (2.5%) food items for which we did not have a match and were therefore not included in our GHG or LU estimates; however, most of these food items were rarely consumed, and thus would have negligible impact on our analyses.

On the basis of this information, we calculated the EAT-Lancet score, representing the adherence to the EAT-Lancet guidelines for a healthy and sustainable diet, for the participants in the study. GHG was expressed in kilograms of carbon dioxide equivalents per kilogram of food as eaten (kg$CO_2$eq/kg food) and LU as meters$^2$ per year per kilogram of food as eaten (m$^2$ year/kg food).

## Statistical analysis

To assess the association of the estimated GHG and LU emissions with all-cause and cardiovascular mortality and all-cancer and gastrointestinal cancer incidence, hazard ratios (HR) and 95% Confidence Intervals (95% CI) were estimated. Appendix D reports the methods used in detail.

A hazard ratio indicates the relative increase in disease risk in those with a certain exposure compared to those without. The main exposures considered in the following analysis are GHG and LU levels derived from individual diets, modelled as quartiles of 0 to 25% (1$^{st}$ as the referent), 25% to 50% (2$^{nd}$ quartile), 50% to 75% (3$^{rd}$ quartile) and above 75% (4$^{th}$ quartile).

Moreover, we examined associations with other risk factors that could play a role as confounding factors: BMI, age, education, physical activity and smoking habits. Results for the latter two factors, however, are not further shown since they are not directly relevant to this analysis.

Finally, we studied the characteristics of the diets followed by the participants to the EPIC study and observed the association between the EAT-Lancet Score and GHG and LU emissions.

# Results

## Analysis of the association of cancer incidence and mortality with GHG and LU emissions

Figure 1 shows hazard ratios and confidence intervals for the association between GHG and land use with total mortality.

Our data show no association between GHG and land use and total mortality, while they show a weak and non-significant association with cardiovascular causes of death (edu=educational level).

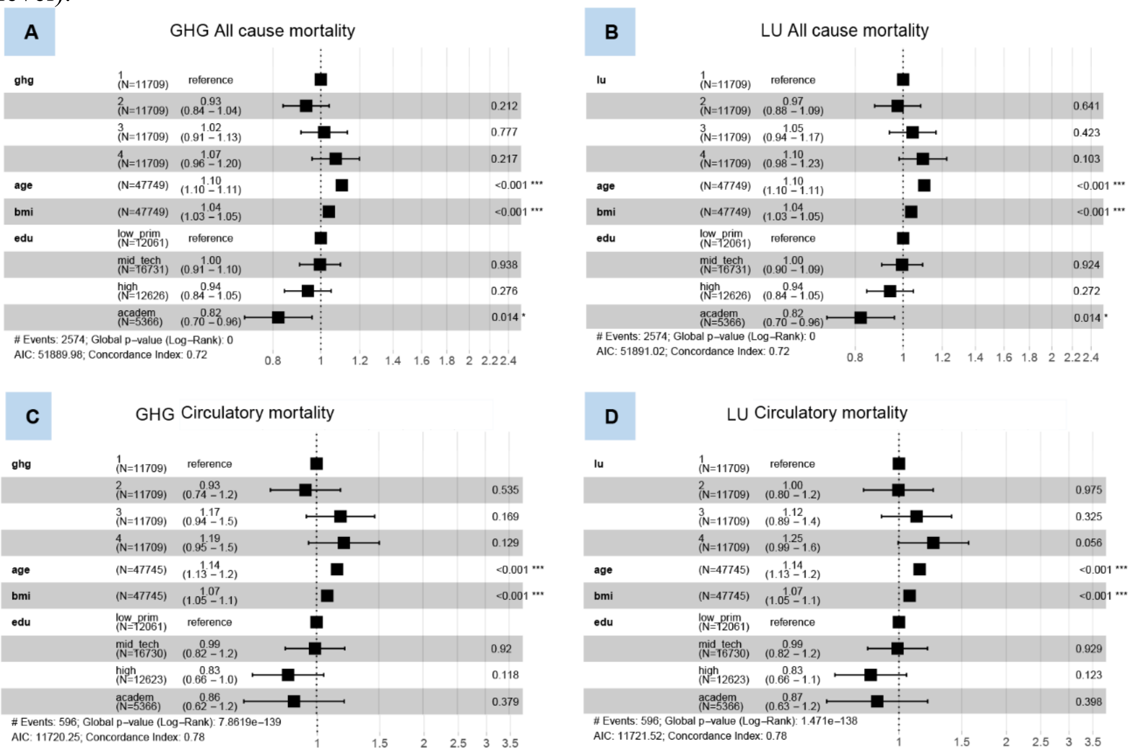


**Figure 1. Hazard Ratios for total mortality (A, B) and cardiovascular mortality (C, D) according to the dietary greenhouse gas emissions (A, C) and land use (B, D) compared to the HR associated to age, body mass index (bmi) and social status represented as educational level (edu)**

On the other hand, a diet associated with considerable GHG emission and extensive LU showed statistically significant association with cancer incidence. Gastrointestinal cancers specifically showed the strongest association (Figure 2).

We do not report here separately cancers that were present in the population only in small numbers and cancers of reproductive organs with well-known hormonal risk factors (breast, uterus) that would probably overshadow dietary effects.

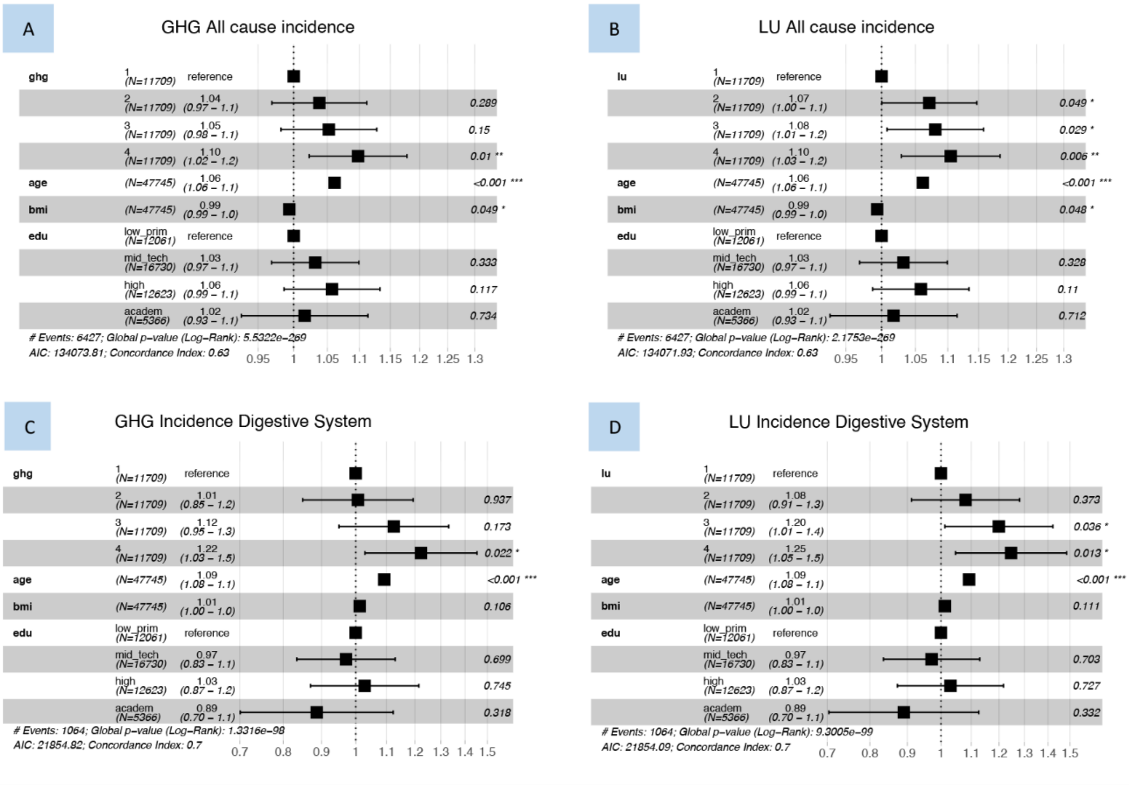


**Figure 2. Hazard Ratios for cancer incidence (A, B) and gastrointenstinal cancer incidence (C, D) according to the dietary greenhouse gas emissions (A, C) and land use (B, D) compared to the HR associated to age, body mass index (bmi) and social status represented as educational level (edu)**

## Analysis by EAT-Lancet score

The EAT-Lancet score has been developed on the basis of the recommendations of the EAT-Lancet Commission to set dietary guidelines that consider both human health and planetary health, including GHG emissions and land use (7, 8). The score goes from 0 (highest negative health and planetary impact) to 13 (lowest).

In our data (Figure 3), we found evidence of the fact that the higher the EAT-Lancet Diet Score was, the lower the mean GHG emissions and LU values were.

These observations were confirmed in the larger study done in the European cohort (5), where it was demonstrated how shifting a diet from 3 to 13 would result in a 50% and 62% reduction in GHG emissions and LU, respectively.

In the European cohort, evidence of an association between a diet with a high EAT-Lancet score and improved health outcomes emerged as well.

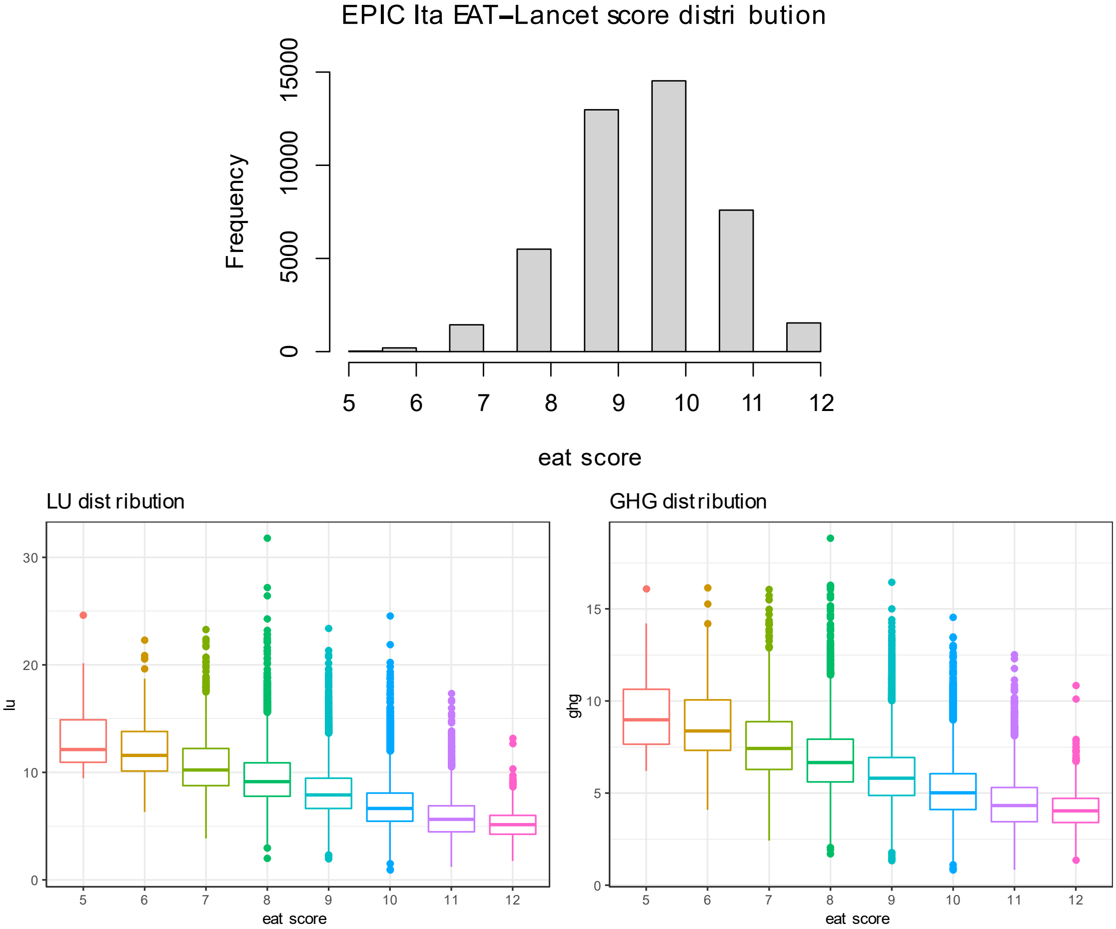


**Figure 3. Visual representation of the EAT-Lancet score distribution in the Italian population (top) and association between the EAT-Lancet score, Greenhouse Gas (GHG) emissions and Land Use (LU)**

# Discussion

Analyses in both the European EPIC study and its Torino component show that a healthy diet, as defined on the basis of the EAT-Lancet score, has also a lower planetary impact, as demonstrated by the lower corresponding GHG emissions and LU values. Conversely, a diet with a high planetary impact is also associated with higher risk of cancer incidence, particularly gastrointestinal cancers. From a dietary perspective the highest impact on both health, GHG and land use comes from meat, the lowest from legumes. Therefore, a gradual reduction of cattle red meat, which by itself determines up to 44.3% of all emissions from agricultural product consumption, would lead to both climate and health gains. It must be pointed out that meat products have such an elevated contribution to GHG emission and LU also because of all the associated fodder and forage. These results need to be examined in the light of affordability and access to healthy and environmentally friendly food by consumers, among other considerations. However, a great advantage in terms of climate change mitigation and health can be achieved with dietary changes.

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# CONCLUSIONS

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Based on the evidence presented in this report, the following recommendations can be formulated to protect and enhance the health of Italian populations in the face of climate change:

- *Foster communication between health and environment authorities*, to ensure health benefits and impacts are taken into consideration in the development of health mitigation and adaptation policies. Promote the involvement of public health agencies in the development and implementation of climate policies, ensuring that possible health outcomes are taken into consideration including their cost-benefit analysis and that policies with potential health co-benefits are prioritised.
- *Enhance actions and policies that promote climate change and health adaptation* to reduce population vulnerability and help building climate-resilient health systems in line with the new EU strategy on adaptation to climate change launched at the beginning of 2021 aimed at improving knowledge of climate impacts and solutions, promoting planning and risk assessment aimed at accelerating response and emergency action.
- *Prioritise and accelerate action on climate change mitigation policies* that reduce air pollution in urban centres. These should include promoting road travel decarbonisation in urban centres by incentivising active travel and the use of public transport systems, and disincentivising the use of private vehicles.
- *Deliver rapid decarbonisation of the energy system*. Promptly eliminate the use of coal for power generation, and provide financial incentives for the uptake of clean, renewable sources of energy, to ensure the pace of decarbonisation of the energy system is in line with the goals of the Paris agreement.
- *Stop subsidising fossil fuels*. Urgently eliminate fossil fuel subsidies, and redirect funds into activities that promote health, wellbeing and equity, including through support measures to minimise the negative impacts of subsidy elimination on the most vulnerable groups.
- *Promote dietary changes* that are in line with the co-benefits philosophy, as expressed, for example, by the EAT-Lancet dietary recommendations that combine attention to health

with consideration of environmental impacts. A reduction in meat consumption is strongly recommended.

- *Ensure that the use of COVID-19 fiscal stimulus funds support decarbonisation* and health protection for Italian populations now and in the future, in line with the WHO's prescriptions for a healthy, green recovery and with the goals of the Paris Agreement.

# APPENDIX A
# Lancet Countdown:
# description of each indicator for Italy

## Climate change impacts, exposure, and vulnerability

The rapidly changing climatic conditions are leading to an increased frequency and intensity of extreme weather events, that threaten the health of Italian population both directly and indirectly. In parallel, Italy has a high percentage of vulnerable population subgroups, including elderly people, people with chronic disease, outdoor workers and migrant groups, which will be more frequently affected by these effects. Climate change, therefore, is threatening to exacerbate health inequities among the Italian population. This section tracks the changing exposure of Italian population to climate-related hazards, including extremes of heat, drought events, and climate-sensitive infectious diseases.

### Heat and health

#### Exposure of vulnerable populations to heatwaves

***Headline finding.*** Adults over 65 were exposed to an average of almost 100 million more person-days of heatwave exposure per year in 2010-2020 compared to the 1986-2005 period.

Rising global temperatures are driving an increase in the frequency, intensity, and duration of extremes of heat, which directly impact on people's health through the exacerbation of pre-existing medical conditions (such as cardiovascular and respiratory diseases) acute kidney damage, mental health and behavioural disorders, adverse mental health outcomes, and increased risk of violence (1, 2). The elderly, the pregnant women, the new-borns, the socially deprived, and those working outdoors or in non-cooled environments, are especially vulnerable, with heat impacts worsening their disadvantaged situation (2, 3).

This indicator, with data taken from the 2021 global Lancet Countdown report (indicator 1.1.2) (4), estimates the total number of days adults aged over 65 and children from birth to 1 year, were exposed to life-threatening heatwave events across Italy. For the purpose of this indicator, heatwaves were defined in alignment to the World Meteorological Organization and previously published work (5,6), as a period of at least two days where both the daily minimum and maximum temperatures are above the 95th percentile of the observed in the 1986-2005 period, at a 0.25 x 0.25 degree geographical resolution.

Results show a steady increase in the person-days of exposure to heatwaves of adults over 65 in Italy, with an average of almost 100 million more person-days of exposure (defined as one person, exposed to one day of heatwave) per year in 2010-2020, than in the 1986-2005 baseline period (Figure A1). For children under 1, there were an estimated average of 3.68 million additional person-days of heatwave exposure affecting this vulnerable group per year in 2010-2020, compared with baseline years (Figure A1). These changes reflect primarily the increased frequency of days of heatwaves in Italy, reflecting the most direct effect of a warming world on human health. Work is underway to improve this indicator for Italy to consider the heat wave definition used in the Health Heat Health Adaptation Plan (HHAP) implemented by the Italian Ministry, and use finer spatial scale resolution data to better capture geographical differences and impacts.

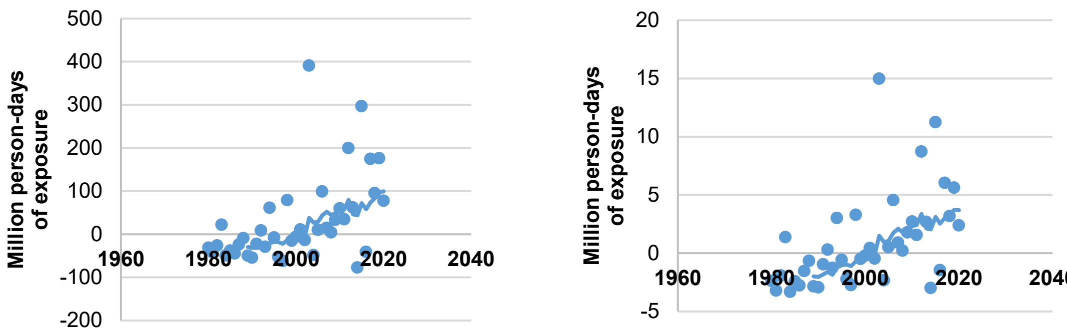



**Figure A1. Change in the number of person-days of exposure to heatwaves of people over 65 years of age (left) and children under 1 year of age (right) with respect to the 1986-2005 baseline. Dots represent yearly totals, line represents the 10-year moving average**

### Heat-related mortality

***Headline finding.*** In 2015, 2.3% of the total annual deaths were attributable to heat exposure in Italy.

Evidence from the epidemiological literature shows that Italy is one of the countries in the world with the highest heat-related effects on daily mortality, considering both extreme heat wave events and overall summer temperatures, as also reported in the WHO climate change and health country profile (7-9). Considering future climate change projections, southern Europe and Italian cities will have a significant increase in temperature-related excess mortality (10).

In Italy there is heterogeneity among cities in the heat effect (11-12). Heat effects are geographically heterogenous, greater in larger urban areas (Turin, Milan, Bologna, Florence, Rome, Naples). A progressive increase in the temperature at which the least temperature-related deaths occur (the so-called "minimum mortality temperature") can be observed from North to South of Italy and throughout summer, reflecting the underlying population characteristics and adaptation to the local climate. After the introduction of national heatwave health prevention plan by the Ministry of Health in 2005 (13), a decrease in heat-related mortality was observed in Italian cities (14-16). These findings show the potential health benefits of heat adaptation measures that prioritise health. With heatwave frequency and intensity on the rise, and with the population aging and increased vulnerability to extreme heat putting people at greater risk of adverse health outcomes (see the previous indicator), enhancing heat adaptation policies that protect human health is particularly urgent.

As described in the chapter "Health impact of temperature and air pollution in Italy" of this report, an indicator for Italy is being defined to estimate the risk in heat-related mortality and heat attributable deaths not only for cities included in the national heat health prevention plan, but at both national and sub-national level based on ongoing research carried out by the Department of Epidemiology Lazio (DEPLAZIO). In brief, DEPLAZIO has defined high spatial scale resolution (1x1 km) heat exposure time series data which is being used to estimate heat risk and health effect estimates. Using high resolution temperature exposure and mortality data for each municipality, risk estimates and heat-attributable mortality can be calculated to evaluate temporal trends and spatial changes across Italy. Figure A2 shows the heat exposure estimated for in Italy between 2003 and 2015. While the complete analysis is still underway, results for a single year, 2015, reported a total of around 14,500 deaths attributable to heat on days in which temperatures were between the 75th to 95th percentile. This corresponding to 2.3% of the total of annual deaths in Italy being attributable to heat exposure.

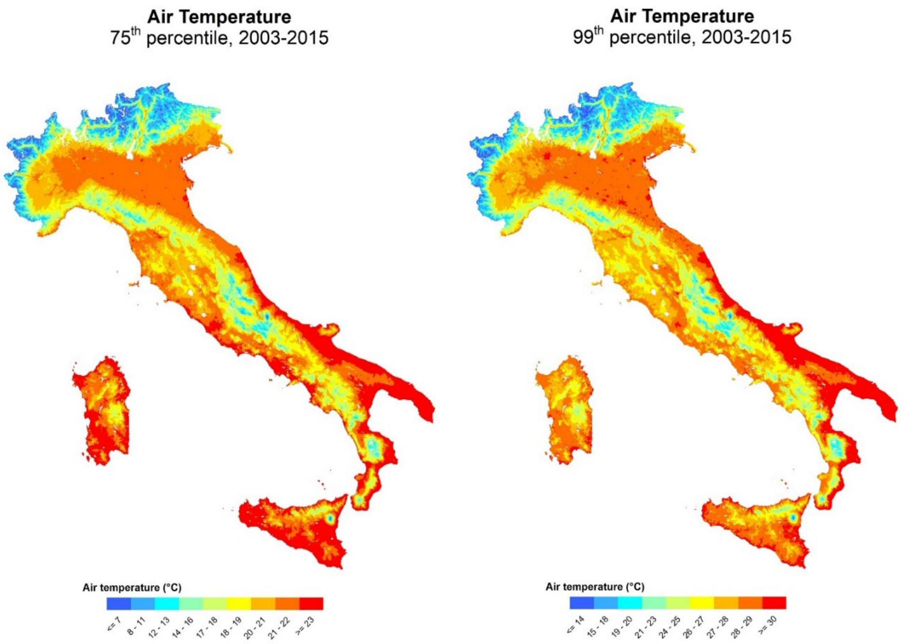



**Figure A2. Average 75th and 99th percentile air temperature estimated in Italy for the period 2003-2015**

## Drought

***Headline finding.*** The Italian land surface area affected by drought conditions for at least 1 month per year doubled in 2020 compared to 1950.

Climate change is driving an increase in the frequency, intensity, and duration of drought events. This is posing threats to water security, sanitation and food productivity, and increasing the risk of wildfires and exposure to pollutants (17, 18).

This indicator, adapted from the 2021 global Lancet Countdown report (indicator 1.2.2) (4), tracks the percentage of the total land area in Italy affected by at least one month of drought, defined through the Standardised Precipitation-Evapotranspiration Index (SPEI). The SPEI captures changes in precipitation and the effect of temperature on evaporation and moisture loss. For the purposes of this indicator, extreme drought is defined as SPEI ≤ -1.6, and exceptional drought as SPEI ≤ -2, in agreement with the definitions of the Federal Office of Meteorology and Climatology MeteoSwiss (19).

The Italian land surface area affected by drought conditions increased since the 50s, with fast increases in the land area affected by exceptional drought observed particularly since the start of the 2000s (Figure A3). On average, in 2016-2020, an additional 41.6% of the Italian land area experienced at least one month of extreme drought, and an additional 27.1% of the land area experienced at least one month of exceptional drought.

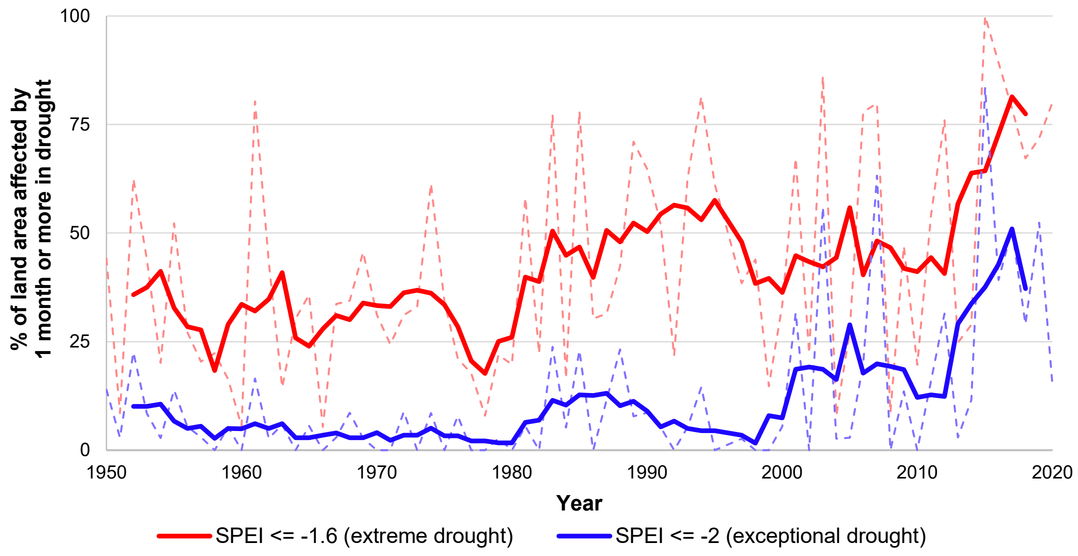



**Figure A3. Percentage of land area affected by at least 1 month of severe (red) and extreme (blue) drought. Dashed lines represent the annual percentage of affected land area. Continuous lines represent the centred 5-year moving averages (2 years forward and 2 years backward)**

This poses a particular risk for Italy, the second European country (after Greece) for freshwater abstraction for public water supply, with 153m³ of water extracted per inhabitant in 2018 (20). Indeed, in 2019, water scarcity forced 9 Italian cities to implement water rationing measures (21). More frequent and extreme weather conditions, coupled with outdated drinking and wastewater infrastructures (60% of Italian infrastructures were more than 30 years old in 2016) (22), could lead to declining quantity and quality of water in the future years, putting sanitation and food and water security at risk in the most vulnerable areas of the Country.

## Climate suitability for infectious disease transmission

***Headline finding.*** The basic reproduction potential ($R_0$) of dengue transmitted by *Aedes albopictus* mosquitoes, while still very low in absolute terms, has increased by 31% in 2020 with respect to the 1950-1954 baseline.

Climate change-driven alterations in environmental conditions are resulting in changes in the environmental suitability for the transmission arthropod-, food-, and water-borne diseases (23, 24). Cases of dengue, transmitted mainly by *Aedes aegypti* and *Aedes albopictus* mosquitoes, doubled every decade since 1990, and climate change has been identified as one of the major drivers of this increase (25, 26). This indicator, presented in the 2021 global Lancet Countdown report (indicator 1.3.1) (4), tracks the environmental suitability for the transmission of dengue. It employs a model that incorporates the influence of temperature and rainfall on vectorial capacity and vector abundance and overlays it with human population density data to estimate its basic reproduction potential ($R_0$).

Results indicate that the $R_0$ for dengue transmitted by *Aedes albopictus* mosquitoes is still relatively low in Italy (0.19 in 2020). However, modelling suggests that, as a result of changes in temperature and rainfall, the $R_0$ was 31% higher in 2020, with respect to the average in 1950-1954 (Figure A4).

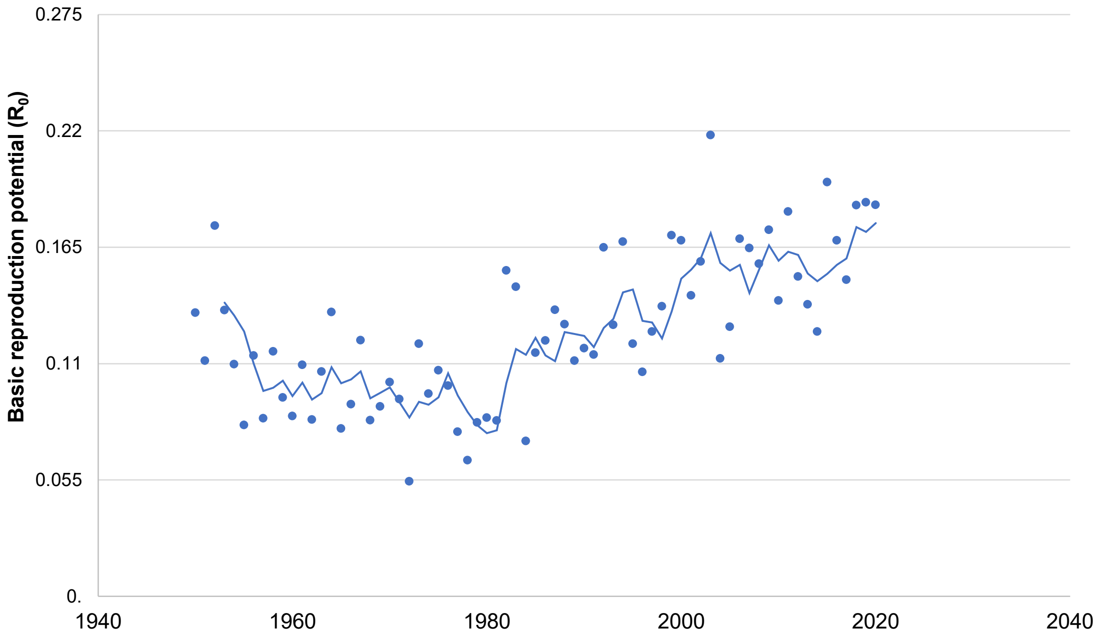



**Figure A4. Basic reproduction potential for the transmission of dengue by *A. albopictus* mosquitoes in Italy. Dots represent yearly total values, line represents the 5-year moving average**

The biggest increase in $R_0$ has been observed in the north of Italy, particularly in Friuli Venezia Giulia, Veneto and Lombardy (Figure A5). In agreement with these modelled data, in 2020 the first outbreak of autochthonous dengue in Italy was reported in Veneto (27). Further, with similar environmental niches, the $R_0$ for Zika and chikungunya diseases are expected to follow similar trends. In fact, two outbreaks of chikungunya disease were detected in Italy in 2007 and in 2017 (28, 29). As the climate continues to change, this emerging risk will become more prominent. It is important, therefore, that Italy builds the required adaptive capacity to cope with these hazards in the short and longer term. In this regard, in 2020 a National Plan against arbovirus infections defined the measures to be implemented to set up effective preparedness and control strategies (30).

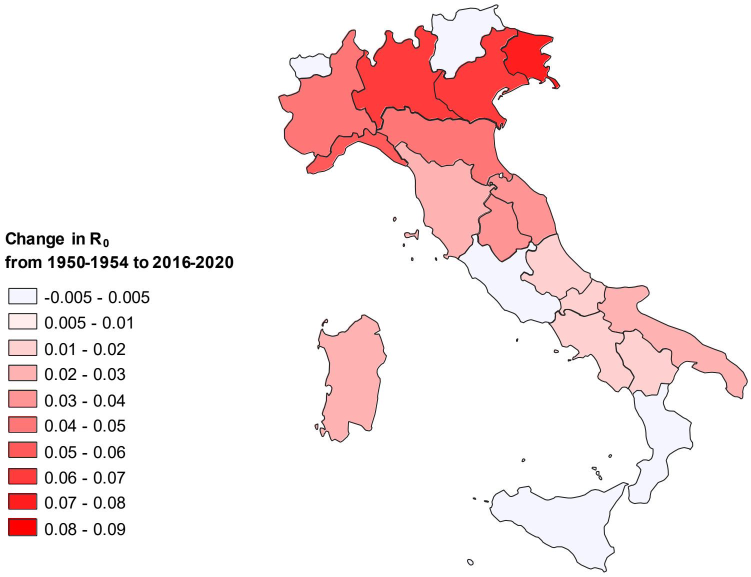



**Figure A5. Absolute change in the basic reproduction potential ($R_0$) for the transmission of dengue by *A. albopictus* in Italy, from 1950-1954 to 2016-2020**

## Conclusions

This section provides evidence that climate changes are already putting the health of Italian populations at risk. The impact of the climate changes on health is increasing over the time as demonstrated by the fact that the three indicators presented here show worsening trends over the last decades. Beyond this, the findings of the 2021 global Lancet Countdown report expose worsening trends in other health impacts and exposures at a global scale, including reduced labour potential (4), increased risk of extreme events like wildfires, reductions in crop growth duration, and rising of the sea levels. These findings highlight the need of stronger adaptation and mitigation measures to protect health. While sub-national data at the region level was only available for one indicator, the diversity of climatology and population characteristics across Italy means that exposures and vulnerabilities to climate change hazards vary throughout the country. This evidence therefore calls for health adaptation and mitigation measures to be tailored at the regional level and with strong national coordination, to enhance resilience and adaptive capacity of local populations to climate change. Work is underway to develop the indicator of heat-related mortality with a greater spatial resolution using high-resolution national data, to identify areas and populations at risk and help define policies for climate change.

## Adaptation, planning, and resilience for health

As the previous section exposed, the changing climate can affect health via multiple interacting pathways, and particularly overburden vulnerable populations. The COVID-19 pandemic has offered a glimpse of the catastrophic effects that acute health shocks can have on the Italian health system. With the effects of climate change on the rise, it is of outmost importance that risks are identified and urgent action taken to protect Italian population from the health impacts of a warming world. This requires building resilience into health and health-related systems (including sanitation, food systems, and essential infrastructure), identifying vulnerable populations, implementing early warning systems to protect their health in the face of climate hazards, and building preparedness and response capacity, including by ensuring the availability of an adequate level of resources. Tracking progress towards climate change adaptation in Italy, this section monitors the development of national and city-level risk assessment and adaptation planning, the use of climate information services for health and the urban green space coverage.

## National adaptation planning and assessment

***Headline finding.*** The Italian National Adaptation plan was submitted to public consultation in 2017. However, by September 2021 it still hadn't been approved, and it still does not formally address health adaptation planning.

This indicator tracks the implementation of a national adaptation planning and assessment.

Italy issued its National Adaptation Strategy (NAS) in 2015, and the first draft of its National Adaptation Plan (NAP) was submitted to public consultation in 2017. However, this NAP has not been formally approved. Furthermore, it does not formally include considerations of adaptation planning for health. An exception is represented by the national heatwave prevention plan implemented by the Ministry of Health for the prevention of heat health effects focused on the elderly and including all regional capitals and cities with more than 200,000 inhabitants (13, 31). This national program includes the core elements of the WHO Heat-Health Adaptation Planning guidance, namely identification of lead body, defining city-specific heat-health warning systems, national prevention guidelines and information campaigns, preparedness of the health and social care system, registries for the identification of susceptible subgroups, real-time surveillance and evaluation (13, 32, 33). Similar actions in response to climate change impacts should be promoted and formally included in climate change adaptation and resilience plans.

Considering the diversity of climate change hazards, exposures and vulnerabilities at the sub-national level, and considering Italy is organised in independently-administered regions (since the reform of the Title V of the Constitution of 2001), the development and implementation of climate change adaptation plans for health at the regional level is of outmost priority to protect health. Indeed, the need for regional adaptation is highlighted in the current version of the NAP, and the need to implement regional adaptation and assessment plans was recognised by regional authorities during a recent inter-regional consultation. In addition, and within the context of the EU Life Project Master Adapt, a guidance document for regional climate change adaptation in Italy was defined and discussed at inter-regional consultations (34). Moreover, the CReIAMO PA project formally addresses adaptation to climate change by promoting methodologies, capacity building and response within regional and local public administrations (35).

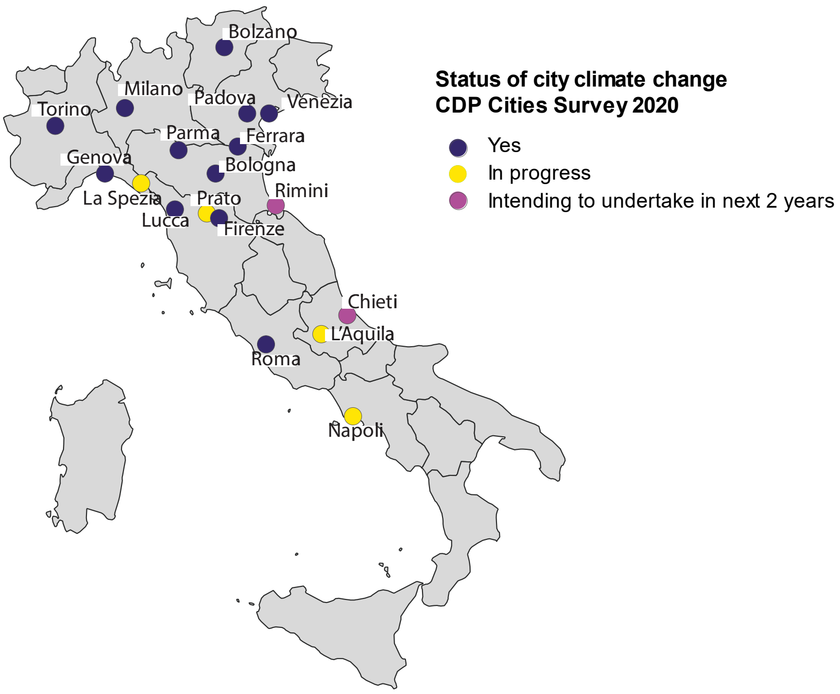
However, and although no exhaustive data is officially available to track adaptation plans for health at the regional level, large variations by region are expected. According to a survey carried out by the Institute for Environmental Protection and Research (ISPRA) on adaptation strategies at subnational level, in 2018 out of 15 Regions completing the survey, 53% (N=8) were working actively towards developing their strategy or strategies focused on specific sectors, 20% (N=3) had already approved their strategy, 13% (N=2) were active on climate adaptation via other initiatives and another 13 did not foresee any adaptation strategy (36). In future, this indicator will be extended to include regional and local adaptation plans, accessing information from local databases and considering local projects in place.

## City-level climate change risk assessments

***Headline finding.*** In 2020 only 18 urban centres in Italy disclosed the status of their climate change risk assessment plans to the CDP. Of these, 16 (89%) reported that they had completed or were in the process of completing a climate change risk assessment. 18 urban centres reported on the risks posed by climate change to health systems and outcomes, but only 7 (39%) identified that their city was facing risks to public health or to health systems due to climate change.

Home to over 70% of Italy's population, the COVID-19 crisis has brought to focus the crucial role that cities play in building resilience and coordinating local responses to health crises.

This indicator, taken from the 2021 global Lancet Countdown report (indicator 2.1.3) (4), uses data from the 2020 survey of global cities of the CDP (formerly known as the Carbon Disclosure Project) to capture the number of Italian cities that reported having completed a climate change risk or vulnerability assessment; and the climate-related health impacts and vulnerabilities that cities identified. The survey from the CDP offers a standardised reporting system, where cities across the world disclose their progress towards climate change adaptation and mitigation efforts in a format that allows for comparison between cities, and across time. In 2020, 18 urban centres in Italy disclosed the status of their climate change risk assessment plans to the CDP (Figure A6), a reduction of 9 cities compared to 2019.



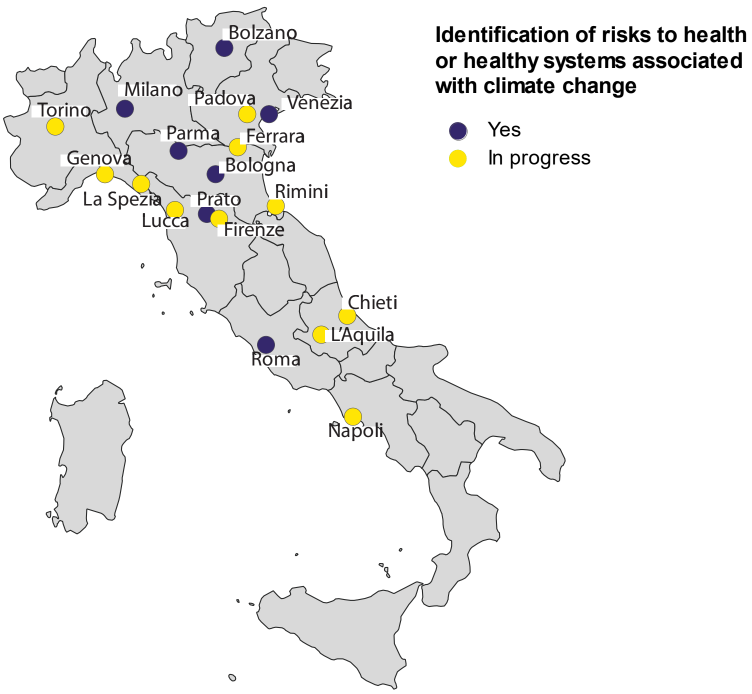




**Figure A6. Status of climate change risk or vulnerability assessment and the identification of climate-related health impacts and vulnerabilities by reporting city, CDP Cities survey 2020**

Only three of these reporting cities (17%) were located in Southern regions of Italy. All three of these were either in the process of undertaking a climate change risk assessment (N=2) or planned to undertake one within the next two years (N=1), however none reported having completed an assessment.

Of the other 15 reporting cities, 12 (80%) had already completed a climate change risk assessment, 2 were in the process of undertaking one (14%), and one planned to conduct an assessment within the next two years (7%).

Similar trends regarding North-South divide were observed in responses to CDP survey questions on health risks associated with climate change. Only seven of the 18 cities (39%) who responded to this question identified that their cities faced risks to health systems due to climate change, all of which were located in Northern or Central Italian regions.

The greatest climate-related health issues identified by these seven cities were heat-related illness (6 out of 7 cities), exacerbation of non-communicable disease symptoms (3 out of 7 cities) and air-pollution related illness (2 out of 7 cities).

The most vulnerable populations affected by these climate-related impacts were identified as elderly (6 out of 7 cities), children and youth (3 out of 7 cities) and low-income households (3 out of 7 cities). Two cities, namely Parma and Prato, also identified women as being particularly vulnerable to the health impacts of climate change.

The main limitation of this indicator is that it relies on the CPD survey, which was completed in Italy by only a small selection of cities as described above. Since CDP reporting is voluntary, many cities that could have developed risk assessments might not be represented in this survey, and as such these results might provide a partial and incomplete picture of the current situation. In the future this indicator will build on different national and regional sources of data, including at least one city per region, to overcome this limitation.

## Climate information services for health

***Headline finding.*** As of November 2020, Italy had not reported whether its national meteorological and hydrological services provide climate services and tailored information to the health sector.

Health system adaptation is essential to minimise the health impacts on populations of the changing climate. This requires the early identification of climate-related health risks that can inform the development of early warning systems, rapid response measures, and adaptation interventions. National Meteorological and Hydrological services (NMS) play a central role by providing tailored climate services to inform the identification of those risks.

This indicator, equally to that in the 2021 global Lancet Countdown report (indicator 2.2) (4), tracks the use of climate information service for health based on the Italian Country Profile Database Integrated questionnaire of the World Meteorological Organisation (WMO).

The WMO helps governments to develop reliable and fit-for-purpose, climate and impact-based services to prepare against climate-related risks, according to international standards and recommended best practices. Among its activities, WMO tracks the extent to which NMSs provide services to health sector, through their Country Profile Database Integrated questionnaire, which has the purpose of providing a summary of information to support the national actions.

As of November 2020, however, Italy had not disclosed whether its NMS provided services to the health sector, representing a missed opportunity for engagement with, and for receiving guidance from, the WMO. This indicator will be in future adjusted to account for the local situation in Italy, where regional and national weather services (Centro Nazionale di Meteorologia e Climatologia Aeronautica, Protezione civile, and Agenzia Regionale per la Protezione dell'Ambiente) provide weather warnings and forecast for different sectors including health. A more effective engagement of the Italian meteorological services and the new national Agency ItaliaMeteo in the WMO activities via sharing information on organization of climate information services for health, identifying gaps, and implementing information-based actions would help to reduce climate-related health risks.

## Urban green space

***Headline finding.*** Despite every Italian city with over 500,000 inhabitants experiencing an increase in urban greenness between 2010 and 2020, the absolute average level of greenness in Italian urban centres, weighted according to the local population, remained low in 2020. Inequities in green space availability between Northern and Southern regions of Italy also persisted, with Naples and Palermo recording the lowest levels of urban greenness in both 2010 and 2020.

When designed keeping considerations of human health at their centre, improving access and availability of urban greenspace can have important benefits to human physical and mental health, including through reduced exposure to air pollution, increased social interaction, and more physical activity (37,38). Green spaces also contribute to climate change mitigation and adaptation by sequestering carbon and delivering local cooling benefits.

This indicator uses data from the 2021 global Lancet Countdown report (indicator 2.3.3) (4) to provide an estimate of the amount of greenspace coverage in urban centres with over 500,000 inhabitants, using the satellite-based Normalized Difference Vegetation Index (NDVI) categorised as previously described (4). To assess human exposure to greenspace, as well as its urban distribution, the urban NDVI level is presented as a population-weighted average at a spatial resolution of 30 arc-seconds (approximately 1km x 1km). Because of the population size restriction in this indicator, only the six Italian cities with over 500,000 inhabitants were included in the analysis: Genoa, Milan, Naples, Palermo, Rome, Turin.

Averaged across the six Italian urban centres sampled, the population-weighted peak NDVI in Italian cities increased of 19% from 2010 to 2020 (population-weighted mean NDVI 0.32 to 0.38). This varied between an 8% increase in Rome and a 27% increase in Milan (Figure A7).

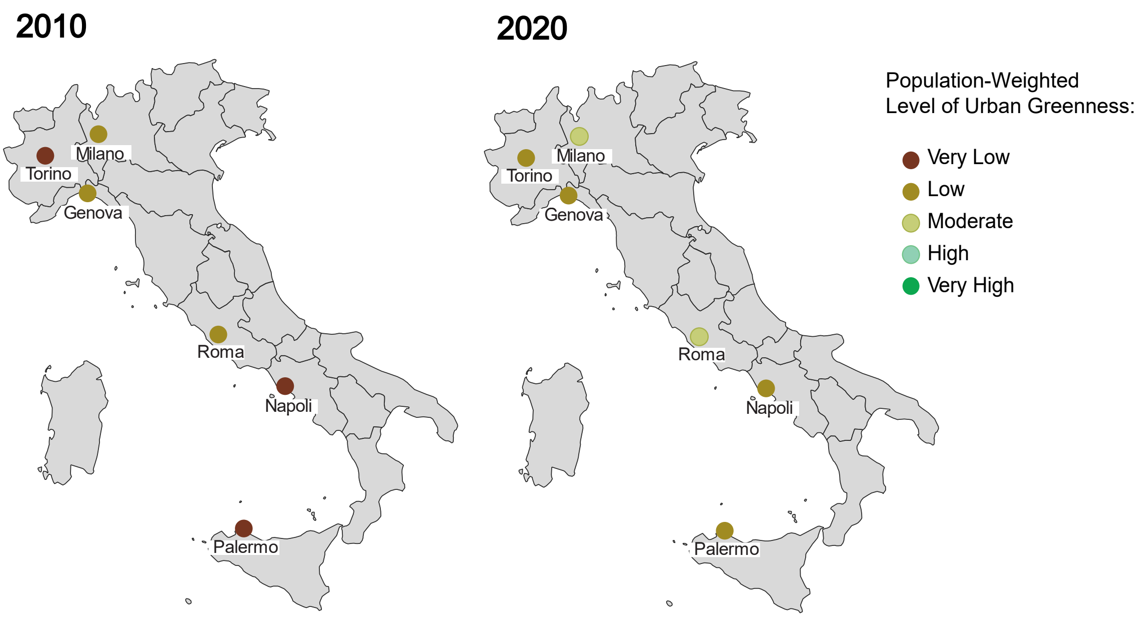



**Figure A7. Level of urban greenness in Italian urban centres with over 500,000 inhabitants in 2010 and 2020**

Rome and Milan were also the only two Italian urban centres classified as moderately green or above in 2020 (population-weighted peak NDVI of 0.42 and 0.43 respectively). However, despite this progress, the overall average level of green space in the mentioned Italian urban centres remained low in 2020 (population-weighted mean NDVI 0.38). Notably, this is lower than the population-weighted mean urban NDVI in 26 of the 48 nations within the WHO European Region included in the sample. Moreover, data exposed persisting inequalities in the availability of green space between cities in Northern and Southern regions of Italy, with Naples and Palermo recording the lowest population-weighted peak NDVI in both 2010 (population-weighted peak NDVI of 0.29 and 0.28 respectively) and 2020 (population-weighted peak NDVI of 0.34 and 0.31 respectively).

These results reinforce the importance of local decision makers across Italy increasing access to urban green spaces that are safe and enjoyed by everyone. With their potential to simultaneously improve health outcomes, reduce health inequities, and facilitate climate mitigation and adaptation, urban green space design must involve interdisciplinary experts to ensure the health and environmental benefits are maximised (39).

## Conclusions

With the impacts of climate change continuing to rise, risk assessment and implementation of adaptation interventions is urgently needed to protect the health of Italian populations. However, the adoption and implementation of adaptation plans has been slow in Italy. Despite the growth of regional and local initiatives, without a central guidance, universality of health protection from risks related to climate change cannot be guaranteed by the National Health System. Differences in the rollout and availability of adaptation measures in different regions, such as those observed in the availability of urban green spaces between Northern and Southern cities, clearly demonstrates that health inequities can be accentuated without central guidance. Concerningly, the health risks of climate change are not adequately addressed by current policies, particularly exposed by the fact that the NAP does not formally include health considerations. This suggests that the health of people in Italy will be increasing unprotected from the rising hazards from climate change, unless urgent action is taken.

Nonetheless, the lack of centralised monitoring on climate change adaptation also means that there is a scarcity of data collected that can reflect the current situation – and therefore our analysis cannot be exhaustive. It is therefore important that mechanisms are put in place to track the implementation of further adaptation and maladaptation measures (including the use and availability of cooling systems, the implementation of climate-resilient infrastructure, and the implementation of early warning systems, among others), that can enable decision makers in Italy to monitor progress and develop evidence-based policies that can protect the health of Italian population in the face of the changing climate.

# Mitigation actions and health co-benefits

In Italy, greenhouse gas emissions reduced from 519 to 418 $CO_2$ equivalent million tons ($MtCO_2$ eq) between 1990 and 2019, for a total decrease of 19.5% (40). Despite this moderate progress, Italy should decrease greenhouse gas emission by 17 $MtCO_2$ eq per year from 2020 to reach the EU target of a 55% reduction by 2030, followed by a cut of 12 $MtCO_2$eq per year over the subsequent 20 years to reach net zero emissions by 2050. Concerningly, Italy is not on track to meeting this ambition, particularly since the trend of decrease in greenhouse gas emissions flattened in the last 5 years, with a mean reduction of only 1 $MtCO_2$eq per year between 2015 and 2019 (40). Restrictions linked to the COVID-19 pandemic offered an opportunity to accelerate the reduction of greenhouse gas emissions, with an estimated 9% decrease in 2020 compared to 2019 (41). However, this decrease was transient, and is likely not to contribute to emissions reductions in the long term. Moreover, the implementation of the measures described in the Italian national energy and climate plan (NECP) would fail in achieving net zero emissions, with an estimated residual of 220 $MtCO_2$ eq in 2050 (42).

Accelerated action towards decarbonisation can not only prevent the most extreme impacts of climate change, but also deliver substantial and immediate health co-benefits through cleaner air, healthier lifestyles, and better diets. This section tracks the effort Italy made towards ensuring a reduction in greenhouse gas emissions, and in delivering the associated health co-benefits. Indicators track progress towards the decarbonisation of the energy system, air pollution reduction, shift to sustainable transportation modes, emissions from agricultural products and the associated health impact of red meat consumption, and progress towards reducing greenhouse emissions from the health system.

## Energy system and health

***Headline finding.*** At the pace of decarbonisation observed from 2015 to 2020, it would take Italy 79 more years, starting from 2020, to fully decarbonise its energy system. After a fast growth, electricity generation from new renewables has stalled in recent years, and represented in 2019 only 17% of the total electricity production.

Fossil fuel combustion within the energy system is the largest single source of greenhouse gas emissions, with a global share of 65% of all emissions (43). A rapid shift to renewable energy use is crucial, not only to mitigate these emissions, but also to prevent deaths due to ambient air pollution from fossil fuel burning.

Following the approach of the 2021 global Lancet Countdown report (indicator 3.1) (4), and drawing on data from the International Energy Agency (IEA), this indicator tracks three components: the carbon intensity of the energy system in Italy; coal phase-out; and electricity production from "new renewables" (solar, wind, geothermal, tidal and wave energy).

The carbon intensity of the energy system in Italy has been declining slowly, reaching in 2019 its lowest value since at least 1970, with a reduction of 25% since that year (Figure A8). However, at the pace of decarbonisation observed since 2015 (the year the Paris Agreement was signed), it would take Italy 79 more years to fully decarbonise its energy system, given the carbon intensity of 48.5 tCO2/TJ registered in 2020 (with a mean ~0.61 $tCO_2$/TJ reduction per year over the 6-year period 2015-2020) (Figure A8).

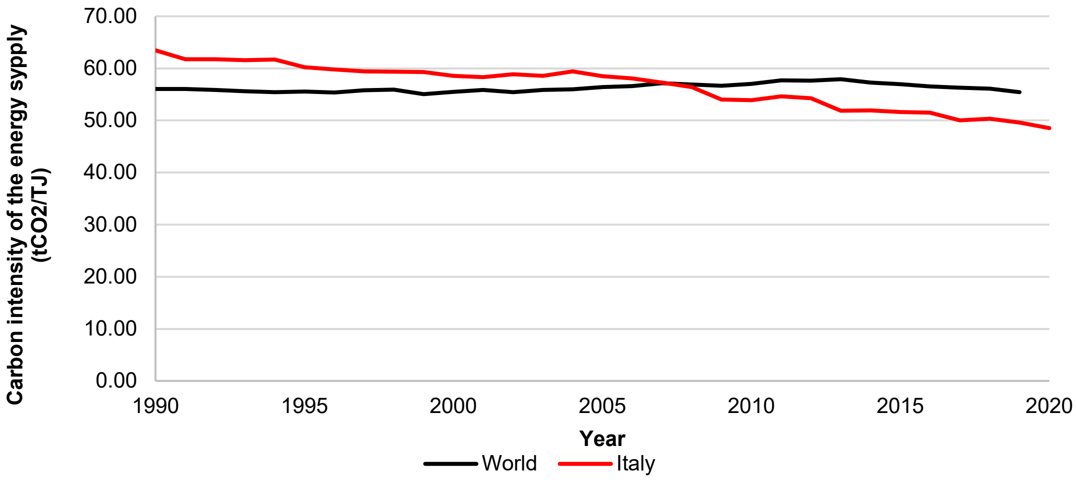



**Figure A8. Carbon intensity of the energy system in Italy and the world. Data source: International Energy Agency**

However, in recent years, Italy has made good progress in reducing its coal consumption: while 16% (45.4 TWh out of 281.6 TWh) of its electricity was produced from coal in 2015, this figure reduced to 6% in 2019 (17.9 TWh out of 290.0 TWh) (Figure A9). Yet, despite this progress, with coal burning resulting in the emission of dangerously high levels of health-harming air pollution, much is yet to be done to decarbonise Italy's energy system while protecting the health of its population (Figure A9). Concerningly, most of the reduction in electricity generation from coal between 2015 and 2019 has been met with an increase in the electricity generated from natural gas, which made up 49% (143.2 TWh out of 290.0 TWh) of all the electricity produced in Italy in 2019 – 10 percentual points more than in 2015, when it contributed to 39% (110.9 TWh out of 281.6 GWh) of the electricity produced. The Integrated NECP set a target of generating 55% of the total electricity from renewables by 2030 (44). However, after some fast progress in the early 2010s, the transition towards electricity generation from new renewables (geothermal, solar photovoltaics, solar thermal, tide, wave and ocean, and wind energy) in Italy has stalled in recent years, and only 17% (50.7 TWh of 290.0 TWh) of the total electricity produced in 2019 came from these sources – just one percentual point more than in 2015, when it represented 16% of all the electricity produced (44.6 TWh of 281.6 TWh) (Figure A9).

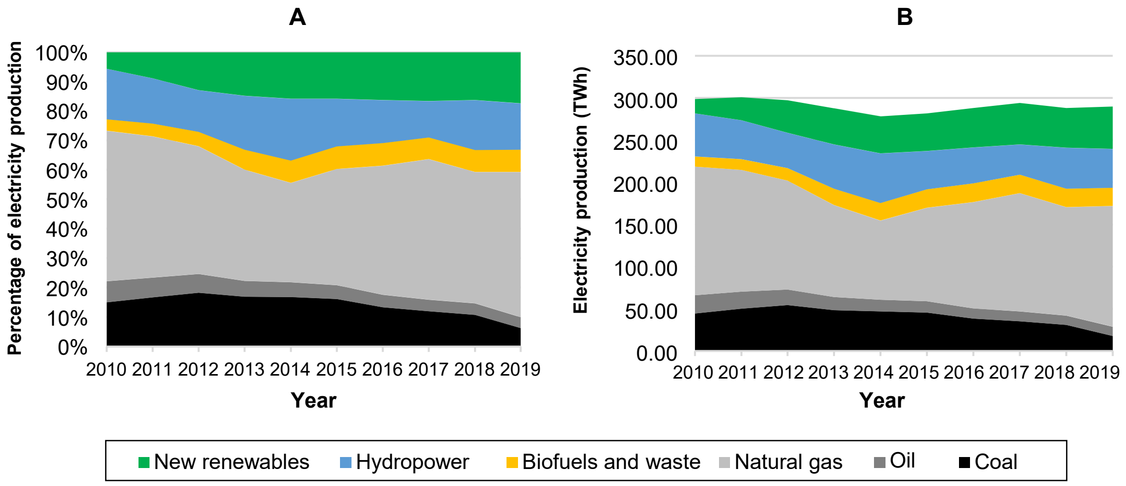



**Figure A9. Electricity production in Italy by source from 2010 to 2019, presented as percentage of total electricity produced (A), and as total electricity produced in terawatt-hours (B). Data source: International Energy Agency**

In parallel, from 2015 to 2019, the electricity generated from other renewable sources that have a higher environmental footprint, such as hydropower, biofuels and waste, has not increased either: 7% of all the electricity generated in 2019 (21.6 TWh out of 290.0 TWh) came from biofuels and waste, one percentual point less than in 2015 (8%) (21.8 TWh of 281.6 TWh). Meanwhile, hydro energy represented 16% of all electricity generated both in 2015 and in 2019 (45.4 TWh of 281.6 TWh and 17.9 TWh of 290.0 TWh, respectively). Under current trends, and unless immediate action is taken to accelerate decarbonisation, Italy is not on track to meet its planned decarbonisation targets.

## Premature mortality from ambient air pollution

***Headline finding.*** In 2019, Italy was the second country with the highest number of deaths attributable to anthropogenic PM2.5 air pollution in the EU.

The burning of fossil fuels, biomass, and the unsustainable use of fertilizers and manure in agricultural practices, not only contribute to climate change through greenhouse gas emissions, but also to air pollution. Exposure to air pollution leads to respiratory infections, loss of function, and aggravated asthma in children, preterm birth and other causes of death in children, as well as increasing the risk of cardiovascular disease, cancer, and neurodegenerative conditions in adults (45). Indeed, air pollution was labelled "one of the biggest environmental threats to human health" in the latest WHO air quality guidelines (45).

Despite in the WHO guidelines the greatest attributable disease burden was seen in low- and middle-income countries, pollutant concentrations still exceed the levels published in Global update 2005 for several pollutants in high-income countries as well. If developed keeping health considerations at their centre, action to mitigate climate change therefore offers major health opportunities through the co-benefit of reduced air pollution.

Data from the 2021 global Lancet Countdown report suggests that, in 2019, Italy was the second county with the highest number of premature deaths attributable to anthropogenic $PM_{2.5}$ air pollution in the EU, only after Germany (15). Nonetheless, Italy has made some progress towards reducing air pollution, which resulted in a 15% reduction in deaths attributable to exposure to $PM_{2.5}$ from 2015 to 2019.

As described in the chapter "Health impact of temperature and air pollution in Italy" of this report, an indicator is currently being refined by the DEPLAZIO to produce more granular estimates for Italy. In brief, DEPLAZIO has defined high spatial scale resolution (1x1km) particulate matter ($PM_{10}$ and $PM_{2.5}$) air pollution exposure data (*see* Figure 3 in chapter "Health impact of temperature and air pollution in Italy") (46), which was used to estimate health effect estimates and impacts at both national and regional level, based on ongoing research in the national context.

In brief, for short-term exposure to air pollution, risk estimates were calculated using time series data on municipality level mortality counts to quantify the numbers of premature all-cause deaths due to daily exceedances in $PM_{10}$ and $PM_{2.5}$ above the WHO's 2005 air quality guideline thresholds and more recent 2021 (45). For long-term impacts, risk estimates from the literature were applied to fine scale population data to quantify the number of deaths attributable to annual PM concentrations above Standards and the 2021 updated WHO air quality guideline thresholds (46). The long-term impact study conducted on 2016-2019 reports around 50000 deaths attributable to $PM_{2.5}$ (8.3% of total deaths for all-natural cause) and around 22000 deaths attributable to $PM_{10}$ every year in Italy.

## Sustainable and healthy transport

***Headline finding.*** Fossil fuels largely dominate road travel in Italy, accounting to 96% of all the energy used for this purpose in 2017. The use of electric vehicles remains very limited, and in 2017 represented only 0.026% of all the energy used for road travel.

With road transport accounting for nearly 18% of global $CO_2$ emissions in 2019, the shift to electric vehicles is an important climate change mitigation measure (47). The promotion of walking and cycling (active travel) could not only cut emissions, but also provide enormous health dividends through the increase of physical activity and the reduction of air pollution (48). This indicator expands on the approach of the 2021 global Lancet Countdown (indicator 3.4) (4), using data from the IEA and from the Italian Ministry of Transport, to monitor fuels used for road transport and electric vehicles (49-51).

The carbon intensity of road transport has remained stable in Italy since 1990 (Figure A10).

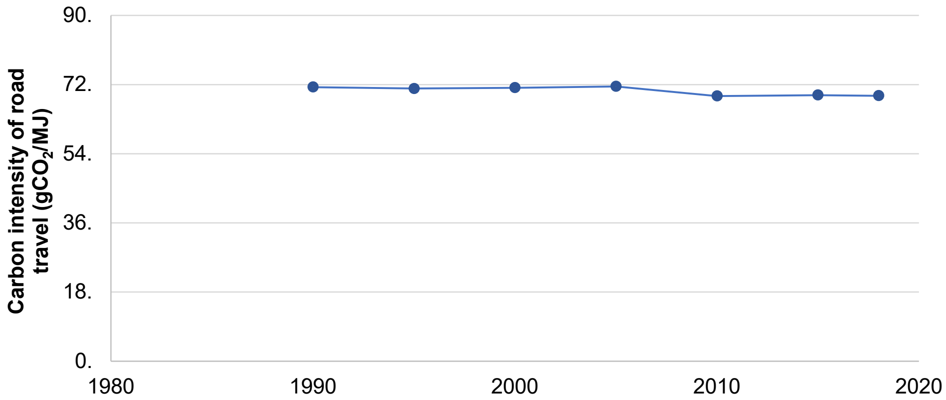



**Figure A10. Carbon intensity of road travel in Italy. Data from the International Energy Agency**

While the energy used for road travel have been on a downward trend in Italy since 2006 (Figure A11), this is most likely a reflection of a reduced use of road travel for the transport of goods, which had decreased by 45% in 2018 with respect to the 2005 level (Figure A12). Car traffic, on the contrary, was in 2018 38% higher than in 1990, and still represented 87% of all passenger road travel (Figure A12).

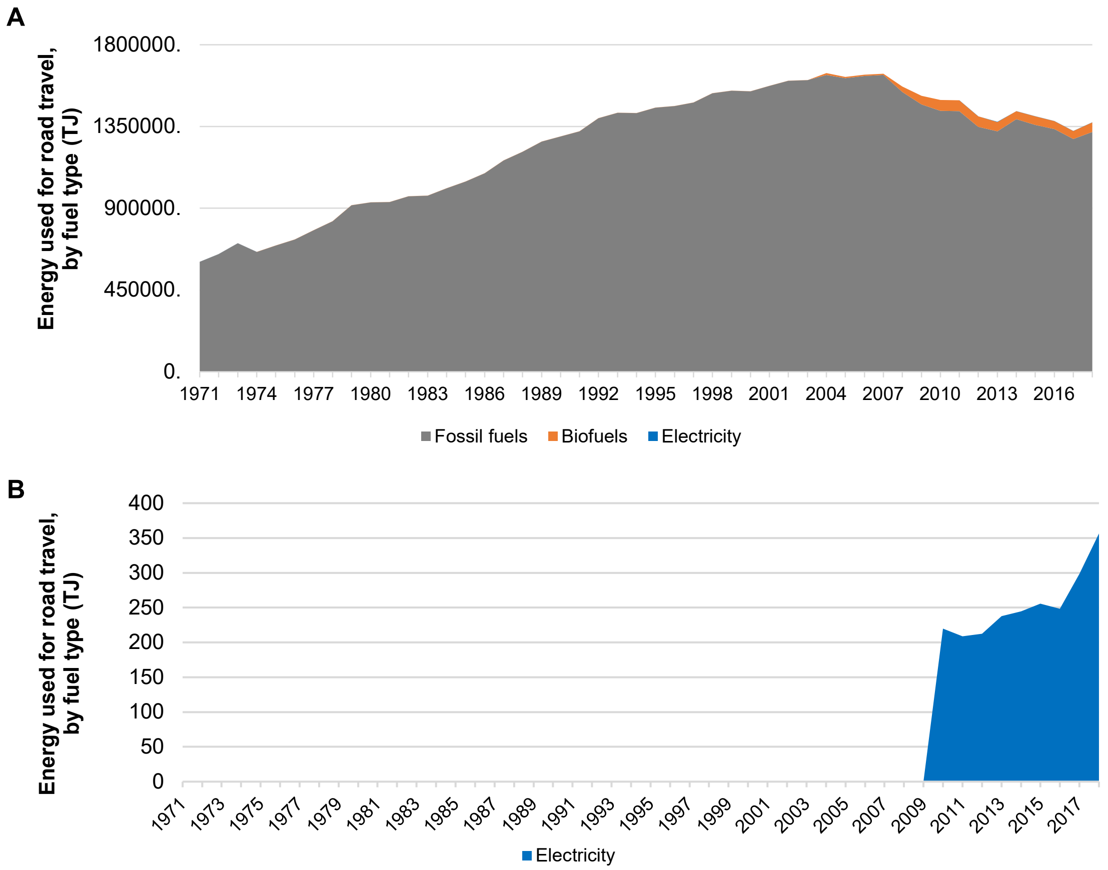



**Figure A11. Energy used for road travel in Italy, by fuel type. The use of electricity, in 2017, accounted for a 0.026% of total energy used for road travel, and are therefore not visible in the top graph: A. emissions from fossil fuels, biofuels and electricity. B. Emissions from electricity alone**

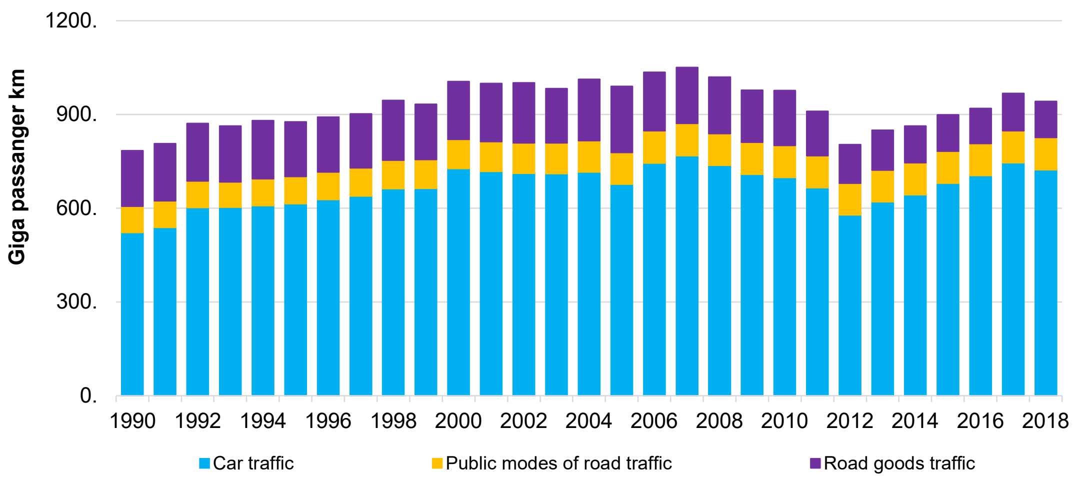



**Figure A12. Passenger and goods road traffic in Italy.**
**The bar charts represent the distance travelled by passenger using car or public transport (primary y axis) using data from the ministry of transport. The line graph represents the total kilometres travelled by road for the transport of goods (secondary axis) using data from ISTAT**

Italy's long-term strategy to achieve net zero emissions includes shifting toward renewables and electro mobility with the goal of reaching 19 million of Battery Electric Vehicles (BEVs), equivalent to 80% of the total vehicle fleet, and 4 million of hydrogen cars, equivalent to 17% of the fleet, by 2050 (42). However, the use of electric vehicles still remains very limited in the Country, and in 2017 electricity still represented only a 0.026% of all the energy used for road travel (Figure A11). Fossil fuels still largely dominate road travel, accounting to 96% of all the energy used (Figure A11).

Shifting away from fossil fuel use in road travel would not only lead to reduced greenhouse gas emissions and reduced air pollution in urban centres, but would also lead to health gains from more active lifestyles if active forms of travel are promoted.

## Emissions from agricultural consumption

***Headline finding.*** In 2018, the greenhouse gas emissions driven by consumption of agricultural goods had fallen by 27% in Italy since 2000. A reduction of consumption of cattle red meat, which still contributed to 44% of all greenhouse gas emissions from agricultural product consumption in 2018, would lead to both climate and health gains.

Food systems, including agricultural production, are responsible for 21-37% of all greenhouse gas emissions, while also holding high carbon sequestration potential (52). This makes them key to limiting global warming to 1.5°C.

This indicator, presented in the 2021 global Lancet Countdown report (indicator 3.5.1) (4), tracks emissions from agricultural consumption of food products, modelling the emissions from each commodity and taking into account data on the consumption of agricultural products, and their trade balances from the Food and Agriculture Organization of the United Nations (FAO) (53). For a full description of this indicator and its modelling, see the 2021 global Lancet Countdown report (4).

Data from this indicator shows that *per capita* greenhouse gas emissions resulting from the consumption of agricultural goods, had fallen 27% by 2018 with respect to the year 2000 in Italy (Figure A13).

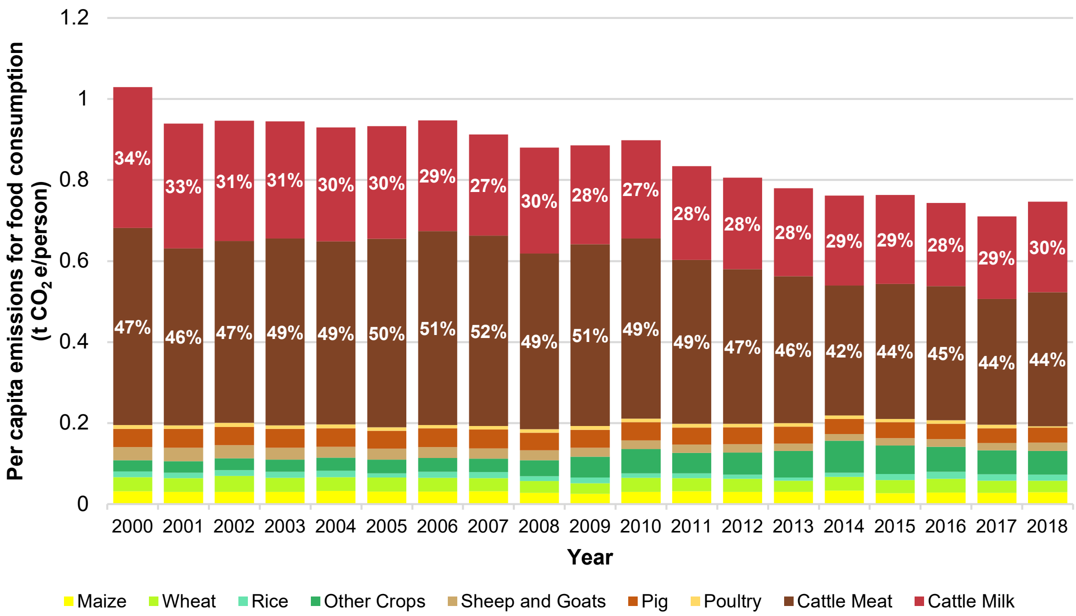



**Figure A13.** ***Per capita*** **yearly greenhouse gas emissions associated with consumption of agri-food products, by commodity. Percentages represent the percentage over total greenhouse gas emissions associated with consumption of agri-food products per each year by commodity**

This was driven primarily by a 34% reduction of emissions related to the consumption of cattle meat and dairy products. However, emissions from consumption of animal products still contributed to 82% of all agricultural consumption-based emissions in 2018. The consumption of products derived from cattle were the main contributors, accounting for 74% of all emissions from the consumption of agricultural products that year – with the consumption of cattle red meat accounting for 44% of all agricultural consumption-based emissions. With current production efficiency interventions failing to curb or reduce agricultural greenhouse gas emissions, dietary shifts – greatly reducing red meat and increasing plant-based foods – are necessary, and would save thousands of lives per year from reduced red meat consumption, as detailed below (48).

## Diet and health co-benefits

***Headline finding.*** In 2018, almost 17000 deaths in Italy were attributable to excess red meat consumption. Shifts towards plant-forward diets can therefore offer major benefits both in terms of climate change mitigation, and of better health.

As the previous indicator shows, the consumption of animal-derived foods, particularly red meats, are a leading source of agricultural emissions in Italy. Importantly, their excessive consumption is also associated with adverse health outcomes.

This indicator, taken from the 2021 global Lancet Countdown report (4), models the deaths attributable to red meat consumption, by linking food consumption estimates from the FAO, with previously-published dietary relative risk parameters. Using this approach, it estimates that almost 17000 deaths (corresponding to a 15% of all deaths attributable to dietary risk factors) were attributable to excess red meat consumption in Italy in 2018 – up by 2% from the previous year. Concerningly, this makes Italy the second country with the highest number of deaths attributable to excess red meat consumption in the EU, only after Germany.

A previous study conducted in Italy evaluated the health co-benefits and decrease in greenhouse gas emissions by changing dietary habits and reducing meat consumption (54). Considering different meat reduction scenarios, around 4% of colorectal cancer and cardiovascular deaths would be avoided with some geographic heterogeneity, while a reduction in emissions due to dietary changes would be in the range of 8000-14000 greenhouse gas emissions $CO_2$ eq per year (54). Reducing red meat consumption in Italy therefore offers the opportunity of simultaneously curbing agricultural greenhouse gas emissions, and improving the health of Italian populations.

## Healthcare sector emissions

***Headline finding.*** The Italian health system has amongst the highest levels of Health care Access and Quality Index (HAQ) and, as compared to other national health systems with similar rankings, it is amongst the ones with lower levels of emissions *per capita*. Nonetheless, at almost 449 kg$CO_2$e/inhabitant in 2018, it is still a major contributor to greenhouse gas emissions in the country.

The healthcare sector is central to improving human development. In providing services, healthcare systems mobilise a vast array of products and use energy in various forms, all of which result in emissions of greenhouse gases and other pollutants that can be traced throughout global supply chains.

This indicator, presented in the 2020 global Lancet Countdown report (indicator 3.6) (55), tracks both direct and indirect emissions from the global healthcare sector using environmentally extended multi-region input-output (EE MRIO) models, combined with annual data on national healthcare expenditure provided by the WHO.

Italy is amongst the countries with the highest healthcare quality, as measured by the healthcare access and quality index (HAQ) – and still, it is also one of the countries with the lowest emissions in the healthcare sector as compared to other countries with similar levels of HAQ index (Figure A14). This reflects the efficacy of resource used in the healthcare sector.

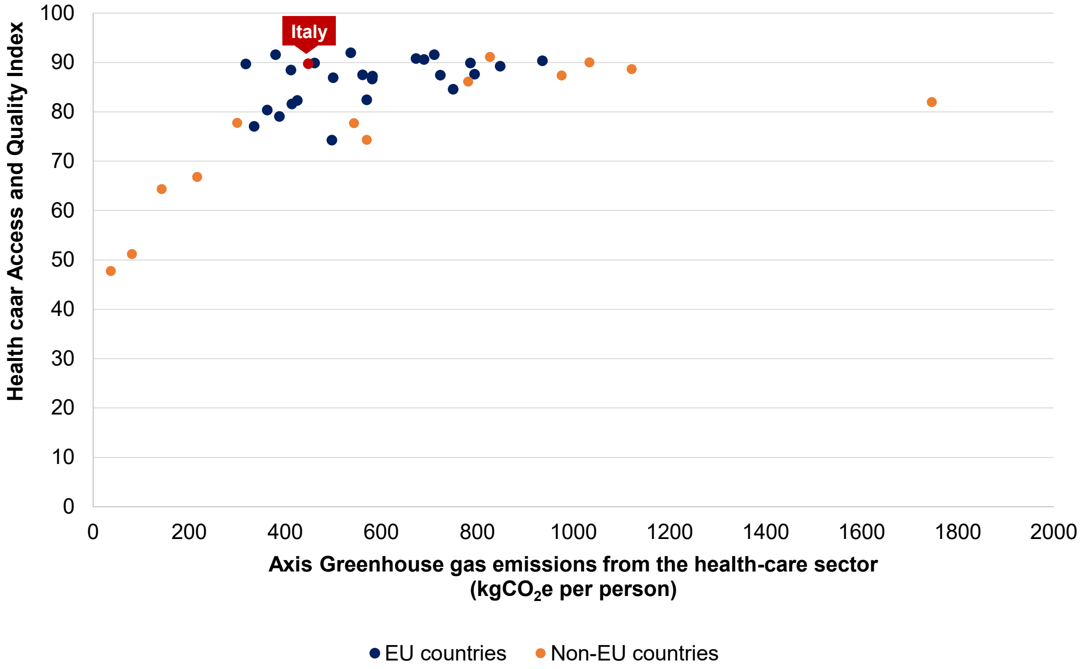



**Figure A14. National *per capita* healthcare greenhouse gas emissions for 2017 against 2015 HAQ index. Reproduced from the 2020 global Lancet Countdown report (55). Each circle represents a country**

However, the Italian health system has not made significant progress in reducing its emissions, and on a *per capita* basis these have remained fairly stable since 2005, at 449 $kgCO_2e$ per inhabitant (Figure A15). In acknowledging the health impacts of climate change, the health sector must lead the decarbonisation efforts if it is to deliver healthcare without doing harm.

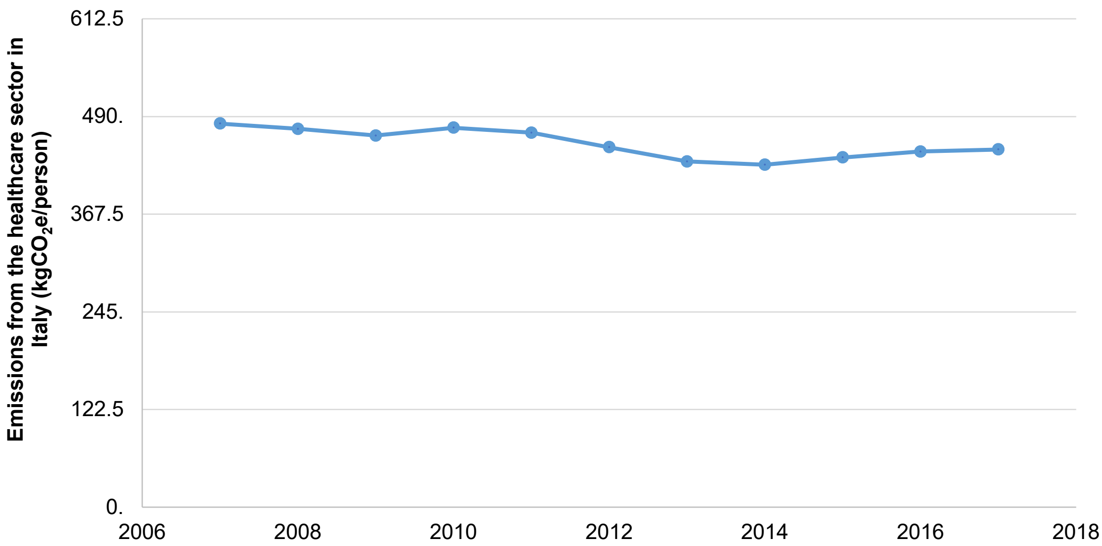



**Figure A15. Greenhouse gas emissions of the healthcare sector in Italy, *per capita***

## Conclusions

Although Italy has made some progress on reducing its greenhouse gas emissions since 1990, all the 6 indicators presented in this section show that the pace of reduction is insufficient to meet the current commitments and would contribute to a world of catastrophic levels of warming in the next decades. At present, 6% of the energy supply in Italy comes from the burning of coal, fossil fuels largely dominate road travel and animal products are the largest contributors of agricultural consumption-based emissions. Accelerated decarbonisation therefore offers not only the possibility of delivering a sustainable, safer future, but would also deliver immediate health benefits to Italian populations through cleaner air, more physical activity and healthier, low-carbon diets.

# Economics and finance

Climate changes impact health directly through exposure to climate hazards, as well as indirectly by affecting social and economic systems, and thus undermining the social determinants of good health (55, 56). The economic costs of climate change are diverse, and include loss of labour due to heat exposure, disease, loss of capital and infrastructure, or climatological disruption; the disruption and loss of physical assets caused by climate change-related extreme events; and the costs to the health system of the direct human impacts of climate change; among others (55).

In parallel, the shift to a low carbon, healthy future requires the rapid transition of economic and financial systems. Despite the near-term costs of decarbonising economic systems, previous studies estimate that accelerated action to limit warming to 1.5ºC by the end of the century would generate a net economic benefit in the order of trillions of US dollars (58). For the economic transition to be possible, the full economic costs of climate change must be taken into account in economic valuations. This section explores one of the key aspects of this transition: the pricing carbon emissions and the value of fossil fuel subsidies. Given the health effects identified in the Section 1 related to climate changes, indicators that monitor the economic losses due to heat air pollution mortality will be developed in the future.

## Net value of fossil fuel subsidies and carbon prices

***Headline finding.*** Italy still had a net-negative carbon price in 2018. The resulting net loss of revenue was equivalent to 4.77% of its national health budget.

Carbon pricing instruments can provide financial incentives that promote the transition towards a low-carbon economy, and help reflect the real cost of fossil fuels burning and its negative externalities. However, few countries around the world have implemented carbon prices, and in many cases are still devoting public funds to subsidising fossil fuels (55). Indeed, a recent analysis from the International Monetary Fund reported that fossil fuels were subsidised for a total of US$6 trillion globally in 2020– equivalent to 6.8% of global GDP (59).

This indicator, taken from the 2021 global Lancet Countdown report (indicator 4.2.4) (4), takes into account all carbon pricing instruments and fossil fuel subsidies, and calculates the annual ‘net’ economy-wide average carbon prices and revenues from the consumption of fossil fuels in each country.

Despite Italy operating under the EU Emissions Trading System (EU ETS), data from this indicator shows that it was still significantly subsidising fossil fuel burning in 2018 (including through both tax expenditures and budgetary transfers), with a net negative carbon price of US$ 28.0 (real 2020 US$) per tonne of $CO_2$ released into the atmosphere. Taking into account all emissions, Italy spent US$ 8.9 billion (real 2020 US). Importantly, these funds are equivalent to 4.77% of all national health spending that year, representing the same amount that is financed each year for disease prevention in Italy. Correcting these distortions could deliver enormous benefits to human health and wellbeing, both through the reduction of fossil fuel burning, and for the redirection of public funds towards public health prevention, health-care and health-related services.

## Conclusions

With the high level of taxation in Italy, redirecting public spending towards public health prevention, health-care and health-related services, Italy could deliver significant net benefits to its entire population. Furthermore, the transition to a low-carbon economy could see a net job generation and economic activity in the renewable energy and energy efficiency sectors (60), and could secure net economic benefits from the transition to a healthier economy .

## Public and political engagement

Action to protect health in the face of the changing climate requires, first and foremost, for the key actors in society to acknowledge and engage with the interlinkages between climate change and health. Engagement from policy makers is paramount to drive change and, especially in a democratic country like Italy, public engagement is central to driving political action. Scientists, as recognised and respected experts, also have a major role to play: they can shape climate action by promoting understanding and generating sound evidence the impacts of climate change, and the benefits of accelerated action. This section monitors these aspects by tracking engagement in climate change and health from the scientific community and political leaders in Italy.

### Coverage of health and climate change in scientific journals

***Headline finding.*** Original research on health and climate change increased from only 3 published original research articles in 2007 to 29 articles in 2020.

Scientific evidence is a key in enabling evidence-based decision making for health and climate change, and is critical in shaping public and political engagement in these issues (61, 62). The indicator, presented in the 2021 global Lancet Countdown report (indicator 5.3) (4), is based on searches in OVID Medline and OVID Embase, using references to health and climate change in article titles and abstracts.

Scientific engagement on health and climate change led by authors in Italy saw an almost tenfold increase between 2007 and 2020 (Figure A16). In 2020, Italy was the 9$^{th}$ country in the world with the highest number of original research articles on health and climate change led by local researchers.

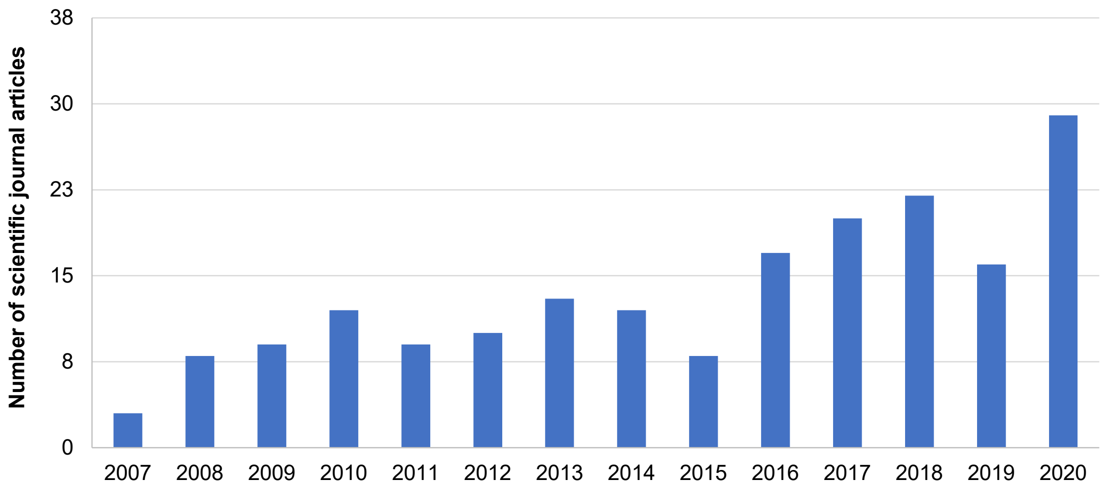



**Figure A16. Scientific journal articles relating to health and climate change led by researchers in Italy**

The increase engagement of the scientific community on health and climate change is a promising trend, which will generate better evidence to tailor interventions that maximise human health. Nonetheless, the transfer of that evidence into policy will require increased collaboration between the academic and public sectors, as well as political commitment to engage with the scientific community, and respond to the evidence generated.

## Government engagement in health and climate change

***Headline finding.*** Italian policy makers have only just begun to engage with the links between climate change and health in the UN General Debate speeches, first making reference to these interconnected issues in the 2016 UNGD speech, and making three mentions to it in the 2020 speech.

With the rising health risks posed by climate change, government engagement on this issue is essential to promote rapid action to protect human health. This indicator, taken from the 2021 global Lancet Countdown report (indicator 5.4) (4), examines the engagement of the Italian government with health and climate change, in its UN General Debate (UNGD) statements. During the UNGD, which open each year the UN General Assembly sessions, UN member states have the opportunity of addressing the global community, and communicate their priorities. By searching for health and climate change key words in the UNGD corpus using natural language processing, this indicator monitors the mentions to health, climate change, and to the intersection between these topics in Italy's annual address (63).

Figure A17 shows that, while Italian representatives have often made mentions to health in their UNGD statements, engagement with health has increased sharply in 2020, a trend that was driven by the ongoing COVID-19 pandemic. Mentions to climate change only started becoming frequent since 2007, often since being more frequent than mentions to health. Nonetheless, Italy has only just begun to engage with the link between climate change and, health making only one mention to the intersection between these topics in 2016, and three mentions in 2020.

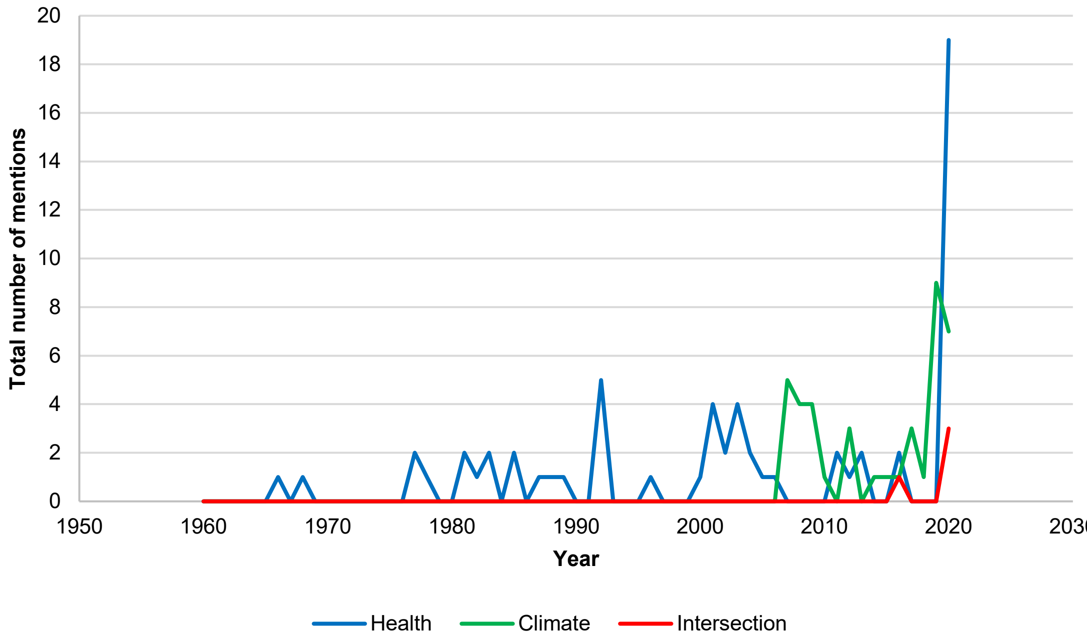



**Figure A17. Total number of references to health (blue), climate change (green), and to the intersection between health and climate change (red) made by Italy in its annual UNGD statements**

## Conclusions

The scientific community in Italy is increasingly exploring the link between climate change and health, and Italian researchers are amongst the world's most engaged with this field. On the other hand, while political engagement with climate change has grown over the past years, the Italian government has only just begun to engage with the link between health and climate change, as exemplified by the fact that this link was mentioned only 3 times in Italian official UNGD statement of 2020. For the evidence produced by scientist to be effectively translated into policies that protect health, increased political engagement is therefore essential.

As host in 2021 of the preparatory meetings of the 26$^{th}$ Conference of the Parties of the UN Framework Convention on Climate Change, Italy is in a unique position to influence the agenda of the climate negotiations, and ensure health is protected for populations in Italy and beyond.

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# APPENDIX B
# Methods to assess temperature effect on mortality

# Estimate of mean temperature exposure

To estimate daily mean air temperature at the national level we selected and merged multiple sources of data:

- Daily mean air temperature observations from approximately 400 Italian monitoring stations;
- Spatial data on: climatic zones, population density, anthropogenic areas, road networks, land cover, etc. downscaled at a fixed squared kilometre spatial resolution
- Spatio-temporal satellite-based data on Land Surface Temperature (LST), with daily temporal resolution and squared kilometre spatial resolution (source: NASA)
- Spatio-temporal model-base data on meteorological parameters and vegetation indexes, with daily temporal resolution and 10x10-km$^2$ spatial resolution (meteorological parameters) or squared kilometre spatial resolution (NDVI) (sources: ECMWF, NASA)

Once all these data have been brought to a common grid, we developed a three-stage approach based on multivariate mixed-effects regression models:

- First stage: we built a multi-variate mixed-effects regression model with air temperature as the target variable, and spatial and spatiotemporal covariates as predictors, the most important of them being LST. The analysis we nested by climatic zones to better capture local climatic differences across Italy. We carefully checked variable importance statistics and cross-validated the models by splitting the monitors into training and testing groups multiple times
- Second stage: we predicted the output of the model in the entire Italian domain with non-missing information on LST
- Third stage: we imputed missing predictions in places/days with no LST by fitting an additional mixed-effects regression model having the output of stage 2 as the target variable, and inverse-distance weighted air temperature from monitors as the main predictor. In this way we obtained estimates of daily mean air temperature for each squared kilometre of Italy (years 2001-2015)

# Statistical analysis of health effect estimates

The relationship between daily mean air temperature and daily mortality was estimated using a two-stage approach: firstly, we modelled municipality specific daily time-series within each province by applying the Distributed Lag Nonlinear model (DLNM) approach, a flexible technique to estimate complex non-linear and lagged dependencies through bi-dimensional functions that specify exposure–response and lag-response relationships, combined in a cross-basis function.

Namely, we applied a conditional Poisson regression and for each municipality i, in province j, at day t, we modelled death counts $y_{tij}$ as:

$$g\left[E(y_{tij})\right] = f\left(x_{tij}, l; \theta_j\right) + mun_i * year_t * month_t * dow_t + pop_t + ie_t + hol_t$$

where $f\left(x_{tij}, l; \theta_j\right)$ represents the aforementioned crossbasis, $mun_i * year_t * month_t * dow_t$ is a quadruple interaction among municipality, year, month and day of the week, $pop_t$, $ie_t$ and $hol_t$ represent indicator variables for summer population decrease, influenza epidemics and bank holidays respectively. We modelled the exposure-response curve with a natural cubic B-spline with three internal knots placed at the 10th, 75th, and 90th percentiles of location specific temperature distributions, and the lag-response curve with a natural cubic B-spline with an intercept and three internal knots placed at equally spaced values in the log scale. We considered a 0-21 lag window to take into account both the long delay of cold effects and the potential harvesting effect during hot days. A quadruple interaction term was fit to control municipality specific long trends and seasonality. This choice was driven by the theoretical equivalence of such an approach to the “time stratified” case crossover analysis with controls selected in the same municipality, year, month and day of the week in which the death was observed. We then reduced the association to the overall temperature–mortality association, cumulating the risk during the lag period.

Secondly, we pooled the reduced coefficients in a multivariate meta-regression to derive an overall national dose-response curve and the best linear unbiased prediction (BLUP) of the dose-response association in each province. Figure 3, in chapter "Health impact of temperature and air pollution in Italy" of this report, shows the mean temperature-mortality curve for Italy grey lines representing province specific curves and the bold coloured line the overall curve (red heat effects, blue cold effects).

The heat effect estimates were defined as the Relative Risk (RR, with 95% Confidence Intervals) for temperature increases between the 75$^{th}$ and the 99$^{th}$ percentile.

# APPENDIX C
# Methods to assess particulate matter effect and impact on mortality

# Estimate of PM exposure

The first element of the study is the estimation of daily mean concentrations of PM at the national level. To achieve this goal, we selected and merged multiple sources of data:

- Daily mean concentrations of $PM_{10}$ (PM with diameter smaller than 10 microns) from approximately 500 Italian monitoring stations;
- Daily mean concentrations of $PM_{2.5}$ (PM with diameter smaller than 2.5 microns) from approximately 250 Italian monitoring stations;
- Spatial data on: population density, anthropogenic areas, road networks, industrial emissions, land cover, etc. downscaled at a fixed squared kilometre spatial resolution
- Spatio-temporal satellite-based data on Aerosol Optical Depth (AOD), with daily temporal resolution and squared kilometre spatial resolution (source: NASA)
- Spatio-temporal model-base data on meteorological parameters and dispersion models, with daily temporal resolution and 10x10-km$^2$ spatial resolution (sources: CAMS, ECMWF)

Once all these data have been brought to a common grid, we developed a four-stage approach based on machine learning method, the "random forest":

- First stage: we used co-located data on $PM_{10}$ and $PM_{2.5}$ (in ~ 250 stations) to establish a statistical relationship between the two PM metrics, and we predicted $PM_{2.5}$ in the other (~ 250) stations monitoring $PM_{10}$ only
- Second stage: we used AOD estimates downloaded from COPERNICUS to impute missing AOD data from the satellite
- Third stage: we built a multi-variate random forest model with PM (either 2.5 or 10, in turn) as the target variable, and spatial and spatiotemporal covariates as predictors. We carefully checked variable importance statistics and cross-validated the models by splitting the monitors into training and testing groups multiple times.
- Fourth stage: finally, we predicted the output of the model in the entire Italian domain, obtaining estimates of daily mean concentrations of $PM_{10}$ and $PM_{2.5}$ for each squared kilometre of Italy (years 2006-2015 for $PM_{10}$, years 2013-2015 for $PM_{2.5}$)

See Stafoggia *et al*. Estimation of daily PM10 and PM2.5 concentrations in Italy, 2013–2015, using a spatiotemporal land-use random-forest model. Environment International. 2019 Mar;124. for further details.

# Statistical analysis of short-term health effect estimates

The second element of the study is the estimation of the association between short-term (e.g., daily) exposure to either $PM_{10}$ or $PM_{2.5}$, and all-cause mortality. To achieve this goal, we adopted a multi-stage approach, consisting of mortality data collection, production of municipality-specific time series, fitting of Poisson regression multivariable model in each Italian province, and meta-analysis of the province-specific regression coefficients. The individual stages are described below:

- Mortality data collection: we obtained from the Italian Institute of Statistics (ISTAT) daily counts of mortality (all causes, both sexes, all ages) for each one of the 8,092 municipalities of Italy, for the period 2006-2015.
- Production of municipality-specific time series: we derived daily mean concentrations of $PM_{10}$ (2006-2015) and $PM_{2.5}$ (2013-2015) at the municipality level by averaging, for each municipality, values of all the squared kilometre grid cells intersecting the municipality. We adopted a double weighting: first, we weighted the grid cells proportionally to their intersection area (weighting more the cells entirely falling in the municipality borders, and less those on the boundaries); second, we weighted each cell proportionally to the population residing in it (weighting more the cells with more resident population, and less those falling in inhabited or rural areas). Next, we produced municipality-specific daily time series of other variables relevant for confounding adjustment in the

epidemiological analysis: daily mean air temperature, weekly regional flu epidemics, bank holidays and summer population decrements.
- Fitting of Poisson regression multivariable model in each Italian province: once the daily time series of outcome, exposure and confounders was derived for each municipality, we stacked together time series of all the municipalities belonging to the same province, and fitted province-specific Poisson regression models, so obtaining, for each of the 110 Italian provinces, estimates of relative risk (and 95% confidence intervals) of all-cause mortality per unit increment of $PM_{10}$ (for the period 2006-2015) or $PM_{2.5}$ (for the period 2013-2015), in turn.
- Meta-analysis of the province-specific regression coefficients: finally, we ran random-effects meta-analytical techniques on the province-specific estimates, and derived a national estimate of the association between short-term exposure to $PM_{10}$ and $PM_{2.5}$ with all-cause mortality

## Statistical analysis of short-term health impact of PM

The pooled associations estimated in the previous are then used to quantify the numbers of all-cause deaths attributable to daily exceedances in $PM_{10}$ and $PM_{2.5}$ above predefined thresholds during 2015. We apply the following formula:

$$AC_t^m = \sum_{i=1}^{n.days} \sum_{j=1}^{n.munic} Y_{i,j} * \left(1 - \frac{1}{e^{\beta(PM_m - t)(PM_m > t)}}\right)$$

where:

$AC_t^m$ quantifies the total number of deaths attributable to, or anticipated because of, daily concentrations of $PM_m$ (*m* = "10" or "2.5") exceeding the threshold *t* (*t* = 20, 25, 30, 35, 40, 45 or 50 µg/m$^3$ for $PM_{10}$, and *t* = 10, 15, 20 or 25 µg/m$^3$ for $PM_{2.5}$);

$Y_{i,j}$ is the count of deaths on day *i* in the municipality *j*;

$\beta$ is the pooled regression coefficient representing the log(relative risk) of mortality per unit increment in exposure. For the computation of attributable cases, we have used the $\beta$ resulting from the base model where exposure was inserted as a linear term at lag 0.

In the formula above, the total number of attributable cases $AC_t^m$ is derived as the sum over all days and municipalities of Italy, so that PM exposure for a specific municipality is compared with the threshold each day, and excess cases can occur in that municipality only when there is an exceedance of the threshold for a specific day and there is at least one all-cause death.

# APPENDIX D
# EPIC cohort and assessment tools

# Description of EPIC cohort

Briefly, the cohort consists of 23 study centres in 9 European countries, including, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, and the United Kingdom. Participants were mostly from the general population and recruited between 1991 and 2000. All participants provided written informed consent and the ethical review boards from the International Agency for Research on Cancer (IARC) and all local centres approved the study. Information on physical activity, history of tobacco smoking, alcohol consumption and education were collected at baseline by questionnaires. Diet was assessed at study baseline using validated country/centre-specific dietary questionnaires (DQs) spanning the previous 12 months. In most centres, DQs were self-administered, with the exception of Ragusa (Italy), Naples (Italy) and Spain, where face-to-face interviews were performed. Extensive quantitative DQs were used in northern Italy, the Netherlands, and Germany that were structured by meals in Spain, France and Ragusa. Semi-quantitative food-frequency questionnaires (FFQs) were used in Denmark, Norway, Naples and Umeå (Sweden). In the United Kingdom, both a semi-quantitative FFQ and a 7-day record were used, whereas a method combining a short non-quantitative FFQ with a 7-day record on hot meals was used in Malmö (Sweden). Post-harmonisation of all the questionnaire data was done by standardized procedures (e.g. decomposing recipes and complex foods into ingredients) to obtain a standardised food list for which the level of detail is comparable between countries. Body mass index (BMI) derived from weight and height measured in all centres, except for Oxford, France and Norway where these were self- reported. Anthropometric characteristics were measured by trained observers using standardized methods. Body weight was measured by electronic digital scales, with subjects wearing only light underwear and after emptying the bladder. Height was measured to the nearest 0.1 cm using a flexible anthropometers. Assessed weight and height were used to calculate BMI defined as weight in kilograms divided by height in metres squared (kg/m$^2$).

Outcomes assessed in the present study include all-cause and cause-specific mortality and incident cancers. Data on vital status were obtained from mortality registries, in combination with data collected through active follow-up and their next-of-kin. The end of follow-up/closure dates of the study period varied between 2009 and 2014 depending on the countries. Causes of death assessed include, coronary heart disease (CHD), cardiovascular disease (CVD), cancer, and respiratory disease. Cause-specific mortality data were coded according to the 10th revision of the International Statistical Classification of Diseases, Injuries and Causes of Death (ICD-10). Incident cancer cases were identified through several methods, including record linkage with population-based cancer registries, health insurance records, pathology registries, autopsy or death certificate, and active follow-up of study subjects. First primary invasive cancers were considered as cases in this study. Main cancer cases were coded according to the International Classification of Diseases for Oncology (ICD-O). An expert panel of pathologists was in charge of the validation of diagnosis and classification of tumours. The panel included a representative from each country participating in EPIC and a coordinator. The methodological issues concerning the panel validation procedures and criteria have been detailed elsewhere.

# Methods

## Causal structure and confounding variables

The main exposures considered in relation to the outcomes of all-cause and cause-specific mortality and cancer are GHG and LU levels derived from individual diets, modelled as quartiles of 0 to 25% (1$^{st}$ as the referent), 25% to 50% (2$^{nd}$ quartile), 50% to 75% (3$^{rd}$ quartile) and above 75% (4$^{th}$ quartile). A set of confounders were selected based on their possible association with the exposure, outcome, and not being on the causal path based on a DAG. All models were adjusted for the following set of potential confounders, including age at recruitment (continuous), marital status (not married or married/living together), education (not educated/primary school, technical/professional school, high school, or higher education of university) physical activity (active or not active), smoking status (never, former or smoker), and BMI (continuous). We considered sex separately from the other potential confounders for the following reasons: while sex is often a confounder or modifier of diet and outcomes assessed in the present study, we are not aware if sex would influence the consumption of GHG- and LU-related foods.

## Association of GHG and LU and mortality

To assess the association of GHG and LU with all-cause and cause-specific mortality, hazard ratios (HR) and 95% Confidence Intervals (CI) were estimated. For all-cause mortality Cox proportional-hazards regression models were run. For cause-specific models, assessing CHD, CVD, cancer, and respiratory disease, competing risk models were run, accounting for each cause of mortality (including other causes not listed) using the R package risk Regression. This method uses a binomial regression model based on a time sequence of binary event status variable. Competing risk models were considered as participants could have experienced one or more events, thus competing for the outcome of mortality; whereby; not doing so may not appropriately estimate the cumulative incidence when competing events are censored. For both all-cause and cause-specific models the underlying time scale considered was person years from the start of the study until the time of death. Adjusted HR were estimated, adjusting for the set of potential confounders. Associations of the exposures and outcomes were determined based on the magnitude of the point estimates and the exclusion of the null value of 1 in the 95% CI.

## Association of cancer and GHG and LU

Cancer rates for all cancers and organ-specific cancers were assessed in relation to quartiles of GHG and LU in pooled and country-specific analyses. Hazard ratios were calculated using Cox proportional-hazards regression models, where the underlying time scale was person years, adjusting for the set of potential confounders and, and additionally for country as a fixed effect for pooled models. Organ-specific cancer assessments were calculated separately for those cancers where there was a sufficient number of cases (n>250) and include brain and central nervous system, bladder, renal pelvis, ureter and other urinary organs, breast, cervix uteri, colorectum, endometrium, oesophagus, gallbladder and biliary tract, kidney, larynx, liver, lung, lymphnodes, myeloma, ovary, pancreas, prostate, skin melanoma, stomach, and thyroid. Associations of the exposures and outcomes were determined based on the magnitude of the point estimates and the exclusion of the null value of 1 in the 95%CI.

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