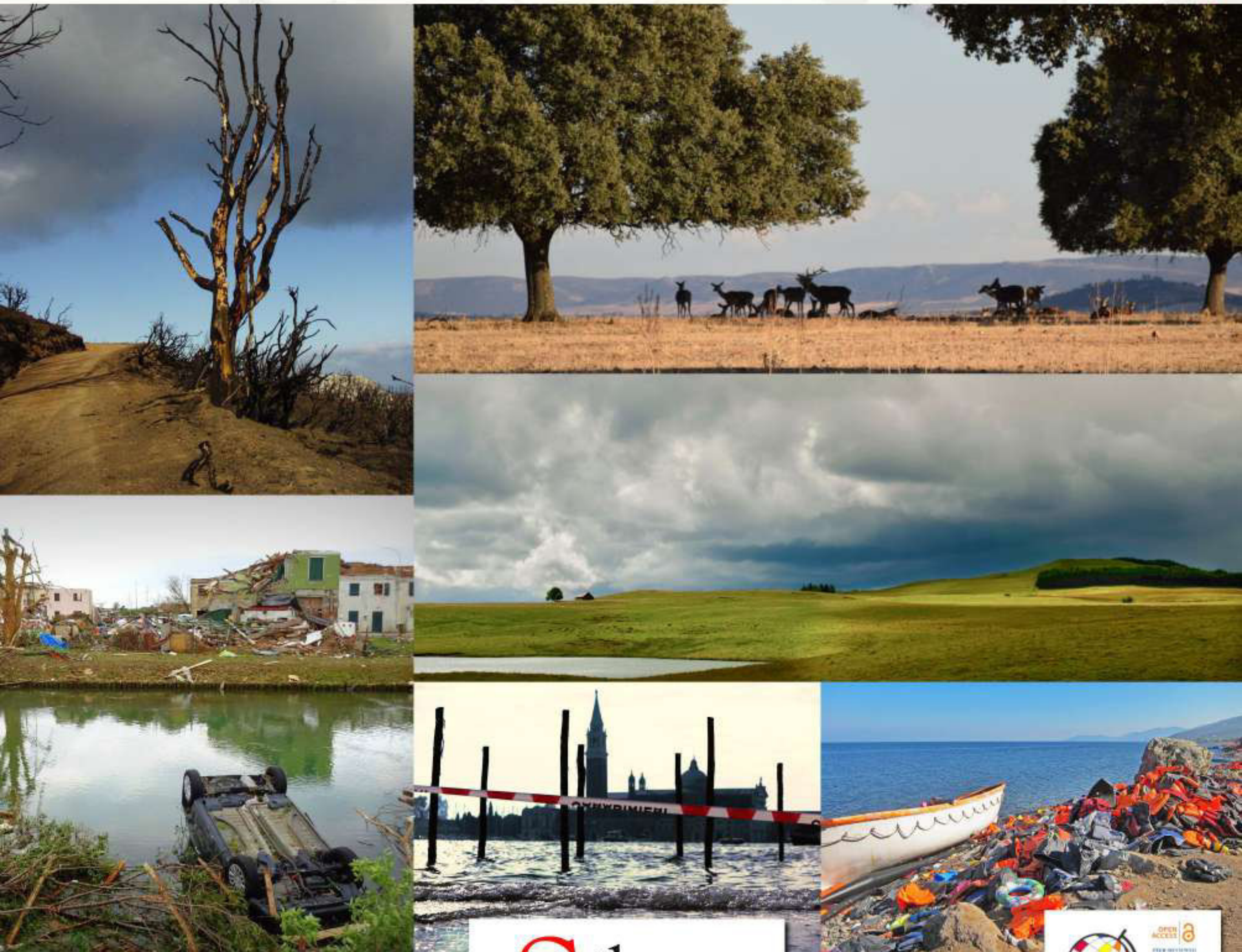
THE CLIMATE CRISIS IN MEDITERRANEAN EUROPE:

CROSS-BORDER AND MULTIDISCIPLINARY ISSUES ON CLIMATE CHANGE

Jonathan Gómez Cantero - Carolina Morán Martínez
Justino Losada Gómez - Fabio Carnelli
(Editors)



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Geographies of the Anthropocene

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Geographies of the Anthropocene

"The climate crisis in Mediterranean Europe: cross-border and multidisciplinary issues on climate change"

Jonathan Gómez Cantero, Carolina Morán Martínez, Justino Losada Gómez, Fabio Carnelli (Eds.)

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Cover: the set of photos shows different causes and effects of climate change.
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The book series "Geographies of the Anthropocene" edited by Association for Scientific Promotion "Il Sileno" (Il Sileno Edizioni) will discuss the new processes of the Anthropocene epoch through the various worldviews of geoscientists and humanists, intersecting disciplines of Geosciences, Geography, Geoethics, Philosophy, Socio-Anthropology, Sociology of Environment and Territory, Psychology, Economics, Environmental Humanities and cognate disciplines.

Geoethics focuses on how scientists (natural and social), arts and humanities scholars working in tandem can become more aware of their ethical responsibilities to guide society on matters related to public safety in the face of natural hazards, sustainable use of resources, climate change and protection of the environment. Furthermore, the integrated and multiple perspectives of the Environmental Humanities, can help to more fully understand the cultures of, and the cultures which frame the Anthropocene. Indeed, the focus of

Geoethics and Environmental Humanities research, that is, the analysis of the way humans think and act for the purpose of advising and suggesting appropriate behaviors where human activities interact with the geosphere, is dialectically linked to the complex concept of Anthropocene.

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1. The impact of climate change in Atmospheric pollution

María Teresa Baeza Romero[1], *Ana María Rodríguez Cervantes*[2]

Abstract

Air pollution harms human health and the environment. Around 90 % of European citizens are exposed to high pollutants concentrations that are harmful to their health. In the last hundred years, there has been a recorded increase in temperature of 1°C in Europe with huge repercussions on the global economy and in agriculture.

Although we do not have a complete understanding of how climate change might affect air quality and vice versa, research indicates that this mutual relationship might be stronger than estimated previously. Climate change could influence future air quality affecting ozone (O_3) and particle concentrations, and inducing changes in allergenic potential of pollen grains, especially in the presence of specific weather conditions.

The challenge ahead is to ensure that climate and air policies focus on "win-win" scenarios. To propose these policies is critical to understand linkages between climate change and air pollution.

In this chapter we review the known effects of climate change onto atmospheric pollution, focusing on O_3 and PM (Particle Matter). Additionally, possible health, environment, patrimony conservation and economic implications will be considered and possible "win- win" policies and technologies will be commented. Future research needs in this area are summarized.

Keywords: climate change, air pollution, win-win policies, ozone, particle matter

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1. Climate change and air pollution as important problems for Europe in the present and in the future

In Europe, emissions of many air pollutants have decreased substantially over the past decades, resulting in improved air quality. However, air pollutants concentrations are still too high, and air quality problems persist. Around 90 % of European citizens are exposed to high pollutants concentrations that are harmful to their health (European Court of Auditors, 2018), especially in cities, where exceedances of air quality standards occur for ozone (O_3), nitrogen dioxide (NO_2) and particulate matter (PM) (European Court of Auditors, 2018). Thus, research has shown that the average person, living in Europe, loses two years of their life due to the health effects of breathing polluted air (Lelieveld *et al*., 2019).

In the last hundred years, there has been a recorded increase in temperature of about 1°C in Europe (European Environmental Agency, 2019), and further increase is expected in the future (Collins *et* al., 2013). This increase has had huge repercussions on the global economy and in agriculture. Climate change affects both people and the environment in Europe, since it has the potential to alter the prevalence and severity of extreme weather events like storms, floods, drought, heat and cold waves. Using a climatic model, a recent study about the impacts of this phenomena in 571 European cities found that heat-wave days increase across all cities, but especially in southern Europe, whilst the greatest heatwave temperature increases was in central European cities; both drought and river flood risks would increase. Over 100 European cities are particularly vulnerable to two or more climate impacts (Guerreiro *et al.*, 2018). Thus, climate change may produce an increase of the number of global climate refugees from 150 million in 2008 to 800 million in future (The Government Office for Science, 2011).

2. Links between climate change and air pollution

Although we do not have a complete understanding of how climate change might affect air quality and vice versa, research indicates that this mutual relationship might be stronger than estimated previously. In its assessments of 2014, the Intergovernmental Panel on Climate Change (IPCC, 2014) predicts a decline in cities´ air quality in the future due to climate change. The main sources of CO_2 emissions, the extraction and burning of fossil fuels, are not only key drivers of climate change, but also major sources of air pollutants. Furthermore, many air pollutants, called short-lived climate-forcing pollutants (SLCPs) include methane (CH_4), black carbon, tropospheric O_3, and sulphate aerosols (IPCC, 2018), that are harmful to human health and ecosystems, also contribute to climate change by affecting the amount of incoming sunlight that is reflected or absorbed by the atmosphere, and therefore triggering warming or cooling of the Earth. In many ways, improving air quality can also improve climate change mitigation and vice versa, but not always.

Climate change could affect future air quality in various ways. One way is through higher temperatures leading to increased O_3 formation. Another potential way is through a change in weather patterns creating 'stagnation events'. In such events, an absence of wind leads to high O_3 and PM concentrations (Orru *et al.*, 2017). A third possible way is through a potential change in patterns of hemispheric transport of air (HTAP, 2010; Colette *et al.*, 2013). In fact, there is observational evidence that indicates recent regional changes in climate, particularly temperature increases, have already affected a diverse set of physical and biological systems in many parts of the world. Allergens patterns are also changing in response to climate change and air pollution can modify the allergenic potential of pollen grains, especially in the presence of specific weather conditions (D'Amato *et al.*, 2014).

However, the complex interplay between climate change and air pollution presents a challenge for their prediction and for the assessment of their total risk in the future (Fiore *et al.*, 2015; Silva *et al.*, 2016). Changes in climate conditions will alter the emission, transport, chemical evolution, and removal of air pollutants and their precursors (Fiore *et al.*, 2012; Fiore *et al.*, 2015; Kleinman *et al.*, 2015)

2.1. Impact of climate change in tropospheric ozone

Climate warming may have a penalty on future ozone levels, even without changes in anthropogenic activities. This penalty has important implications for policy-making, but its quantification involves complex chemical, meteorological and biological processes and feedbacks that are not well understood (Fu and Tian, 2019).

Recent studies have challenged earlier paradigms on how climate change could affect tropospheric ozone (Fu and Tian, 2019). The widely accepted links of high ozone events with stagnation and heatwaves require re-evaluation. Emission responses of natural precursors to climate warming may be significantly modulated by CO_2 levels and ecosystem feedbacks. Recent studies have generally projected a climate change penalty on ozone air quality, although the magnitudes are smaller than this projected by earlier studies (Fu and Tian, 2019).

Current critical uncertainties in these predictions are associated with the meteorological, chemical, and biological processes linking climate warming and ozone, since many of the known feedbacks are not yet included in models. Further research is needed to examine those processes in order to better quantify the climate change penalty on surface ozone to inform policymaking.

The impact of climate change on tropospheric ozone in Europe has been studied extensively with different approaches concluding that ozone concentration could increase (Jacob *et al.*, 2009) with climate change in the future or even decrease if current environmental legislation is enforced until 2030 (Markakis et al., 2016; Watson *et al.*, 2016). A recent study based on European Monitoring and Evaluation Programme (EMEP) network, which observed background ozone in the period 1995–2014 (Yan *et al.*, 2018), showed that although reductions in anthropogenic emissions have lowered the peak ozone concentrations, especially during daytime, in this period, the lower level of ozone concentrations have increased continually since 1995. Furthermore, the number of days with exceedance of the ozone information threshold and the long-term objective have continuously declined during the 20-year period considered, and the decrease has accelerated since the year 2003. Model simulations combined with observational data has shown that climate variability generally regulates the interannual variations of European surface ozone, while the changes in anthropogenic emissions predominantly contribute to ozone trends. However, it appears that the negative ozone trend, due to European emission controls, has been counteracted by a climate related tendency and hemispheric dispersion of pollutants from other regions.

Further research like the previous study is necessary combining different models and observational data to confirm these tendencies in the future.

2.2. Impact of climate change in particles

Climate factors may considerably influence natural aerosol emissions and atmospheric distributions. The interdependencies of processes within the aerosol-climate system may thus cause climate feedbacks that need to be understood (Tegen and Schepanski, 2018). However, the relationship between climate change and PM is more complex than the relationship between climate change and O_3, as the various components of PM are influenced by changes in meteorological variables in different ways.

While generally atmospheric aerosol distributions are affected by changes in precipitation, atmospheric mixing, and ventilation due to circulation changes, emissions from natural aerosol sources strongly depend on climate factors like wind speed, temperature, and vegetation. Aerosol sources affected by climate are desert sources of mineral dust, marine aerosol sources, and vegetation sources of biomass burning aerosol and biogenic volatile organic gases that are precursors for secondary aerosol formation. Different climate impacts on aerosol distributions may offset each other (Tegen and Schepanski , 2018). In regions where anthropogenic aerosol loads decrease, the impacts of climate on natural aerosol variabilities will increase. Detailed knowledge of processes controlling aerosol concentrations is required for credible future projections of aerosol distributions (Tegen and Schepanski, 2018).

Some components of PM are affected by temperature. Studies have found a positive association between temperature and sulphate aerosols (Unger *et al.*, 2006; Pye *et al.*, 2009) and increasing VOCs (Heald *et al.*, 2008). On the other hand, a negative association has been found between temperature and nitrate aerosols, with higher temperatures causing nitrate aerosols to transition from the particle to the gas phase (Pye *et al.*, 2009). This means that increasing temperatures may cause PM to decrease in regions where NOx emissions are high.

Wildfire activity is predicted to increase with global climate change, resulting in longer fire seasons and larger areas burned (Reisen *et al.*, 2015). In Europe, climate change combined with other factors is expected to increase the number of wildfires that will increase PM2.5 concentration (San-Miguel-Ayanz *et al.*, 2012). Hodzic *et al.*(Hodzic *et al.*, 2007) estimated that 30 kilotonnes of fine aerosol particles (PM2.5) were emitted as a result of European fires during the heatwave period in 2003, which led to an average PM2.5 ground concentration of 20-200 per cent (up to 40 $\mu g/m^3$) over Europe. An effect in PM10 concentration is as well expected in the case of at least Portugal (Carvalho *et al.*, 2011).

Further research relating climate change and particle concentration is necessary to predict future PM2.5 and PM10 concentrations.

2.3. Impact of climate change in allergens

The prevalence of allergic respiratory and skin diseases within the general population in Europe has been estimated to be of 40% and has increased dramatically over the past decades (Haines and Ebi, 2019). Changes in climate, specifically rising temperatures, altered precipitation patterns, and increasing concentrations of atmospheric CO_2, are expected to contribute to increase the levels of some airborne allergens and associated asthma episodes and other allergic illnesses (U.S. Global Change Research Program, 2018; Ziska *et al.*, 2019). However, the influence of climate change and increased CO_2 is complex in the way that affect the range of allergic species, timing and length of pollen season and productivity. The reason is that the pollen season is not only influenced by the classical climatic variables. Further research in this is required to improve our knowledge of this impact.

3. Implications of the links between climate change and air pollution

Air pollution is a major environmental factor associated with:

1. human health impacts, which causing up to 7 million premature deaths annually with an even larger number of hospitalizations and days of sick leave;
2. environmental impacts, that may directly affect to vegetation and fauna, as well as the quality of water and soil;
3. built environment and cultural heritage impacts, since air pollution can damage materials, properties, buildings and artworks; and economic impacts, because the effects before mentioned also entail considerable costs (European Environmental Agency, 2018).

It is also well known, human beings and environment are exposed to climate change through changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in water, air and food quality, and changes in ecosystems, agriculture, industry and economy (IPCC, 2014). However, as previously mentioned (section 2), there are recent evidences about the impacts of climate change on air pollution, and therefore the challenge is also to evaluate the interplays between both and their implications on the health, natural and built environment, and economy.

3.1. Health implications

Essentially, all the important climate-altering pollutants have near-term health implications, either directly or by contributing to secondary pollutants in the atmosphere. Human ozone exposure represents a major health issue playing an important role in the pathogenesis of chronic respiratory diseases (D’Amato *et al.*, 2019; Hew *et al.*, 2019; Liu *et al.*, 2019; Sokolowska *et al.*, 2019). Elevated O_3 concentrations are associated with increased hospital admissions for pneumonia, chronic obstructive pulmonary disease, asthma, allergic rhinitis and other respiratory diseases (Alvaro-Meca *et al.*, 2015; Luong *et al.*, 2018). In this sense, asthma emergency hospital admissions for all ages increased by 4.04% per 10 ppb 24 h ozone in three European countries: The Netherlands, Spain and the UK (Ji *et al.*, 2011). Moreover, ozone currently causes 55.000 premature deaths annually in Europe due to long-term exposure (Orru *et al.*, 2019).

If we consider ozone formation is temperature dependent, projections focusing only on temperature increase generally conclude that ozone-related mortality could increase with additional warming (IPCC, 2018). Up to an 11% increase in ozone-associated mortality is expected in some countries in Central and Southern Europe in 2050 only considering the climate change effect (Orru *et al.*, 2019). However, the climate penalty on O_3 in Europe is compensated by emissions changes (Geels *et al.*, 2015), and projected decreases in ozone precursor emissions are expected to result in a decrease in ozone- related mortality (−30%), although the decrease could be smaller (−24%) due to aging and increasingly susceptible populations (Orru *et al.*, 2019).

Similar health risks are associated to particulate matter, since this pollutant causes acute and chronic respiratory and cardiovascular diseases (Pope and Dockery, 2006; WHO, 2013; Atkinson *et al.*, 2015; Tobaldini and Bollati, 2017; Yuan *et al.*, 2019).The fine particles (PM2.5) have been shown to pose a greater health risk than the coarse particles, since their small size enables them to reach deep into the human lungs and bloodstream. Estimates of the health impacts attributable to exposure to fine particles from long-term indicate that about 400,000 premature deaths in Europe were produced by PM2.5, which suppose more than 90 % of premature deaths by air pollution (European Environmental Agency, 2018; Im *et al*., 2018). Epidemiological studies have addressed the correlation between the concentrations of PM and hospital visits due to respiratory and heart diseases. In the southern Europe, increases of 10 $\mu g/m^3$ in PM2.5 and 14.4 $\mu g/m^3$ in PM10 were associated with increases in cardiovascular admissions of 0.51% and 0.53%, respectively. Stronger associations were estimated for respiratory hospitalizations, ranging from 1.15% for PM10 to 1.36% for PM2.5 (Stafoggia *et al.*, 2013). Similar associations were projected for cardio-respiratory mortality (Stafoggia *et al.*, 2016).

The combined effect of climate change and emission reductions of primary PM2.5 and precursors will decrease PM-related premature mortality in Europe (−65% and −80% in the 2050s and 2080s, respectively) (Geels *et al.*, 2015). However, this decrease will not such large due to the combined effect of decreases in PM2.5 concentrations and changes in population and baseline mortality rates. Considering every factor, the avoided premature mortalities in Europe by 2100 ranging between −103,000 and −112,000 deaths/year (Silva *et al*., 2016).

Overall, the climate penalty effects on O_3 and PM indicates that stronger emission controls will be needed in the future to avoid higher health risks associated with climate change induced worsening of air quality. Key uncertainties in the models limit our confidence in future projections of air quality. For O_3 and PM-related health effects, besides uncertainty in future O_3 and PM concentrations, there is also uncertainty in risk estimates such as effect modification by temperature on pollutant-response relationships and potential future adaptation that would alter exposure risk (Doherty *et al.*, 2017).

In relation to allergens, it has already commented in section 2.3., that it is expected that allergic respiratory and skin diseases are expected to increase due to combination of climate change and air pollution. Thus, Lake *et al*. (Lake *et al.*, 2017)) claimed in their study that ragweed pollen allergy will become a common health problem across Europe by 2041–2060, expanding into areas where it is currently uncommon. Climate change consequences will not be restricted to ragweed; further studies are required to predict future climate change induced changes on pollen allergy for other species.

Moreover, according to current climate change scenarios, there will be an increase in intensity and frequency of heavy rainfall episodes, including thunderstorms, over the next few decades, which can be expected to be associated with an increase in the number and severity of asthma attacks both in adults and in children (“thunderstorm asthma”). Associations between thunderstorms and asthma morbidity have been identified in multiple locations around the world including Europe (D’Amato *et al.*, 2019).

3.2. Ecosystems implications

The relationships between air pollution, climate change and ecosystems are complex and still little known (Matyssek *et al.*, 2012, Fuhrer *et al.*, 2016). Climate change increases both growing season length (~7 days/decade) and plants stomatal conductance. This fact enhances the stomatal ozone uptake, leading to an overall increase of potential ozone damage (Anav *et al.*, 2019). Accordingly, current ozone concentration is already decreasing biomass growth, and as this concentration continues to rise, an average reduction of biomass loss of 9 % is predicted over Europe (Pleijel *et al.*, 2014). Thus, without effective O_3 reductions, wheat production in Europe by 2030 is expected to fall by 6.9% to 10.7% depending the climate change scenario considered, being this crop mostly sensitive to ozone levels. Similar losses are also expected to maize and soybean, worsening potentially the global malnutrition (Avnery *et al.*, 2011, Tai *et al.*, 2014).

On the other hand, the damage O_3 causes to plants leads to an additional, highly uncertain, influence on the carbon cycle and thus atmospheric CO_2. Several studies found a significant suppression of the global land-carbon sink as increases in O_3 concentrations affect plant productivity. In consequence, more CO_2 accumulates in the atmosphere, and therefore the resulting indirect radiative forcing by ozone effects on plants could contribute more to global warming than the direct radiative forcing due to tropospheric ozone increases (Sitch *et al.*, 2007; Fry *et al.*, 2012; Collins *et al.*, 2013).

3.3. Patrimony conservation implications

The impact of air pollution on cultural heritage materials is a serious concern because it can lead to the loss of parts of our history and culture. Damages induced by the O_3 concentration increase includes the weathering and fading of digitally-printed materials (Gordeladze and Burge, 2012), and the corrosion of materials such as copper, limestone and silver (Screpanti and DeMarco, 2009; Wiesinger *et al.*, 2015). The high ozone concentrations in synergistic action with other pollutants, lead to a corrosion exceeding the tolerable thresholds for cultural heritage buildings (Spranger *et al.* 2004). In particular, the monuments registered on UNESCO's list of the world heritage require special monitoring. For example, in Italy 34% and 97% of the territory is exposed to corrosion risk higher than the tolerable level for limestone and copper, respectively. The tolerable O_3 concentration for copper was calculated in the central area of Milan, observing that concentrations between 30 and 40 mg/m^3 cannot be exceeded, at unchanged of other pollutants, to maintain corrosion levels below the tolerable ones (Screpanti and De Marco, 2009). Beyond this, the atmosphere in cities has become more photochemically active, ozone can attack polymers in modern architecture (Saiz-Jimenez, 2004).

Similarly, PM causes monuments surface degradation in urban environments. These particles, mainly that formed by elemental and organic carbon, either can be embedded into gypsum providing the characteristic black colour (Comite and Fermo, 2018), or may be responsible for the surface discoloration of buildings by light absorbing (Bergin *et al.*, 2015). Therefore, the deposition of particulate matter in regions of high aerosol loading are not only influencing cultural heritage but also the aesthetics of both natural and urban surfaces.

3.4. Economic implications

The effects of the interplay between the air pollution and climate change on health, ecosystems and the built environment also entail considerable economic resources. Between the most important economic implications there are the additional health expenditure associated with increased mortality and morbidity, crop and forest yield losses, and the associated costs with degradation of water and soil quality and, consequently, in the ecosystem services (European Environmental Agency, 2018).

An economic valuation of the air-pollution-associated health impacts estimates a total mean cost of 300 ± 70 billion euros over Europe, of which 5 % (1-11 %) is due to exposure to O_3, while 89 % (80–96 %) is due to exposure to PM2.5 (Im *et al.*, 2018). Moreover, the crop losses in Europe due to O_3 exposure represents an economic value of 0.9–1.1 billion of dollars (Van Dingenen *et al.*, 2009).

Considering these data, the Organization for Economic Cooperation and Development (OECD) projects that these expenditures will increase to reach about 2 % of European gross domestic product in 2060 (OCDE, 2016), leading to a reduction in capital accumulation and a slowdown in economic growth. These losses could be smaller or even reduced considering the combined effect of climate change and emission reductions. In this sense, Italy by 2030 would experience monetary gains as compared to the year 2000 due to crop production improvements resulting from decreases in O_3 levels (Avnery *et al.*, 2011).

4. "Win-Win" policies and technologies

Both the exposure to air pollutants and the climate change impacts require action by public authorities at national, regional, and international levels. A multi-sectoral approach, engaging relevant sectors such as transport, housing, energy production and industry, is needed to develop and effectively implement long-term policies (D'Amato *et al.*, 2014). A challenge for Europe is to ensure that air and climate policies for the next decade promote and invest in "win-win" scenarios and technologies that are mutually reinforcing.

Combining policies that tackle local air pollution and global climate change deliver enhanced benefits than the costs of them. Besides, a beneficial synergy between both it can be created, with an additional energy-related CO_2 emission reduction of 15% in Western Europe (Bollen *et al.*, 2009).

As it was mentioned before, proposed policies for reduction in anthropogenic emissions leads to a decrease in O_3 and PM2.5 surface concentrations, and this reduction poses a stronger effect than climate change alone (Geels *et al.*, 2015; Silva *et al.*, 2016; Orru *et al.*, 2019). The combined effect of climate change and global emission cuts will decrease the premature mortality across Europe, estimating decreases by 36%–64% in the 2050s and 53%–84% in the 2080s (Geels et al., 2015). Furthermore, the latest climate change scenarios show the strong influence of future CH_4 levels on air quality due to its positive effect in surface O_3 concentration. Controlling CH_4 and possibly black carbon are viewed as win-win policies for mitigating air quality as well as climate change (Shindell *et al.*, 2012; Baker *et al.*, 2015).

Regarding the role of the technology in the link between air pollution and climate change, there are technological solutions that address both concerns at the same time: for example, switching from fossil fuels to renewable forms of energy cuts down on air pollution emissions, (eg. PM, SO_2 and NOx), whilst simultaneously reducing emissions of the greenhouse gases, (eg. CO_2). However, not all climate and air quality technologies are necessarily mutually beneficial. Some of them that are promoted as climate-friendly, such as the combustion of some kind of biomass and biofuels for home heating or transport, may emit more PM than the technology it replaced, and thus continue to harm human health and, potentially, warm the climate (Institute for Advanced Sustainability Studies, 2019).

Finally, it should be noted that strategies to reduce climate changes and air pollution are political in nature, but citizen must continuously and persistently raise their voices in the decision process to give strong support for clean policies on both national and international levels.

5. Discussion and conclusions

Air pollution and climate change are two important problems that Europe have to face due to its importance in health, economic and ecosystems. Research indicates that there is a mutual relationship between air pollution and climate change. Climate change can have different impacts in air pollution especially in the levels of ozone, particles and allergens. Still it is not clear if ozone and particle concentrations will increase or decrease due to climate change, and although it is clear that climate change has a direct impact in allergenic concentrations and distributions, further research is required to understand these impacts.

The challenge ahead for Europe is to ensure that climate and air policies focus on “win-win” scenarios. To propose these policies is critical to understand linkages between climate change and air pollution.

Further research studies are recommended in this field, especially trying to understand future trends in ozone and particle concentrations using both field data and modelling approaches. A detailed knowledge of processes controlling aerosol concentrations is vital for future projections of aerosol distributions. Moreover, further studies are required to predict future climate change induced changes on pollen allergy for species different from ragweed.

Additionally it is necessary to improve our understanding of the implications of both air pollution and climate change and their interplay in health, ecosystems and patrimony conservation to develop technology and “win-win” policies.

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