Synergy of policies for more efficient tackling of climate change and air pollution in Croatia

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Abstract:
Air pollution and climate change, although they have different physical manifestations, are both closely linked to similar causes and concerns. Fossil fuel and biomass burning are the main anthropogenic sources of greenhouse gas and air pollutants emissions that change the composition of the atmosphere. Some of pollutants that are responsible for air quality deterioration are also responsible for the global warming. The question is whether current policies to address climate change and air pollution in Croatia are in synergy, or if they have some contradictions (e.g. biomass combustion in the residential sector). This paper gives an overview of greenhouse gas (GHG) emissions projections and primary air pollutants (NO_x, PM) emissions projections in Croatia, it discusses the interconnections and the importance of the residential sector and road transport sector as key sources of urban air pollution. An overview of the current state of emissions and air quality in the case of particulate matter in Croatia is also given. The importance of black carbon (BC) is highlighted as one of the components of fine particulate matter ($PM_{2.5}$) and also as short-lived climate pollutants (SLCP). In addition, some funding mechanisms for implementing climate change and air protection policies in Croatia are considered.

Key words: air pollution, climate change, policy, emission, black carbon (BC), funding

1. Introduction

Air pollution and climate change are linked in many ways. They have similar causes which can be generated by humans, like burning fossil fuels, cutting down rainforests, farming livestock [1], or natural (for example, forest and wildfires, eruptions of volcanos, wind-blown sand and dust, and emissions from vegetation). Climate change and air pollution are a result of the current energy model. Both are aggravated by the burning of fuel, increasing the CO_2 emissions that cause global warming, and generating air pollutants, such as nitrogen oxides, sulphur oxides and particulate matter, which are the main reason of air pollution.

The changing climate has modified weather patterns, which in turn have influenced the levels and location of air pollutants such as ground-level ozone (O_3) and fine particulate matter. Increasing carbon dioxide (CO_2) levels also promote the growth of plants that release airborne allergens, which will not be discussed in this paper. Climate change influences air pollutant concentrations in many ways. The climate influences temperatures, cloudiness, humidity, the frequency and intensity of precipitation, and wind patterns, each of which can influence air quality. Over longer time scales, human responses to climate change may also affect the amount of energy that humans use, as well as how land is used and where people live. These changes would in turn modify emissions (depending on the fuel source) and thus further influence air quality. Some air pollutants such as ozone, sulphates, and black carbon also cause changes in climate. [2]

Climate change affects all regions around the world. Polar ice shields are melting, and the sea is rising. In some regions extreme weather events and rainfall are becoming more common while others are experiencing more extreme heat waves and droughts [3]. Air pollution leads to poor air quality, which in turn influences human health, and environment.

Policies that address climate change and air pollution on international level are for now regulated under two separate regulations. Change in climate is addressed by the United Nations Framework Convention on Climate Change (UNFCCC), while air pollution is regulated through the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP). Both policies have the main challenge to limit future emissions, even though the CLRTAP does not have global coverage. By implementing air quality and climate policies, mutual benefits can be provided: climate change mitigation actions can help reduce air pollution, and clean air measures can help reduce GHG emissions leading to reductions in global warming [4].

The paper presents the position of Croatia as a party of both conventions and as one of the EU-28 Member States, and also one of 41 European countries considering the state of emissions and emissions projections, and the current state of air quality in the case of particulate matter.

The overview of the policies and measures in place in Croatia is given, along with most effective ones, which require intensive implementation to combat poor air quality and climate change.

Some contradictions observed in current policies addressing climate change and air pollution in Croatia are a reminder that more needs to be done. One way for resolving existing contradictions is through the funding mechanisms for implementing climate change and air protection policies in Croatia.

2. Air pollution and climate change – physical manifestations, linkage, causes and concern

Air pollution and climate change influence each other through complex interactions in the atmosphere. Although two different topics and separated by different policies, in the reality they are quite related [5, 6].

Greenhouse gases absorb and emit radiant energy within the thermal infrared range. They trap heat in the atmosphere and contribute to climate change. The primary greenhouse gases are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Water vapor accounts for the largest percentage of the greenhouse effect, between 36% and 66% for clear sky conditions and between 66% and 85% when including clouds [7]. Water vapor concentrations fluctuate regionally, but human activity does not directly affect water vapor concentrations except at local scale. The average residence time of a water molecule in the atmosphere is only about nine days, compared to years or centuries for other greenhouse gases such as CH_4 and CO_2. The most common greenhouse gases, after H_2O is carbon dioxide (CO_2). The atmospheric lifetime of CO_2 is estimated of the order of 30–95 years [8]. Although more than half of the CO_2 emitted is removed from the atmosphere within a century, some fraction (about 20%) of emitted CO_2 remains in the atmosphere for many thousands of years [9]. At current emission rates, temperatures could increase by 2°C, which the United Nations' Intergovernmental Panel on Climate Change (IPCC) designated as the upper limit to avoid "dangerous" levels, by 2036 [10].

Many air pollutants contribute to climate change by affecting the amount of incoming sunlight that is reflected or absorbed by the atmosphere, with some pollutants warming and others cooling the Earth. These short-lived climate-forcing pollutants (SLCPs) include methane (CH_4), black carbon (BC), ground-level ozone (O_3), and sulphate aerosols [6]. Figure 1 shows radiative forcing (RF) of climate change during the Industrial Era shown by emitted components from 1750 to 2011. After CO_2 and CH_4, BC is the third top component of positive radiative forcing [11].

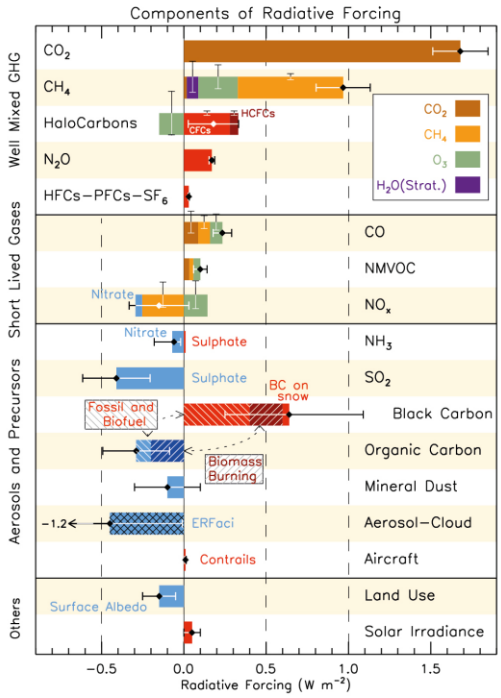

Figure 1. Radiative forcing of climate change during the Industrial Era shown by emitted components from 1750 to 2011 (Source: Figure TS.7, p. 57 [11]).

[12] Methane (CH_4) is the second most prevalent greenhouse gas emitted by human activities and approximately one- third of those emissions come from oil production and the production, processing, transmission, and storage of natural gas [13]. Methane does not have any direct effects on human health in the sense that inhaling typical ambient concentrations of methane is not harmful to human health but has a very important indirect impact on human health as a precursor to ground-level O_3.

Tropospheric or ground-level ozone (O_3) is produced by photochemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs), where UV rays from the Sun are the catalyst for these reactions. Ozone is of high concern in Europe due to its effects on human health, vegetation, and materials. It is also a short-lived climate pollutant, since it is a greenhouse gas and contributes to the warming of the troposphere [14]. According to EEA Indicator assessment [15] future climate change is expected to increase O_3 concentrations, due to changes in meteorological conditions, as well as due to increased emissions of specific ozone precursors and/or emissions from wildfires that can increase under periods of extensive drought.

The impact of particulate matter (PM) on climate change is complex because PM is made up of many different chemical components with different physical properties [16], with either warming or cooling effects on the climate. For example, black carbon, a particulate pollutant from combustion, contributes to the warming of the Earth, while particulate sulphates cool the Earth's atmosphere [17]. According to the NASA fact sheet on atmospheric aerosols [18], both stratospheric (volcanic) and tropospheric aerosols have the same climatic effect: “Stratospheric SO_2 aerosols reflect sunlight, reducing the amount of energy reaching the lower atmosphere and the Earth’s surface, cooling them”. Human-made sulphate aerosols “absorb no sunlight but they reflect it, thereby reducing the amount of sunlight reaching the Earth’s surface” [19].

Some of air pollutants and the main greenhouse gas, which are the main cause of air pollution and climate change, are presented at Figure 2 along with their impact on climate and human health, the ecosystem, scale of their impact, and lifetime in the atmosphere.

Figure 2. Some of air pollutants and greenhouse gas, their impact on climate and health/ecosystem, scale of impact and lifetime in the atmosphere (Source: *Ekonerg Ltd, 2020).*

3. Concern – consequences

The consequences of climate change are melting ice and rising seas, more frequent extreme weather events like heavy rain, which can lead to floods and decreasing water quality, and also more frequent heat waves, forest fires and droughts. The Mediterranean area is becoming drier, making it even more vulnerable to drought and wildfires. Urban European areas are exposed to heat waves, flooding or rising sea levels, but are often poorly equipped and ill-prepared for adapting to climate change [2].

Air pollution affects the environment and human health. In many cases it can impact the process of plant evolution by preventing photosynthesis, with serious consequences on the purification of the air we breathe. The accumulation of polluting gases in the atmosphere also generates environmental problems such as: acid rain, depletion of the ozone layer, global warming, the greenhouse effect, etc. [20].

Our continued exposure to air pollutants is responsible for the deterioration of human health and can cause cardiovascular problems, allergies, asthma attacks, conjunctivitis, bronchial diseases, lung or skin cancers, vision problems, blood problems in the mental development of the child, among others. Numerous studies have shown cause-and-effect relationship between air pollution and human health. Some of the conclusions of the studies that confirm this are as follows: the increase of polluting particulate matter in cities and the thickening of the internal wall of the arteries or atherosclerosis are in direct relationship, people living in large urban areas with high traffic volumes have more respiratory problems than average, and are more likely to develop disease, in large cities, cases of children with bronchitis and delayed pulmonary development are much more common [20].

According to Air quality in Europe — 2019 report [21], air pollution continues to have significant impacts on the health of the European population, particularly in urban areas. Europe's most serious pollutants, in terms of harm to human health, are PM, NO_2 and ground-level ozone (O_3, also known as tropospheric ozone). Air pollution also has considerable economic impacts, cutting lives short, increasing medical costs, and reducing productivity through working days lost across the economy. Estimates of the health impacts attributable to exposure to air pollution indicate that $PM_{2.5}$ concentrations in 2016 were responsible for about 412 000 premature deaths originating from long-term exposure in Europe (over 41 countries), of which around 5 300 were in Croatia. The estimated impacts of exposure to NO_2 and O_3 concentrations on the population in these 41 European countries in 2016 were around 71 000 and 15 100 premature deaths per year respectively, and in Croatia around 260 and 190 premature deaths per year, respectively.

4. The importance of black carbon (BC) on air pollution and climate change

Black carbon (BC, also known as soot and black smoke) is a component of fine particulate matter (PM) ≤ 2.5 µm in aerodynamic diameter. Chemically, black carbon consists of pure carbon in several linked forms. It is formed through the incomplete combustion of fossil fuels, biofuel, and biomass, and is emitted in both anthropogenic and naturally occurring soot. Black carbon causes human morbidity and premature mortality [22].

In climatology, black carbon is a climate-forcing agent. Black carbon warms the Earth by absorbing sunlight and heating the atmosphere and by reducing albedo when deposited on snow and ice (direct effects) and indirectly by interaction with clouds, with the total forcing of 1.1 Wm^{-2}. [23, 24] Black carbon stays in the atmosphere for only several days to weeks, whereas carbon dioxide (CO_2) has an atmospheric lifetime of more than 100 years [25].

Major source of black carbon is a major component of diesel engine exhaust—the black, sooty smoke that spews from tailpipes of diesel cars and heavy-duty vehicles and busses. The World Health Organization has determined that diesel exhaust, outdoor air pollution and particulate matter (which includes black carbon) cause cancer. Black carbon is also not climate friendly. In fact, scientists have identified black carbon as the second most powerful contributor to climate change after carbon dioxide. As a short-lived climate pollutant (SLCP), black carbon emissions last a matter of days in the atmosphere, meaning its effects can be felt almost immediately [26].

Reducing BC emissions, particularly from combustion sources such as cooking and heating stoves and engines, delivers combined health and climate change benefits. This is because BC is estimated to be responsible for approximately 15 per cent of the current excessive warming of global temperatures. In addition, short-term reductions in BC can potentially delay the impact of global warming by approximately 10 years, "buying" time for more research and action. Efforts to reduce BC emissions should not replace measures to reduce CO_2 emissions, which in the long term will dominate climate change [27]. Several studies suggest that, in addition to health benefits, reducing black carbon sources would lead to cooling of global temperatures. On the other hand, other studies point out that reducing air pollution could worsen climate change in the short-term by contributing to an increase in global temperatures [28].

5. Fossil fuel and wood burning as the main anthropogenic emission sources

Fossil fuel and wood (biomass) burning play a crucial role in the total primary energy supply in Croatia. According to IEA Bioenergy country report for Croatia [29] Croatia`s target to increase the share of renewable energy to 20% in the annual gross energy consumption of the country by 2020 is defined in the National Energy Strategy 2009–2020 and implemented according to the National Renewable Energy Action Plan's (NREAP) dynamics. The total primary energy supply of Croatia in 2016 amounted to 355 petajoule (PJ) and is dominated by fossil fuels (70%). Renewable energy sources have a share of 24.6% or 84 PJ – 15.3% bioenergy, and 8.3% other renewable energy sources. The total primary energy supply of renewable energy sources is mostly covered by energy from biomass, with 65% (54 PJ).

Fossil fuel and wood burning as the main anthropogenic sources of greenhouse gases and air pollutants emission in Croatia are associated with climate change and air quality with negative impact on human health. When carbon-based fuels are burned, combustion causes the emission of carbon dioxide (CO_2) and other pollutants, including particulate matter (PM) (aerosols), which include particles that can cool or heat the Earth's climate by reflecting or absorbing the radiation of the Sun. BC remains in the atmosphere for a relatively short time (one week), but strongly absorbs solar radiation. BC emitted from domestic burning of solid fuels, particularly indoors, and high-emitting diesel engines is likely to contribute to climate warming [28].

Wood burning is very popular in many homes and is commonly used as a primary or secondary home heating fuel in Croatia [30, 31]. Popularity comes from lower price in comparison to other types of energy source, the ability to warm a place in a short time, market availability of wood, and fireplaces and stoves in homes give a cosy feeling. It is a general belief that wood is natural, that wood smoke is a natural substance, and these cannot be harmful. However, it is scientifically well established that wood burning and wood smoke result in health-harmful pollutants, including several carcinogenic compounds [32, 33, 34].

According to Lelieveld 2019 [35], the switch from fossil to renewable, clean energy sources has the potential to prevent morbidity and mortality from aerosol pollution. Because the particles have a net climate cooling effect, removing them will lower the prospects of meeting the goals of the Paris Agreement, but the public health gain is nevertheless a strong motivation for emission controls [36, 37].

6. Policies that address climate change and air pollution

The issue of climate change on a global scale is addressed by the United Nations Framework Convention on Climate Change (UNFCCC). The Republic of Croatia has been a party to the UNFCCC since 1996, and a party to the Kyoto Protocol[1] and the Paris Agreement[2]. The most important regulation of the Republic of Croatia governing climate change is the Act on Climate Change and Ozone Layer Protection (OG 127/19). Strategies that address decarbonisation and climate change issues and also determine Croatia's "roadmap" for future energy orientation are: The Energy Development Strategy of the Republic of Croatia until 2030 with an outlook to 2050, The Long-Term Strategy to Encourage Investment in the Renovation of the National Building Stock of the Republic of Croatia by 2050, Low-Carbon Development Strategy of the Republic of Croatia until 2030 with an outlook to 2050, and Climate Change Adaptation Strategy in the Republic of Croatia until 2040 with an outlook to 2070 with the action plan. These strategies are directly influencing future air quality and air pollution.

Air pollution on an international level is regulated through the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP Convention)[3]. Eight protocols under the LRTAP Convention identify specific measures to be taken by Parties to cut their emissions. The LRTAP Convention provides access to emission, measurement and modelling data, and information on the effects of air pollution on ecosystems, health, crops and materials. It is implemented by the European Monitoring and Evaluation Programme (EMEP).

[1] Pursuant to the Act on the Ratification of the Kyoto Protocol along with the United Nations Framework Convention on Climate Change (International Treaties, OG No. 5/07) and the Act on the Ratification of the Doha Amendment to the Kyoto Protocol (International Treaties, OG No. 6/15)

[2] Pursuant to the Act on the Ratification of the Paris Agreement (International Treaties OG No. 3/17)

[3] The 1979 Geneva Convention on Long-range Transboundary Air Pollution entered into force in 1983, now has 51 Parties. Based on the notification of succession, the Republic of Croatia is a party to the Convention of 8 October 1991 (NN-MU no. 12/93)

To improve air quality, the European Union adopted in 2013 a Clean Air Policy Package[4], including a Clean Air Programme for Europe setting objectives for 2020 and 2030, and accompanying legislative measures. Implementing the clean air package would result in improved air quality for all EU citizens, and lower healthcare costs for governments. The proposals would also benefit industry, as measures to reduce air pollution should boost innovation and enhance EU competitiveness in the field of green technology. [38] The main legislative instrument to achieve the 2030 objectives of the Clean Air Programme for Europe is the National Emission Ceilings Directive (NEC Directive)[5]. The NEC Directive was formed on the basis of the original Gothenburg Protocol under LRTAP Convention. It sets national emission reduction commitments for Member States and the EU for the five pollutants (sulphur dioxide, nitrogen oxides, volatile organic compounds, ammonia and fine particulate matter) responsible for acidification, eutrophication and ground-level ozone pollution, which lead to significant negative impacts on human health and the environment. The NEC Directive requires Member States to draw up National Air Pollution Control Programmes that should contribute to the successful implementation of air quality plans established under the EU's Air Quality Directive. The most important regulation of the Republic of Croatia governing air pollution is Air Protection Act (OG 127/19).

7. The state of emissions and emissions projections in Croatia

The main challenge of international climate change policy and air pollution policy is to limit future emissions. Projections of emissions trends strongly depend on assumptions such as economic and population trends and the rate of technology development and diffusion. As a Party of UNFCCC, LRTAP Convention and EU, Croatia is obligated to prepare emissions inventory and emission projections. Results of recent reported emissions of GHG and air pollutants NO_x and $PM_{2.5}$ detected as primary pollutants responsible of air quality deterioration and global warming, the pollutants along with emission projections are shown at Figures 3 – 5.

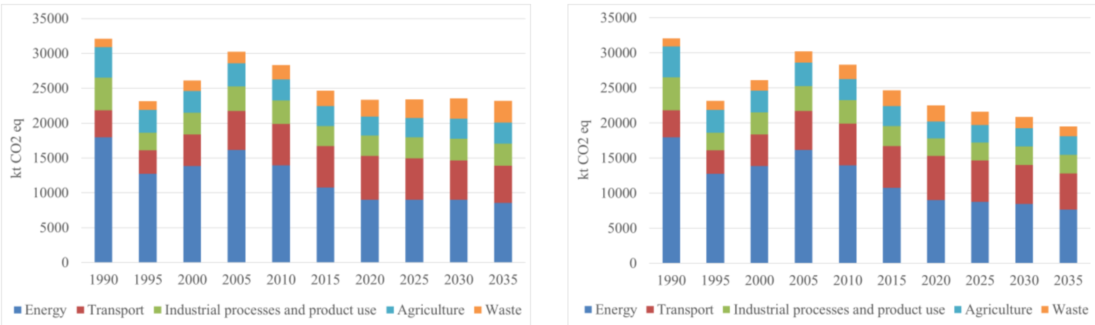

Figure 3. Historical and projected GHG emissions by sectors, with measure (WM) scenario (left graph) and with additional measures (WAM) (right graph) scenario in Croatia (Source: [39])

Concerning greenhouse gas (GHG) emissions, the most significant contributor is energy at 71%, followed by industry at 12%, agriculture at 11% and waste at 6% (Fig. 3). Projections of GHG emissions show that in the "with measure" (WM) scenario, the emissions in 2035 in comparison to 1990 are reduced by 27.6%, and in the "with additional measure" (WAM) scenario, emissions are

[4] Includes the Clean Air Programme for Europe, as well as a proposal for Directives on the reduction of national emissions of certain atmospheric pollutants (the NEC Directive) and on limitation of emissions of certain pollutants into the air from medium combustion plants (the MCP Directive).

5 Directive 2016/2284/EU entered into force on 31 December 2016, replacing earlier legislation (Directive 2001/81/EC).

reduced by 39.2%. In the WM scenario, projections show a decrease of emissions until 2020. In the period from 2020 to 2035, this scenario shows just a slight decrease of emission. In the WAM scenario, projections show a steady downward trend of emissions. In the WAM scenario in relation to the WM scenario in 2035, GHG emissions will be reduced by 16.0% [39].

Figures 4 and 5 show historical (2005–2018) and projected NO_x and $PM_{2.5}$ emissions, WM scenario (left graph) and WAM (right graph) scenario. The NO_x emission trend has an overall decreasing character since 2007. The key sector of NO_x emissions is the road transport sector with contribution of 42%-60% in national total in the period 2005-2018. Projections of NO_x emissions show that in the WM scenario, the emission in 2050 in comparison to 2005 is reduced by 84.2%, and in the WAM scenario emission is reduced by 92.4%. In scenario WAM in relation to the scenario WM in 2050, NO_x emissions will be reduced by 8.2%.

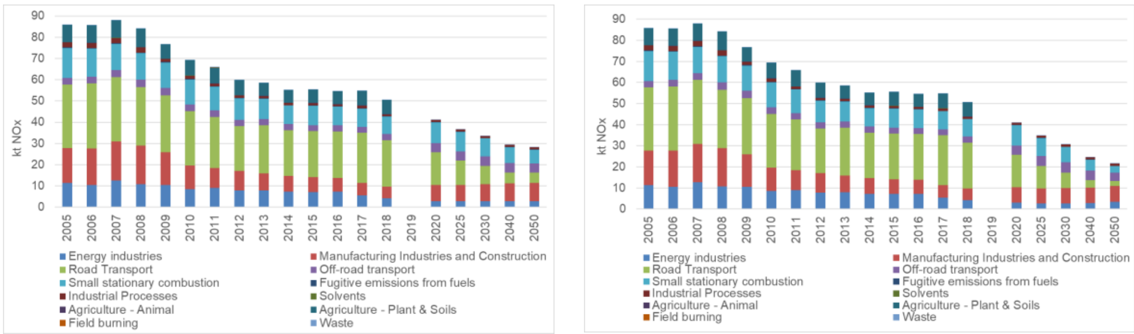

Figure 4. Historical and projected NOx emissions, with measure (WM) scenario (left graph) and with additional measures (WAM) (right graph) scenario in Croatia (Source of emission data: [40, 41]).

An overview of the current state of emissions in the case of $PM_{2.5}$ is presented because it is regulated and measured in SB. The $PM_{2.5}$ emission in 2018 amounted 28.7 kt. The $PM_{2.5}$ emission trend has overall decreased since 2005 by 31.4%. The key sector of $PM_{2.5}$ emissions is the small stationary combustion with contribution of 42%-60% in national total in the period 2005-2018. The small combustion sector is dominated by wood combustion in the residential sector [11]. Projections of $PM_{2.5}$ emissions show that in the WM scenario, the emission in 2050 compared to 2005 is reduced by 80.3%, and in the WAM scenario the emission is reduced by 91.2%. In the WAM scenario in relation to the WM scenario in 2050, $PM_{2.5}$ emissions will be reduced by 11%. The residential sector is responsible for the biggest reduction in historic and projected $PM_{2.5}$ emissions. The reduction occurs due to the replacement of traditional wood stoves and open fireplaces with new technologies that have significantly lower emissions.

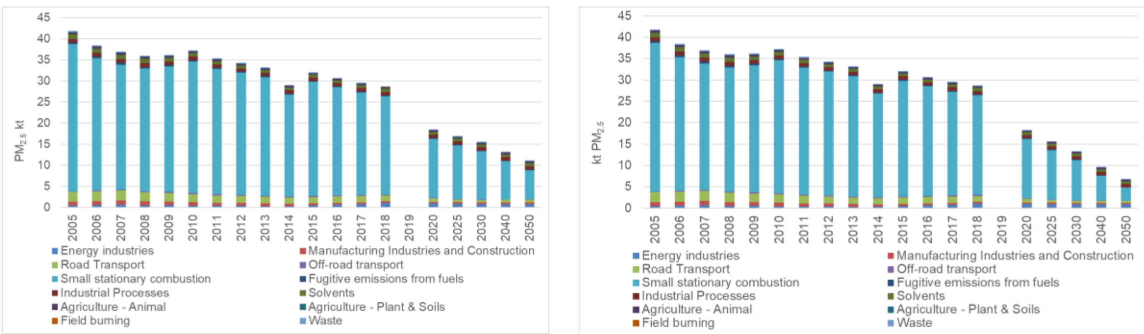

Figure 5. Historical and projected $PM_{2.5}$ emissions, with measure (WM) scenario (left graph) and with additional measures (WAM) (right graph) scenario in Croatia (Source of emission data: [40, 41]).

Projected GHG, NO_x and $PM_{2.5}$ emissions in Croatia are based on the same policy and measures (PaMs). The biggest reduction in GHG, NO_x and $PM_{2.5}$ emissions is expected in the road transport sector and residential sector as these are key sectors in current GHG, NO_x and $PM_{2.5}$ emissions. Some of PaMs for reduction of emissions in the road transport sector are:

- Financial incentives for the purchase of plug-in hybrid and electric vehicles,
- Promotion of integrated and intelligent transport systems and alternative fuels in urban areas,
- Promotion of clean and energy efficient vehicles in road transport,
- Development of the infrastructure for alternative fuels,
- Special environmental fee for motor vehicles and Special tax on motor vehicles.

Some of PaMs for reduction of emissions in the residential sector [42, 43] are:

- Programme for energy renovation of apartment buildings,
- Programme for the increase of energy efficiency and use of renewable energy sources in commercial non-residential buildings,
- Programme for energy renovation of family houses,
- Promotion of the use of renewable energy sources and energy efficiency by EPEEF (the Environmental Protection and Energy Efficiency Fund) resources,
- Integration of measures for pollutant emission mitigation into planning documents and projects for road transport, and
- Integration of measures for pollutant emission mitigation into planning documents and projects for energy renewal of buildings.

Continental parts of Croatia have a pronounced particulate air pollution problem during heating seasons. The air quality standard is mostly exceeded because of frequent occurrence of high daily PM_{10} concentrations during wintertime. The overview of local sources of PM_{10} emission is presented below.

In 2018, PM_{10} emission was 37.8 kt (Fig. 6) and was down by 28.5% compared to 2005. The energy sector is the sector with the highest contribution to the total PM_{10} emission (in 2018 with 74.3%). The key category in the Energy sector is Small stationary combustion (63.2% in the national total in 2018). Industrial processes and product use sector is the second largest source (14.4% in 2018), followed by agriculture, which contributed to the overall emissions in 2018 with 11% [30].

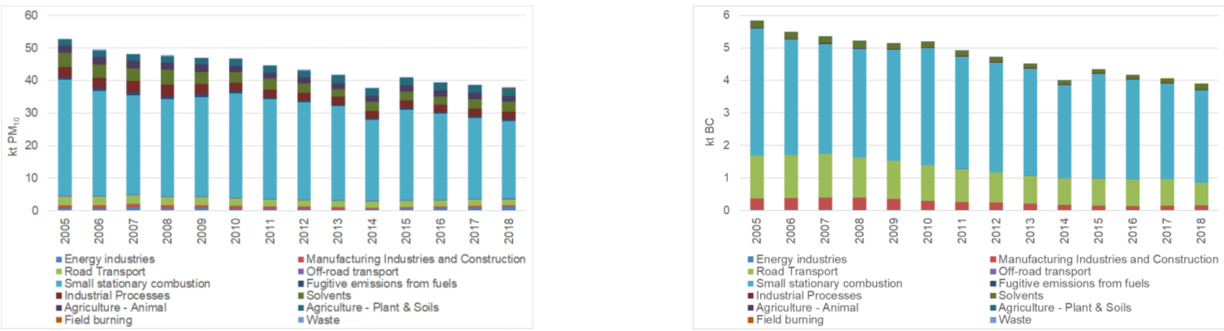

Figure 6. Historic emissions for PM_{10} (left graph) and BC (right graph) in Croatia (Source of emission data: [40]).

The historic state of emissions in the case of BC is also presented because it is an indicator of the impact of traffic on air quality, and it was measured earlier. In 2018, BC emission was 3.9 kt (Fig. 6) and was down by 33.3% compared to 2005. The energy sector is the sector with the highest contribution to the total of BC emission (in 2018 with 95.3%). The key category in the energy sector is small stationary combustion (73% in the national total in 2018). The second dominant sector is road transport (18% in the national total in 2018).

It can be concluded that the small stationary combustion with the domination of residential wood combustion and road transport sector are the key sources of GHG, NO_x, PM_{10}, $PM_{2.5}$ and BC emissions. In compliance with EU goals to reduce GHG emissions and considering growing air pollution, it is essential to emphasise the importance of green transportation, i.e. energy efficiency in transport, and to encourage the projects aimed at increasing energy efficiency of transportation systems and use of more efficient vehicles (vehicles using RES, which emit less CO_2 and electric vehicles) [44]. Croatia has prescribed and set policies and measures packages to meet international and EU obligations. Since their implementation is mandatory, it can be considered that Croatia contributes to the global effort to climate change mitigation and improvement of air quality by reducing its greenhouse gas emissions, decarbonizing economy, and reducing air pollution.

Diesel vehicles and especially diesel cars could be a significant source of NO_2 and PM air pollution in the busy urban streets. Even though the majority of new cars in Croatia run on petrol, a large share of old diesel cars had been imported to Croatia over the last seven years. For example, 55,686 used cars were imported into Croatia in 2017, and as many as 87% had diesel engines and they were produced from 2005-2015 which means their emissions are according to old Euro 4 and Euro 5 emission standards [45], [46]. Average age of passenger cars in Croatia increased from 9.89 years in 2008 to 12.58 years of age in 2019. The impact of economic crises and the effect of import of old used diesel cars result that after the year 2014, reduction in emission of PM_{10} has been stopped as can be seen in Figure 7.

The emission of PM_{10} from the transport sector consists of exhaust emissions and non-exhaust emissions such as tyre wear, brake wear and road abrasion. Stricter EURO emission standards for vehicle emissions led to reduction of non-exhaust emissions so they have limited impact on the total transport emissions, but they have a major impact on BC emission. Namely, BC is a major part of exhaust particulate emissions from vehicles, but it is not a major constituent of particles that originated from road transport. A closer look at the road transport PM_{10} emissions in Croatia in the figure below shows that in the year 2018 less than half of PM_{10} emission comes from vehicles' exhaust gases (Fig. 7). It could be expected that urban driving leads to higher automobile tyre and brake wear as well road abrasion, while exhaust emissions are continuously dropping by the "rejuvenation" of the vehicle fleet.

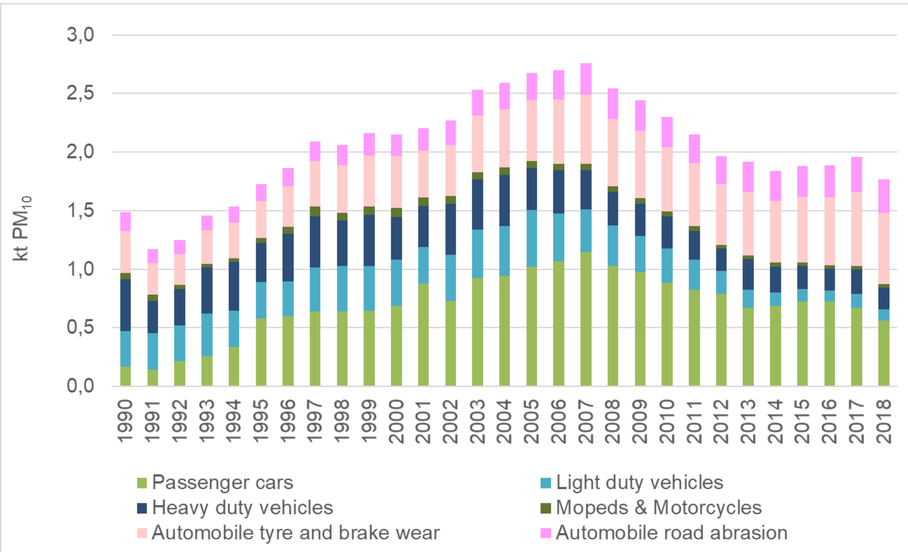

Figure 7. Historic trend of PM_{10} emission from road transport in Croatia (Source of emission data: [40]).

8. The current state of air quality in the case of particulate matter in Croatia

The territory of Croatia is divided into 5 zones (HR 1, HR 2, HR 3, HR 4, HR 5) and 4 agglomerations (HR ZG, HR OS, HR RI, HR ST) for air quality assessment (Fig. 8). The air quality monitoring network, for compliance assessment, consist of 9 monitoring stations in agglomeration and 13 monitoring stations in zones (Fig. 8). There are 7 rural background monitoring stations (Višnjan, Hum, Žarkovica, Parg, Plitvička jezera, Desinić, Kopački rit) sited in 4 zones (HR1, HR3, HR4, HR5).

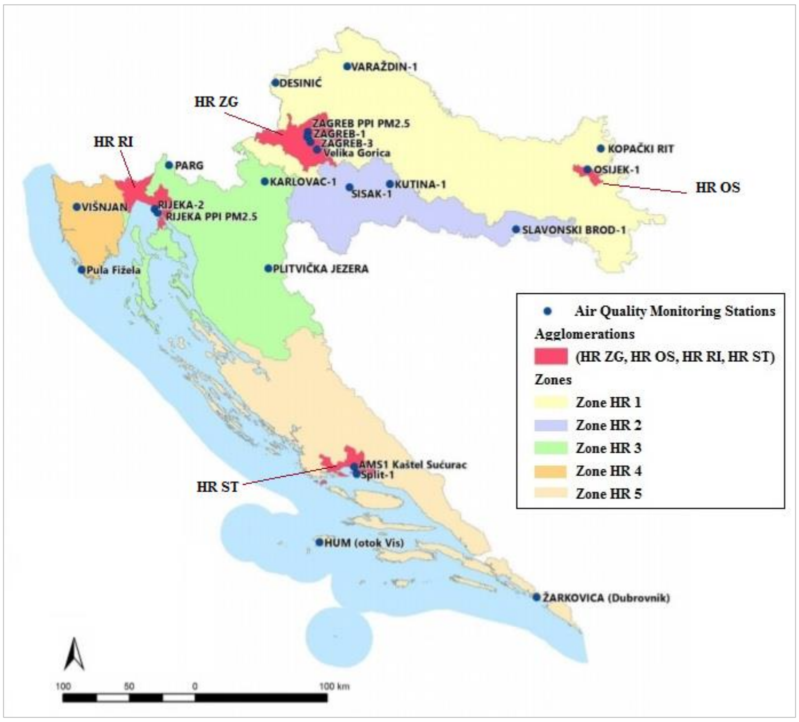

Figure 8. Air quality monitoring stations in zones and agglomerations of the Republic of Croatia (Source: Figure adopted from *Croatian Environment Agency*: [48]).

The compliance assessment, based on national air quality report [48] for the year 2017 is summarised below:

- The limit value for NO_2 was exceeded in one agglomeration (HR ZG),
- The limit value for PM_{10} was exceeded in two agglomerations (HR ZG, HR OS) and one zone (HR 2),
- The limit value for $PM_{2.5}$ was exceeded in one agglomeration (HR ZG) and one zone (HR 2),
- The target value for benzo(a)pyrene was exceeded in one agglomeration (HR ZG) and one zone (HR 2),
- The target value for ozone was exceeded in two agglomerations (HR ZG, HR RI) and four zones (HR 1, HR 3, HR 4, HR 5).

The NO_2 pollution is localized in one agglomeration (HR ZG) and is caused by road traffic emission. On the other hand, the ground level ozone pollution is widely spread over Croatia and it is mostly under the influence of transboundary transport of ozone and ozone precursors. The highest number of exceedances for ozone target value in the year 2017 were measured in the coastal zones (HR 3, HR 4, HR 5).

The air quality standards for particulate matter (PM_{10} and $PM_{2.5}$) and benzo(a)pyrene are only exceeded in continental parts of Croatia. Non-compliance for all three pollutants were assessed in the year 2017 for one agglomeration (HR ZG) and one zone (HR 2) but not necessarily at the same monitoring stations. Only the non-compliance for PM_{10} is assessed for agglomeration HR OS but it should be mentioned that $PM_{2.5}$ and benzo(a)pyrene are not measured in that agglomeration.

Compliance with annual and daily limit values for PM_{10}, presented in Figure 9, shows that exceedance of limit value for PM_{10} daily concentration are major cause of non-compliance for that pollutant in the year 2017.

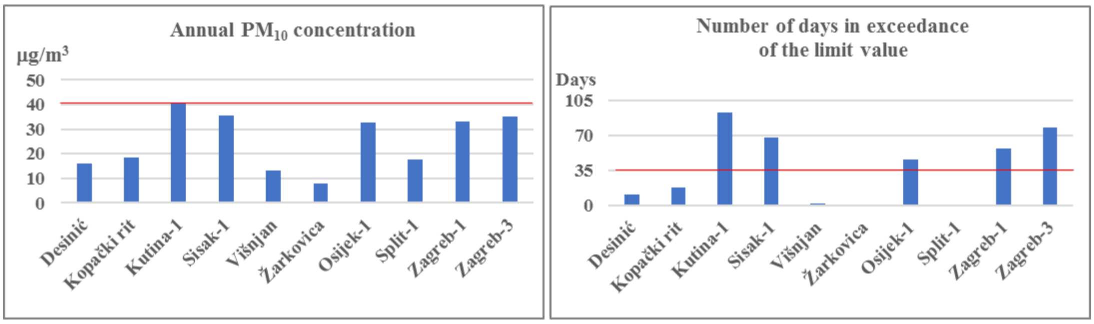

Figure 9. Compliance with limit values for PM_{10} in the Croatia for the year 2017 (Source: Data from *Croatian Environment Agency* [49]).

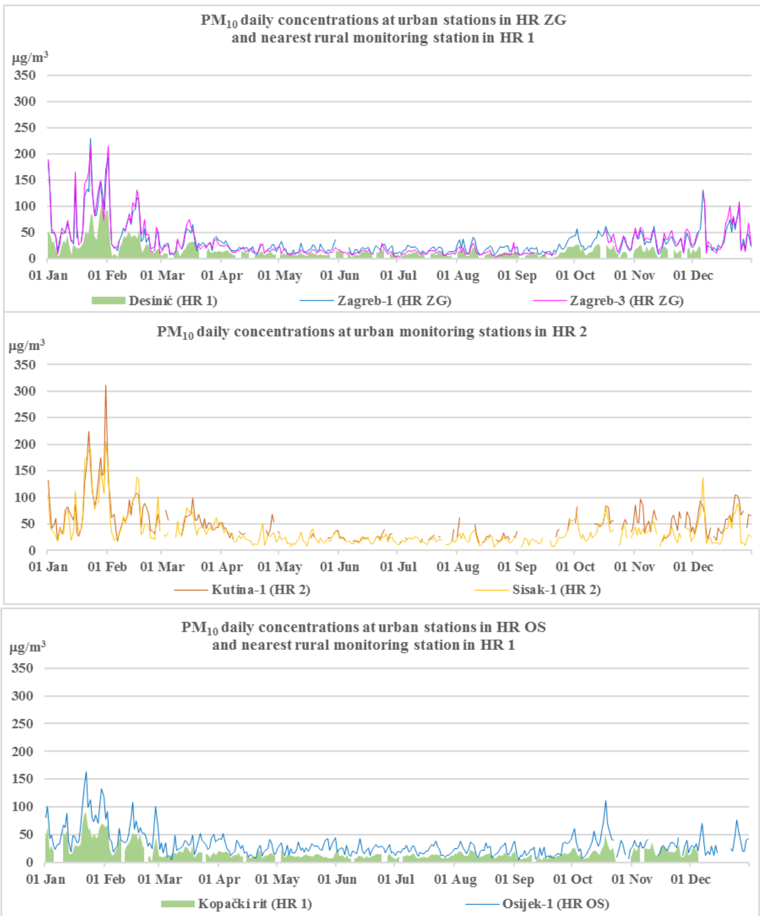

Figure 10. Urban and rural background daily concentrations of PM_{10} for the year 2017 (Source: Data from *Croatian Environment Agency* [49]).

Seasonal variation of daily concentrations for urban and rural background air quality monitoring stations are presented in Figure 10. Rural background monitoring stations (Desinić, Kopački rit) are less than 50 km from the monitoring stations in the nearest agglomeration (HR ZG, HR OS). The PM_{10} pollution episodes mostly occur at the same time at all monitoring stations during winter. The pollution episodes are most pronounced in zone HR 2 where there is no rural background monitoring station.

Emission and air pollution maps of PM_{10} based on EMEP data [50] in the year 2017 are presented in Figure 10. The PM_{10} concentration map (Fig. 9) shows that eastern parts of continental Croatia are exposed to transboundary particulate pollution.

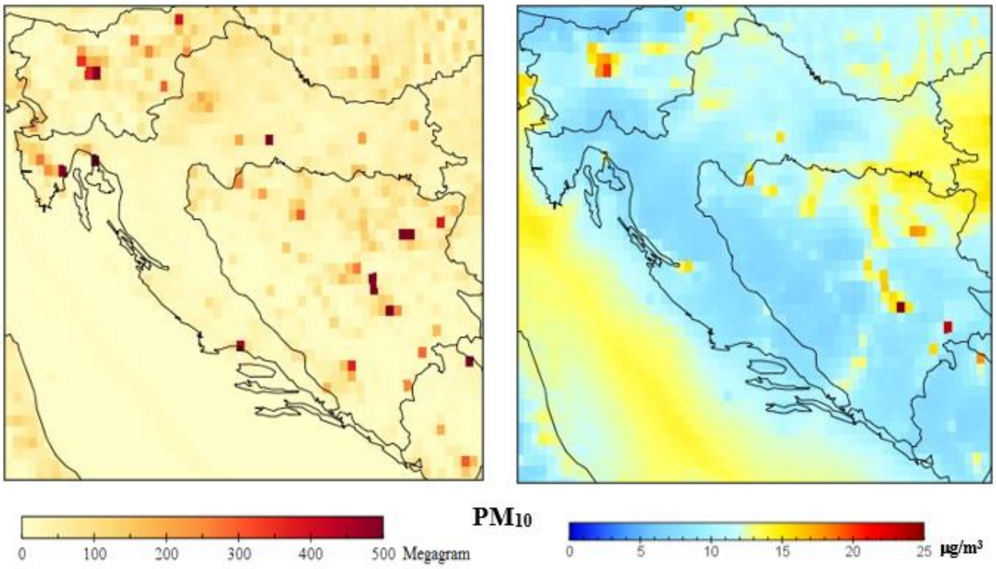

Figure 11. Map of annual primary PM_{10} emission (left) and concentrations (right) for the year 2017 (Source: Data from The Norwegian Meteorological Institute [50]).

9. Local air pollution policy and climate policy

At the municipality level, mitigation measures to reduce air pollution are set out by the obligatory *air quality plans*, while the measures to reduce GHG emissions are set by voluntary policies, such as *Sustainable Energy (and Climate) Action Plans* (SE(C)AP). All Croatian municipalities, which have developed air quality plans because of particulate pollution, also have SEAPs as presented in Table 1.

According to air quality plans listed in Table 1, the major source of particle pollution are household emissions and road transport. All measures to improve energy efficiency and promotion of public transport and the shift to environmentally friendly ways of transport set by SEAPs, are integrated in air quality plans. Since air quality plans aim at reducing particle emissions as soon as possible, there is the question about the use of natural gas instead of GHG-neutral wood stoves for heating, which is in contradiction to the goals set by SEAPs.

Table 1. The overview of air quality plans and SEAPs in continental parts of Croatia.

Municipality	Air quality plan	Sustainable Energy (and Climate) Action Plan
Zagreb	✔ NO_2, O_3, $PM_{2,5}$, PM_{10}, BaP	✔
Slavonski Brod	✔ $PM_{2,5}$	✔
Sisak	✔ PM_{10}	✔
Kutina	✔ PM_{10}	✔
Osijek	✔ PM_{10}	✔
Vinkovci	✔ $PM_{2,5}$, PM_{10}	✔

10. Funding mechanisms for implementing climate change and air protection policies in Croatia

The Government of the Republic of Croatia, the Ministry of Construction and Physical Planning, and the Ministry of Environmental and Nature Protection, adopted on 27 March 2014 the Programme of energy renovation of family houses, which is implemented by the Environmental Protection and Energy Efficiency Fund. The goal of the Programme is to increase energy efficiency of the existing houses, to reduce energy consumption and emissions of CO_2 into the atmosphere, and to reduce the monthly costs for the energy generating products, with the overall improvement of the quality of living. At the same time, the planning of such interventions implies the engagement of the local companies and experts, meaning it promotes economic activities. The first Amendments to the Programme were adopted in 2015, and the Second amendments in 2020. After the adoption of the Amendments to the Programme, the Environmental Protection and Energy Efficiency Fund will continue with the national financing of the Programme of energy renovation of family houses in 2020. On 25 June 2020, the Public Call was invited for the citizens (co)owners of the existing family houses falling in the minimum energy category (according to $Q_{H,nd}$, the specific annual thermal energy required for heating, the Ordinance on energy audit of buildings and energy certification OG 88/17, 90/20) D or below in the continental part of Croatia, or in the energy category C or below in the coastal part of Croatia [47].
For the Programme of energy renovation of family houses in the period 2015 - 2020, the Fund has secured the amount of HRK 836 million, and additional funding was invested in the Programme of energy renovation of multi-apartment buildings in the amount of HRK 195 million, while HRK 204 million for the Programme of energy renovation of public buildings, all in the same timeframe.

The Environmental Protection and Energy Efficiency Fund co-financed the measures for enhancing energy efficiency in transportation through 3 programmes:

- co-financing the purchase of electric and plug-in hybrid vehicles for citizens, companies and trades, and co-financing the construction of charging stations for electric vehicles
- co-financing eco-driving training
- co-financing other measures for energy efficiency in traffic [44].

The Fund provided HRK 325 million for the implementation of the above measures in the period 2015 – 2020.

Investment of the Fund in renewable energy sources (RES) for the mentioned 5-year period amounts to HRK 192 million. Part of the investment was allocated for co-financing the replacement of the conventional wood-burning stoves and boilers with high particle emissions with the new devices, which ensure low particle emissions in the burning of biomass, i.e. using better combustion technology.

11. Conclusion

This paper provides a brief overview of what is causing air pollution and climate change at global and local level, and what can be done to tackle both. An overview of the latest status of air quality and emissions of the main polluters in Croatia with policies in place to combat both are presented.

It should be emphasized that the implementation of both air and climate quality policies can bring mutual benefits to both health and climate. Reducing ambient air pollution can reduce the incidence of diseases attributable to air pollution, but it can also reduce CO_2 and SLCP (such as black carbon) emissions, thus contributing to short-term and long-term climate change mitigation.

Sustainable energy path with energy efficiency and renewable energy is imposed as an overall path for tackling climate change and air pollution. By adopting the Energy development Strategy[6] in March 2020, Croatia is a step closer towards realizing the vision of low-carbon energy. But more synergy of policies is needed for tackling climate change and air pollution more efficiently. Coordination among ministries with different authorities is getting better, but activities should be continuously intensive, both on horizontal and vertical level with local authorities.

This paper shows that the residential wood combustion and road transport sector are the key sources of GHG, NO_x, PM_{10}, $PM_{2.5}$ and BC emissions in Croatia. Historical trends of pollutants along with their projected emissions and air quality plans in Croatia are one of the proofs of the above. With that in mind, Croatia has prescribed and set policies and packages of measures to meet international and EU obligations, implementation of which is mandatory, and Croatia will take part in the global effort to reduce greenhouse gas emissions, decarbonise its economy and reduce air pollution and improve air quality. Increasing Green transportation, energy efficiency of transportation systems and use of more efficient vehicles, along with replacing conventional wood-burning stoves and open wood fireplaces with new stoves and boilers with low PM emissions will ensure combined health and climate benefits compared with costs.

The observed contradictions in current policies to address climate change and air pollution in Croatia mentioned in this paper, is a reminder that more needs to be done. One way for resolving the existing contradictions is through the funding of joint mechanisms for implementing climate change and air protection policies in Croatia.

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