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Policy pressures on air

Anticipating unforeseen effects of EU policies on Air Quality

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Foreword

In recent decades, European Union (EU) policies have contributed to reducing emissions of air pollutants, but overall air quality has not improved at the same rate and the impact on public health remains considerable. Over 400 000 people die prematurely in the EU each year because of diseases related to air pollution, primarily in the eastern and central parts of the EU.

The European Court of Auditors (ECA), in its role as a politically neutral institution published a report assessing the effectiveness of EU solutions and the resources spent on air quality in the European Union.

Such an important publication reveals a number of management weaknesses in this area, while identifying possible measures to remedy the situation. It is a report that has generated great public interest and has been the subject of many publications in the European media, as well as outside Europe. Such public interest is entirely understandable, given that air pollution causes considerable harm to public health in the EU.

One of the conclusions in the ECA audit report is that EU policies are inconsistent with its activities to improve air quality and therefore the ECA has recommended more effective action to improve air quality in the EU.

The Joint Research Centre (JRC), in agreement with the Directorate-General for Environment of the European Commission has reacted to the solicitation from the ECA, *inter alia*, developing the in-depth examination of gaps in the EU system presented in this report and suggesting possible research lines aimed to address them. The report is based on both literature screening and expert input and has identified a series of "pressures" on European air quality coming from transformations often horizontally involving one or more key sectors.

The report provides a wide-ranging analysis of the causes of air pollution and possible countermeasures, that are fully in line with the zero-pollution target of the ambitious "European green deal" envisaged in the 2019-2024 political guidelines of the incoming European Commission.

We hope that the ECA's air quality audit and this JRC report will together help to stimulate more effective action to improve air quality in the EU and, by extension, to protect EU citizens' health.

Janusz Wojciechowski
Member of the European Court of Auditors

Charlina Vitcheva
Acting DG of the Joint Research Centre

Abstract

This report analyses the main sectors involved in air pollution generation and provides a first assessment and prioritisation of the main ongoing or foreseeable structural changes that may pose a threat to the European air quality in Europe.

In particular the following questions have been addressed with the support of selected experts:

"*Is it true that there are regulatory aspects that could result in slowing down of the decrease in air pollutant emissions, or even potentially leading to their increase?*"

"*If so, is it possible to identify one or more specific issues, maybe related to structural sectorial changes, that needs to be addressed?*"

"*For these key issues, is it possible to quantify (or at least estimate) the unintended impact on air quality in order to prioritise appropriate countermeasures?*"

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Finally, it has to be reminded that most of the report is based on information gathered through two workshops organized in the first part of 2019. The availability of both JRC and external experts (see list) contributing to these workshops with content and discussion points deserves a special mention.

Andreas Unterstaller – European Environmental Agency
Cristina Reche – Consejo Superior de Investigaciones Científicas
Carlos Lima Azevedo – Danish Technical University
Uwe Fritsche - International Institute for Sustainability Analysis and Strategy
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Marco Giuli – European Policy Centre)
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Executive summary

Policy context

Since the 1980s, the European institutions have progressively legislated to combat the impact of air pollution on citizens' health, putting in place a wide spectrum of measures that have proven to be effective in improving the European air quality landscape. Nevertheless, air pollution remains the single largest environmental health hazard in Europe, leading to about 400,000 premature deaths each year within the European Union and it is the right time to examine how the regulatory frameworks of key sectors are, or are not, contributing to cleaner air in Europe.

In the words of the European Court of Auditors: *"Some EU policies do not yet sufficiently well reflect the importance of improving air quality"* and that in particular *"climate and energy, transport, industry and agriculture are EU polices with a direct impact on air quality, and choices made to implement them can be detrimental to clean air".*

This report responds to these observations, analysing the main sectors involved in air pollution generation and providing a first assessment and prioritisation of the main ongoing or foreseeable structural changes that may pose a threat to the European air quality, beyond the current regulatory framework. In particular the following questions have been shared with experts and researchers involved:

"*Is it true that there are regulatory aspects that could result in slowing down of the decrease in air pollutants emissions, or even potentially leading to their increase?*"

"*If so, is it possible to identify one or more specific issues, maybe related to structural sectorial changes that need to be addressed?*"

"*For these key issues, is it possible to quantify (or at least estimate) the unintended impact on air quality in order to prioritise appropriate countermeasures?*"

Main findings and conclusions

The investigation, based on both literature screening and expert input, identified a series of "challenges" to European air quality coming from transformations in one or more key sectors and classified them in terms of urgency and importance as shown in the following table (detailed description of each issue can be found in Chapter 3).

	Future	**Immediate**
Critical	Electric mobility Decarbonisation of heating and cooling sector Power systems flexibility	Biomass and biofuels Energy poverty Transport inequalities Batteries & electric network
Relevant	Power-to-X Democratizing energy & transport	Rural development Territorial policies Power system flexibility Ammonia from catalysts

Secondly, the report has confirmed that for several of the challenges, today's legislative system overlooks the impact on air quality as a major concern that should in fact be addressed. Finally, many of the issues identified are complex, spanning multiple sectors and including technical, economic and societal aspects. Further investigation is both necessary and requires a more holistic perspective.

Related and future JRC work

This report is a preliminary qualitative investigation of a complex and multi-faced issue and the "natural" evolution would be to investigate quantitatively, at least some of the threats identified. Furthermore, as shown in the report, the JRC is well equipped for such a task thanks to the availability of a robust suite of fit-for-purpose tools, including, *inter alia*, life cycle analysis, techno-economic models and composite indicators.

1 Introduction

-Scope of the report

Air pollution is responsible for an estimated 4.2 million premature deaths globally every year, with more than 90% of the world population living in places where air is unsafe to breathe. In Europe, air pollution remains the single largest environmental health hazard leading to about 400,000 premature deaths each year within the EU (EEA, 2019). By comparison, heart attacks cause about 4 million deaths every year. More than 90% of urban population in Europe is exposed to air pollution above World Health Organisation guidelines and the direct annual cost of air pollution, including working days lost, healthcare costs and crop damage, has been estimated to be €23 billion while annual indirect costs are between €330 and €940 billion. (European Commission, 2013)

Since the 1980s, the European institutions have progressively legislated to combat the impact of air pollution on citizens' health, putting in place a wide spectrum of measures that have proven to be effective in improving the European air quality landscape. A detailed view of the current state of air quality in Europe and a summary of the main policies and initiatives tackling it, is provided in Chapter 2.

Nevertheless, threats to clean air persist and in order to identify possible future lines of action, it has been suggested to look beyond policies specifically designed to combat air pollution and examine how policies not directly conceived to improve air quality are affecting and will affect it in future.

In the words of the European Court of Auditors (ECA): "Some EU policies do not yet sufficiently well reflect the importance of improving air quality" especially noticing that "climate and energy, transport industry, and agriculture are EU polices with a direct impact on air quality, and choices made to implement them can be detrimental to clean air." (ECA, 2018)

-Policy questions

Responding to this challenge from ECA, the report analyses policies regulating the main sectors involved in air pollution generation in order to provide an initial qualitative assessment. In particular the following questions have been shared with experts and researchers involved:

"*Is it true that there are regulatory aspects that could result in slowing down of the decrease in air pollutants emissions, or even potentially leading to their increase?*"

"*If so, is it possible to identify one or more specific issues, maybe related to structural sectorial changes, that needs to be addressed?*"

"*For these key issues, is it possible to quantify (or at least estimate) the unintended impact on air quality in order to prioritise appropriate countermeasures?*"

These questions are meant to move from a general view to a more detailed identification of punctual key issues. Clearly, these are very general questions that translate case by case into sometimes very specific and sectorial questions that have been explicitly formulated in the sections of the report.

-Knowledge base for the report

The report content stems from two main sources: a literature study and expert elicitation. Two workshops for expert discussion have been organised, in February and in April 2019. The first workshop involved experts from universities and research institutions and focused on the energy and transport sectors. The second workshop involved JRC colleagues and covered other topics including agriculture, territorial policies and the bioeconomy.

-Structure of the report

The report follows a simple structure leading the reader from problem formulation to its analysis and decomposition into challenges that need more detailed investigation. Chapter 2 provides a summary of the status and causes of air pollution in Europe, together with a general picture of the current legislation and initiatives directly addressing the problem. Chapter 3 gives an overview of those policies that do not directly address air pollution, but impact on sectors known to be the sources of the most significant pollutant emissions. The second part investigates how unforeseen evolution or structural changes of these sectors, sometimes triggered by the legislation itself, could jeopardise the pursuit of cleaner air quality. Chapter 3 is largely qualitative, while in Chapter 4 a possible prioritisation is proposed, based on a quantitative assessment of the scale of challenges and the likelihood of their actual deployment. In the same chapter the main research gaps are also discussed. Conclusions and outlook are provided in Chapter 5.

2 The air quality in the EU

2.1 Status and sources

2.1.1 Summary of the state and projections of air quality in EU

EU is committed to reduce negative impact of air quality on human health and ecosystems. To do so, there is legislation in place, with limit values on different pollutants as particulate matter, ozone, nitrogen oxides, etc… among others. Even if the situation is improving, air quality in Europe is still an issue, with several exceedances reported in 2017 (the last available year) in various parts of Europe for both EU limit values and World Health Organization (WHO) Air quality guidelines. For Particulate Matter (PM) with a diameter of 10 µm or less (PM_{10}), concentrations above the EU daily limit value were registered (in 2017) at 22% of the available stations, involving 17 of the 28 EU Member States. For $PM_{2.5}$, concentrations above the annual limit value were registered at 7% of the reporting stations in seven Member States. These seem reassuring values, but the picture changes a lot when compared with the long-term WHO Air Quality Guidelines (AQG). WHO guideline values for PM_{10} were exceeded at 51% of the stations and in all the reporting countries, except Estonia, Finland and Ireland. The long-term WHO AQG for $PM_{2.5}$ was exceeded at 69 % of the stations located in all the reporting countries except Estonia and Finland.
For ozone (O_3), in 2017, 20% of stations recorded concentrations above the EU ozone target value for the protection of human health. The long-term objective was met in only 18% of stations, while the lower WHO AQG value for O_3 was exceeded in 95% of all the reporting stations (EEA, 2019).
For nitrogen dioxide (NO_2), in 2017 the annual limit value continued to be widely exceeded across Europe, even if concentrations and exposure are decreasing. In 2017, around 10% of all the reporting stations had concentrations above this standard (same as the WHO AQG). These stations were located in 16 of the EU-28 Member States, and 86% of concentrations above this limit value were observed at traffic stations.

Converting these results into population exposure, the values presented in Figure 1 are obtained; the Figure shows, in particular, the percentage of the urban population in the EU-28 exposed to air pollutant concentrations above EU and WHO reference concentrations (EEA, 2019)

Pollutant	EU reference value ([a])	Urban population exposure (%)	WHO AQG ([a])	Exposure estimate (%)
PM_{10}	Day (50)	13-19	Year (20)	42-52
$PM_{2.5}$	Year (25)	6-8	Year (10)	74-81
O_3	8-hour (120)	12-29	8-hour (100)	95-98
NO_2	Year (40)	7-8	Year (40)	7-8
BaP	Year (1)	17-20	Year (0.12) RL	83-90
SO_2	Day (125)	< 1	Day (20)	21-31

Key	< 5 %	5-50 %	50-75 %	> 75 %

Figure 1 Percentage of the urban population in the EU-28 exposed to high concentrations of pollutants. BaP stands for Benzo[a]pyrene. Source: (EEA, 2019)

In terms of trends and projections for the future, the Clean Air Outlook (European Commission, 2018) analysed how the percentage of the EU population exposed to concentrations above the WHO $PM_{2.5}$ guideline values will change in future (the focus of the study was on $PM_{2.5}$, as it is the pollutant with the highest impact on health).
The study found that the implementation of the most recent policy should reduce exposure substantially. In particular, Figure 2 shows the expected evolution between the

National Emission Ceiling Directive (NECD)[1] base year (2005) and the NECD target year 2030, based on the assumption of full implementation of the NECD. From 88% of the population exposed to concentrations above the WHO guideline value in 2005, the proportion falls to 13% in 2030, and exceedances are limited to a few areas in Europe, with most of those within 5 µg/m3 of the limit value. Thus, the projections performed in support to the Clean Air Outlook show that, by 2030, most urban concentrations should be at or under the air quality guidelines of the World Health Organization.

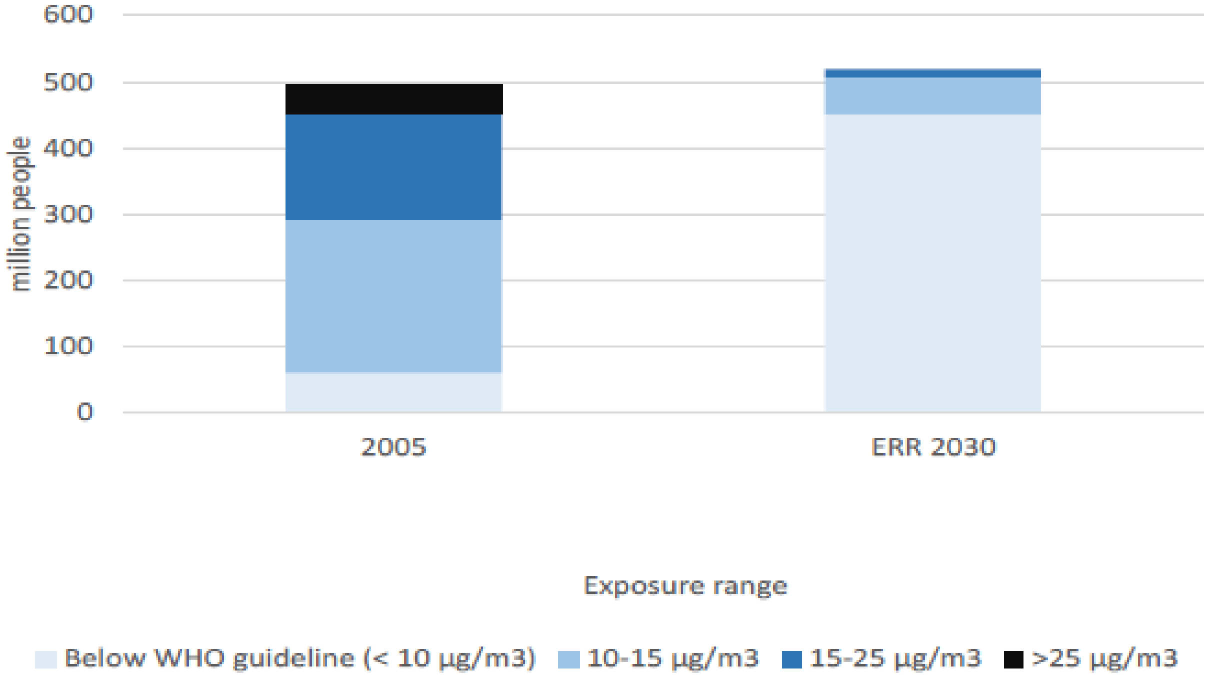

Figure 2 Distribution of population exposure in the EU to $PM_{2.5}$ levels in 2005, and in 2030 assuming full implementation of NECD ERRs (National Emission Ceiling Directive, Emission Reduction Requirements) and of the other air quality related legislation (European Commission, 2018)

2.1.2 Main air pollution sources

Figure 3 shows the contribution of different sectors to EU-28 emissions from main sources in 2016, for various regulated pollutants (EEA, 2019). It is worth recalling that some of the listed pollutants also act as precursors for secondary pollutants formation. In particular, sulphur oxides (SO_x), nitrogen oxides (NO_x, which includes both NO and NO_2), primary particulate matter, ammonia (NH_3), black carbon (BC) and organic carbon (OC) are precursors of PM_{10} and $PM_{2.5}$ while non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and methane (CH_4) lead to the formation of ozone (O_3)

[1] See paragraph 2.2.1

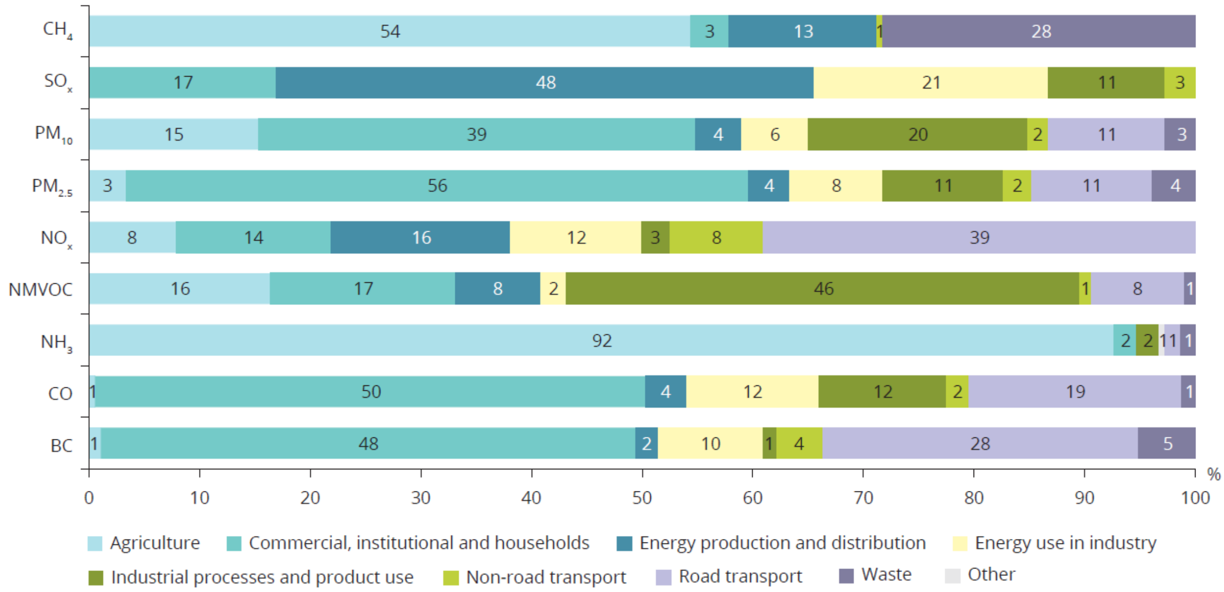

Figure 3 Contribution to EU-28 emissions from main sectors in 2016 of SO_x, NO_x, and primary PM_{10}. Source: (EEA, 2019)

The main sectors contributing to emissions are:

- The road transport sector, which was the largest contributor to total NO_x emissions and a significant contributor of BC, CO, primary $PM_{2.5}$ emissions;
- Energy production and distribution, which was the largest contributor to SO_x, as well as a significant contributor of NO_x and CH_4 emissions;
- Agriculture contributed the majority of NH_3 and CH_4, as well as a significant amount of primary PM_{10} and NMVOC emissions;
- The commercial, institutional and households sector was the largest contributor to total primary PM_{10} and $PM_{2.5}$, CO and BC and also contributed to NMVOC, SO_x and NO_x emissions;
- Industrial processes and product use contributed the majority of NMVOC emissions and a significant amount of primary PM.

This variety of contributions calls for an in depth analysis of their effects on air quality, as these emissions are then converted in concentrations (of $PM_{2.5}$, PM_{10}, NO_2, O_3) through physical and chemical reactions.

2.2 EU policies and initiatives addressing air pollution

2.2.1 Policies

Air pollution is tackled at different decision levels, encompassing international, European, national and local actions.
At the international level, the main existing tool is the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (UNECE, 1979), that regulates emissions of air pollutants mainly through the 2012 Gothenburg Protocol, across the pan-European region. In this Convention the Parties commit to act to reduce their emissions, so that air quality should be improved and health impacts reduced in an optimised way through the continent.

The EU bases its clean air policy on three pillars (Figure 4):

- The "Ambient Air Quality Directives" (EU) 2008/50 and (EU) 2004/107 that set out air quality standards to be achieved in the Member States and requires the implementation of "air quality plans" whenever the limits are exceeded;
- The already mentioned "National Emission Ceilings Directive" (EU) 2016/2284, requiring Member States to develop "National Air Pollution Control Programmes" in order to comply with their emission reduction commitments. The NECD builds to a large part on the negotiations done in the framework of the UNECE Long Range Transport of Air Pollution convention;
- Emission and energy efficiency standards for key sources of air pollution, from vehicle emissions to products and industry. This is achieved with source-specific legislation[2]

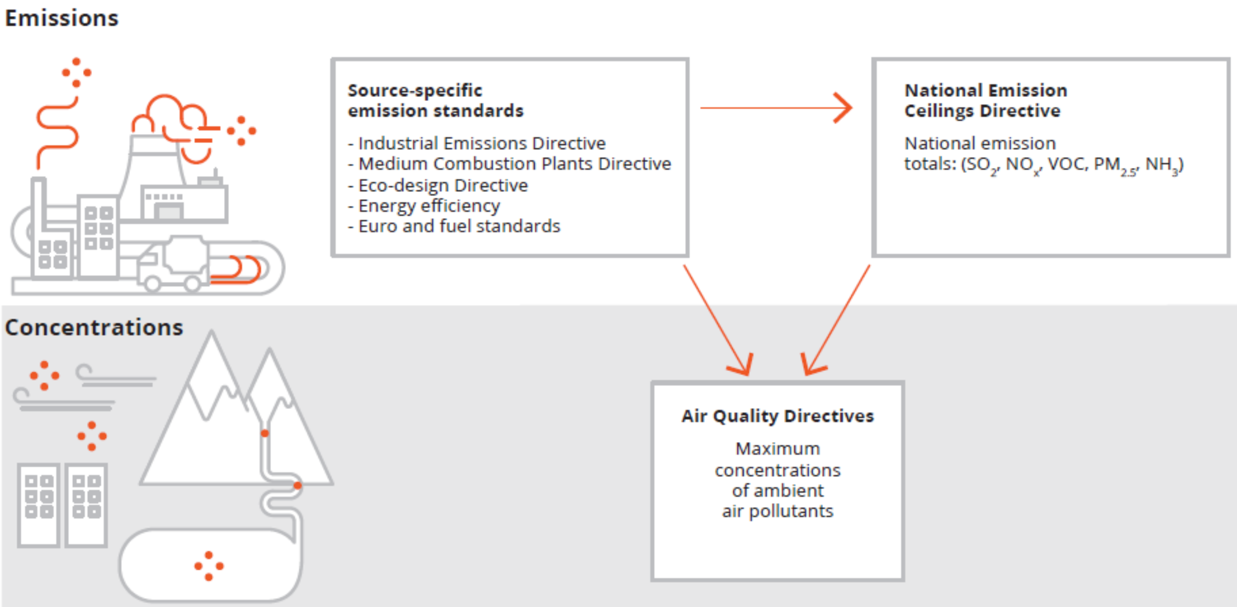

Figure 4 EU clean air policy framework. Source: (EEA, 2018a)

Legislation is then implemented "on the ground" by the national and subnational levels. In this context, most of the measures reported by the Member States under the Ambient Air Quality Directives over the last 3 years are aimed at reducing road transport emissions (encouraging a shift among transport modes; improving public transport; etc…) and commercial and residential combustion (targeting a shift towards low-emission fuels, emission control equipment and retrofitting, etc…). Other sectors (previously mentioned) are mainly targeted through dedicated EU measures (i.e. through "Best Available Techniques" for industries, etc…).

2.2.2 Ongoing initiatives addressing air pollution

The European Commission is actively committed to continuously improve air quality in Europe. Among others, the most recent actions taken by the Commission (in terms of policies) in this field are related to:

- The 2019 "Clean Air Forum": it will be organized the 28-29 November in Bratislava. The main themes for the event are air quality and energy; air quality and agriculture; and clean air funding mechanisms[3].

[2] for more details in http://ec.europa.eu/environment/air/quality/existing_leg.htm
[3] https://ec.europa.eu/info/events/eu-clean-air-forum-2019-nov-28_en

- The 2018 "Communication "A Europe that protects: Clean air for all", outlining measures available to help EU Member States to fight air pollution[4]

- The 2017 "Clean Air Forum": organized in Paris on 16 and 17 November 2017, it provided an occasion for decision makers and stakeholders to share knowledge and assist in the implementation of European, national and local air policies. The Forum focused on three areas: air quality in cities; agriculture and air quality; and clean air business opportunities[5].

- The "Fitness check of the EU Air Quality Directive"[6]: This fitness check is looking at the performance of the two complementary EU Ambient Air Quality (AAQ) Directives (Directives 2008/50/EC and 2004/107/EC). The findings of the fitness check will be used to inform further reflections on whether the AAQ Directives are fit for purpose and continue to provide the appropriate legislative framework to improving air quality.

Furthermore, the Commission is also funding projects to improve air quality 'on the ground'. Important funding strands are (among others):

- "LIFE programme", the EU's funding instrument for the environment and climate action created in 1992[7].

- "INTERREG programme", that helps regional and local governments across Europe to develop and deliver better policy[8].

- "HORIZON 2020 programme", that funds research also in the field or air quality[9].

Apart from policies, legislations and funding, various initiatives are currently ongoing in Europe addressing air quality. The main ones to be mentioned in this context are the "Partnership on Air Quality" (part of the "Urban agenda" of the EU), the "FAIRMODE" (Forum for air quality modelling in Europe) network, and the "AQUILA" (Network of Air Quality Reference Laboratories) network.

The "Urban Agenda" of the EU has recently introduced a new working method, to promote cooperation between Member States, Cities, the European Commission and other stakeholders, in order to stimulate growth, liveability and innovation in the cities of Europe. The "Partnership on Air Quality" (one of the "Thematic Partnerships of the Urban Agenda of the EU") aims at improving air quality in cities, bringing the 'healthy city' higher on the local, national and EU agendas.

After almost three years of intense cooperation (from 2016 to 2018), the "Partnership on Air Quality" has recently delivered a suite of integrated tools to help cities and Member States overcome the challenge of air pollution and reduce its negative impact on health.

These tools [10] are related to:

- A joint Position paper on the EU Ambient Air Quality Directives;
- A Code of good practice for designing and implementing Air Quality Plans;
- A Guidance for financing air quality plans;
- A tool for measuring benefits in terms of impact on citizen's health;
- A Communication toolbox on air quality.

The Partnership main work is now finished, and in 2019 it will focus on dissemination activities, so that the Partnership final results will be distributed to a growing number of cities.

[4] https://ec.europa.eu/environment/air/pdf/clean_air_for_all.pdf
[5] https://www.euconf.eu/clean-air/
[6] https://ec.europa.eu/environment/air/quality/aqd_fitness_check_en.htm
[7] For an overview of the LIFE funded projects, see https://life.easme-web.eu/
[8] Running project (also on air quality) can be found at www.keep.eu
[9] The list of running projects is available at: https://cordis.europa.eu/search/en
[10] Tools are available at https://ec.europa.eu/futurium/en/air-quality/partnership-air-quality-delivers-tools-help-cities-and-member-states-overcome-challenge

The Forum for Air quality Modelling[11] (FAIRMODE) was launched in 2007 as a joint response initiative of the European Environment Agency (EEA) and the European Commission Joint Research Centre (JRC). The forum is currently chaired by the Joint Research Centre. Its aim is to bring together air quality modellers and users in order to promote and support the harmonized use of models by EU Member States, with emphasis on model application under the European Air Quality Directives. The FAIRMODE network intends to support model users at all administrative levels (national, regional urban and local) in their policy-related model applications. The network aims at establishing tools and mechanisms to enhance communication and promote good modelling practice among Member States. The network provides a framework for exchanging experience at all levels of application, including electronic interfaces, databases and tools as well as workshops, seminars and common projects/activities; in particular, focusing on benchmarking tools for emissions, modelled concentrations, planning application results.

The "AQUILA" (Network of Air Quality Reference Laboratories) is a network involved in the implementation of existing EU air policy and advising on new developments. With the latest developments of the European air quality directives, the importance of the national air quality reference laboratories has grown significantly. Their activity had long been acknowledged and their role has now been formally established: they are legally responsible for the quality assurance of air pollutant measurements in their respective Member States, which implies the organisation of national quality assurance and quality control (QA/QC) programmes and the participation in European QA/QC programmes. In addition, they may be actively involved in standardisation activities, the validation of measurement methods and the type approval of instruments. Meetings of AQUILA usually deal with, among others: harmonisation of air quality measurements among EU, EFTA and Candidate Countries, coordination of QA/QC activities, method development and validation.

[11] https://fairmode.jrc.ec.europa.eu/

3 Main sectorial policies and their impact on air quality

3.1 Relevant legislation and policies

As pointed by among others the European Court of Auditors (ECA, 2018) policies and initiatives not targeting air pollution directly, are also likely to have an impact on air quality. A complex economic and social system such as the European Union is strongly interconnected and regulations, plans or even spontaneous trends targeting a specific domain or sector may well generate additional impacts elsewhere in the system. In the case of air quality, special attention should be taken when regulating the sectors, listed in 2.1.2., where most pollutant emissions are known to take place.

3.1.1 Energy and industry

Emissions from the energy and industry sectors are regulated by the Industrial Emissions (IED) Directive (EU) 2010/75. Power plants and large industrial installations with more than 50 MW of thermal energy input (irrespective of the fuel) fall under the definition of "Large Combustion Plants" and are subject of specific emission limits. Other large[12] industrial activities must request a permit under the condition they respect emission limit values based on the Best Available Techniques (BAT). BATs are defined through an exchange of information with experts from Member States, industry and environmental organisations coordinated by the European integrated pollution prevention and control (IPPC) Bureau[13] and then adopted by the Commission as Implementing Decisions.

Besides the IED, other legislation in the energy and industry sectors are relevant for air quality: on May 22nd, 2019 the European Council has adopted the final elements of the "Clean energy for all Europeans" package, a set of legal acts deployed in order to achieve the key targets of the 2030 Energy and Climate framework, including the overall ambitious cut of at least 40% in greenhouse gas emissions (from 1990 levels).

The main legislative acts contained in the package are:

- A recast Renewable Energy Directive fixing the binding target of 32% of renewable energy sources in the EU's energy mix by 2030 and allowing households, communities and business to become clean energy producers (Directive (EU) 2018/2001).

- An Energy Efficiency Directive setting binding targets of at least 32.5% energy efficiency by 2030, relative to a 'business as usual' scenario (Directive (EU) 2018/2002).

- An updated new electricity market design, *inter alia* introducing a new emissions limit for power plants eligible to receive subsidies under capacity mechanisms (550 g CO_2/kWh), enabling more flexibility to accommodate an increasing share of renewable energy in the electricity grid and promoting the active participation of better protected consumers (EU Regulation 2019/943).

- An updated energy performance in buildings directive (Directive (EU) 2018/844), designing a path towards a low and zero-emission building stock in the EU by 2050 (see Section 3.1.2).

The air quality co-benefits of the "clean energy package" are explicitly addressed in the accompanying documents (European Commission, 2018a) which states that, going climate neutral is expected to reduce by more than 40% the half a million premature deaths annually caused by air pollution and save up to €200 million in healthcare costs.

Air quality is also mentioned as a concern in most of the directives cited, while Member States are asked to evaluate consequences on air quality of mid-term planning in the field of energy efficiency, wherever possible.

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[12] The notion of "large" industrial activity depends on the activity itself and it is regulated in the Annex 1 of the IED.

[13] https://eippcb.jrc.ec.europa.eu/about/

The Energy Efficiency Directive establishes that: "The National Energy Efficiency Action Plans shall list significant measures and actions taken towards primary energy saving in all sectors of the economy. […] Where available, information on other impacts/benefits of the measures (greenhouse gas emissions reduction, improved air quality, job creation, etc.) and the budget for the implementation should be provided"

Moreover, the Renewable Energy Directive leaves room to evaluate consequences on air quality as far as biomass use is concerned and the article 30 on "Verification of compliance with the sustainability and greenhouse gas emissions saving criteria" provides that "The Commission may decide that voluntary national or international schemes setting standards for the production of biofuels, bioliquids or biomass fuels […] contain accurate information on measures taken for soil, water and air protection"

The Energy and Climate framework is completed by a revised Emission Trading System (ETS), through which large greenhouse gases emitters, not only in the energy sector, but also including the large industrial Greenhouse Gases (GHG) emitters, are able to trade emission permits across 31 countries, and an effort sharing legislation package establishing national targets for sectors not covered by the ETS system. Air quality concerns are not directly addressed in either of these pieces of legislation.

Taking a planning perspective, the Energy Union Governance Regulation (EU Regulation 2018/1999) requires the Member States to submit a draft National Energy and Climate Plan (NECP) by end 2018, to be followed by a final version end 2019 and by subsequent biannual progress reports. Progress report will have to contain a quantification of the impact of the policies and measures of the NECP on air quality and on emissions of air pollutants and should ensure the consistency between their NECPs and the National Air Pollution Control Programmes from the NEC directive.

3.1.2 Households and residential heating

The "Clean Energy for all Europeans" also updated the energy performance in buildings directive designing a path towards a low and zero-emission building stock in the EU by 2050. As for air quality, Article 2a states that "Each Member State shall establish a long-term renovation strategy to support the renovation of the national stock of residential and non-residential buildings [..] and shall encompass [..] an evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality".

By its nature, the residential sector is one of the main targets of the EU Regional Policy, as it addresses regions and cities in order to enhance, *inter alia*, sustainable development and citizens' quality of life. The practical instruments of EU regional policy are the Cohesion Fund and the European Regional Development Fund (ERDF), half of which is invested in urban areas. Among the 11 thematic objectives set for the ERDF in the period 2014-2020, two ("Supporting the shift towards a low-carbon economy" and "Preserving and protecting the environment and promoting resource efficiency") are clearly relevant for air quality. Air quality is also one of the 14 priorities of the EU urban agenda for cities[14], launched in 2016 that includes the "partnership on air quality" (see paragraph 2.2.2).

Another highly relevant initiative for cities and the buildings therein, involving the urban and local governance level, is the Covenant of Mayors (CoM), launched in 2008 in Europe. The CoM gathers local governments voluntarily committed to achieving and exceeding the EU climate and energy targets and has so far involved more than 7000 participants (signatories) in the EU and beyond. The primary goal of the CoM initiative is climate mitigation: participants must then prepare a Sustainable Energy and Climate Action Plan where they should detail the measures to be deployed, providing also a quantification of actual emission savings. However, in recent years climate adaptation has been inserted in the CoM while energy poverty is under discussion. Although the CoM

[14] https://ec.europa.eu/futurium/en/node/1829

initiative does not target air quality *per se*, scientific evidence (Monforti *et al.*, 2018) shows that measures developed in its context also impact air quality to a level that could be quite substantial, given the growth of the CoM over the last years.

3.1.3 Transport and mobility

The transport sector has an important impact on air quality and results in major exposure to pollutants, especially in urban areas. Because of this link, transport policies have traditionally been very attentive to air pollution and major pieces of legislation have taken air quality into account together with energy saving and decarbonisation. Therefore, the type-approval process of passenger cars in the European Union includes environmental requirements including the monitoring of tailpipe emissions regarding hydrocarbons, carbon monoxide and dioxide, nitrogen oxides and particles (mass and number).

From 1 September 2017, according to EU Regulation 2017/1151[15], all new car models have to pass new and more reliable emissions tests in real driving conditions ('Real Driving Emissions' – RDE) as well as an improved and more realistic laboratory test ('World Harmonised Light Vehicle Test Procedure' – WLTP[16] - see Figure 5). Both tests are necessary for type approval of all light duty vehicles circulating in EU Member States. The regulation proposed stricter emission limits of total hydrocarbons (THC), CO, NO_x, PM and Particle Number (PN) from light-duty and commercial vehicles tested under a more realistic cycle (See Table 1)[17].

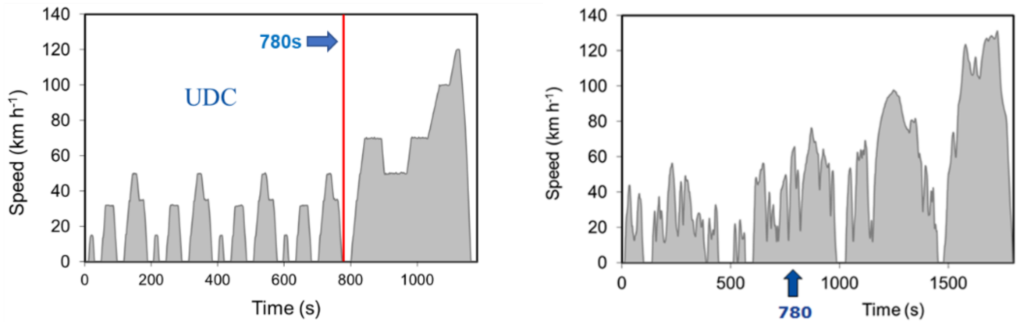

Figure 5 Left panel: old test cycle for type approval in EU (NEDC) – Right panel: new text cycle (WLTC) for type approval in EU according to EU Regulation 2017/1151

The Real Driving Emissions regulation introduced on-road testing with Portable Emissions Measurements Systems (PEMS) to complement the laboratory Type I test[18] (based on WLTC cycle, 23°C) for the type approval of light-duty vehicles in the EU. Under the real driving emission, PEMS are attached to the car that is tested to check that the emission levels of nitrogen oxides and particle numbers are confirmed under real driving conditions. RDE was included in the European Union legislation through several consecutive regulatory packages: RDE1 (EU Regulation 2016/427), RDE2 (EU Regulation 2016/646), RDE3 (EU Regulation 2017/1154) and RDE4 (EU Regulation 2018/1832).

[15] EU Regulation 2017/1151 is supplementing Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information. This regulation is applicable to all new types since September 1st 2017 and to all new vehicles since September the 1st, 2018.

[16] https://ec.europa.eu/growth/sectors/automotive/environment-protection/emissions_en

[17] Hereafter, we will refer to THC, CO, NO_x, PM and PN as regulated pollutants in LD vehicle exhaust according to latest legislation in force.

[18] The new emissions tests will ensure results that are more reliable and help to rebuild confidence in the performance of new cars.

During the phasing-in of the RDE regulation (2017-2019), also a not-to-exceed limit applies and a temporary conformity factor of 2.1 for NO_x tailpipe emissions may apply upon the request of the manufacturer. Vehicles type approved under this requirement fall under Euro 6d-TEMP standard (see Table 1). Based on an amendment done in RDE4, a conformity factor of 1.43 should be applicable for all new types and all new vehicles from January 1st 2020 and January the 1st, 2021, respectively. (see again Table 1)

Table 1 Recent and future evolution of emission limits in the European Union

Evolution of gaseous emission limits for LDV in Europe (mg/km)				
Standards	Euro 6b	Euro 6c	Euro 6d temp	Euro 6d
Date of application	Sep-2015	Sep-2018	Sep-2019	Jan-2021
Driving Cycle	NEDC	WLTP	WLTP	WLTP
Compression ignition emission limits (Diesel)				
CO	500	500	500	500
HC	-	-	-	-
HC + NO_X	170	170	170	170
NO_X	80	80	80	80
PN*	$6x10^{11}$	$6x10^{11}$	$6x10^{11}$	$6x10^{11}$
RDE conformity Factor*	-	2.1	2.1	1.43
Positive ignition emission limits (Gasoline)				
CO	1 000	1000	1000	1000
HC	100	100	100	100
HC + NO_X	-	-	-	-
NO_x	60	60	60	60
PN*	$6x10^{11}$	$6x10^{11}$	$6x10^{11}$	$6x10^{11}$
RDE conformity Factor*	-	2.1	2.1	1.43

*Emission limits for PN are set in #/km

In December 2018, the General Court annulled some of the provisions of RDE Act2 (EU Regulation 2016/646), concerning the so-called "conformity factors"[19], on the grounds that they should not have been adopted via comitology procedure, but via ordinary legislative procedure. The annulment is of a partial nature and does not affect the actual RDE test procedure, which remains in force and must still be conducted at type-approval.[20] The amendment proposal, keeping the factors unchanged (i.e. 1.43) was sent to Parliament in June 2019. The resolution is expected through the regular legislative procedure by February 2020 and the procedure is still ongoing.

Following this legislative process, a consolidated version of WLTP EU Commission Regulation 2017/1151 was published in January 2019 containing amendments made by Regulations 2017/1154, 2017/1347 and 2018/1832.[21]

In summary, the new approach by including RDE tests[22], provides a better indication of the current state of real-driving emissions not only to the Commission, but also to the public, as well as setting new emission factors. The overall objective is to improve knowledge of the sector's progress in reducing real-driving exhaust emission levels of air pollutants from new vehicles reaching the EU market (R. Suarez-Bertoa et al., 2019).

3.1.4 Agriculture and rural development

The EU's Common Agriculture Policy (CAP) is a major chapter of the EU acquis. Launched for the first time in 1962 as an economic policy, the CAP has more recently incorporated environmental concerns and since 2003 farmers receive an income support on condition that they look after the farmland and fulfil food safety, environmental, animal health and welfare standards.

Starting from the observation that inappropriate agricultural practices and land use can also have an adverse impact on natural resources, including water, soil and air pollution, in 2000, the European Commission has started to identify a set of agri-environmental indicators aimed at *inter alia* understanding and monitor the linkages between agricultural practices and their effects on environment.

Currently, a pool of 28 indicators is developed and maintained through a collaborative effort between Eurostat, JRC, EEA and three directorates of the European Commission: AGRI, ENV and SANTE (European Commission, 2006). Such a pool includes one main indicator with a direct meaning for air quality, ammonia emissions, and others that are partially or indirectly related to air pollution such as energy use or renewable energy production.

From the governance point of view, the environmental aspects of the CAP fall in the so-called "rural development" pillar, funded through the European Agricultural Fund for Rural Development. In order to gain access to funds, Member States should prepare their rural development programmes either in the form of a unique national plan or split into a number of regional plans.

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[19] https://curia.europa.eu/jcms/upload/docs/application/pdf/2018-12/cp180198en.pdf

https://eur-lex.europa.eu/legal-content/EN/HIS/?uri=COM:2019:208:FIN

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_12686_2019_INIT&from=EN (1-Oct-2019)

[20] https://europa.eu/rapid/press-release_QANDA-19-2850_en.htm

[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1553789751781&uri=CELEX:02017R1151-20190101

[22] RDE1 (EU Regulation 2016/427), RDE2 (EU Regulation 2016/646), RDE3 (EU Regulation 2017/1154) and RDE4 (EU Regulation 2018/1832), available at https://ec.europa.eu/growth/sectors/automotive/environment-protection/emissions_en

3.2 From policies to pressures – an overview

Coming to the core of the policy questions listed in the introduction, it is crucial to understand if and to what extent, the legislative framework described in Chapter 2 and in the previous section effectively protects air quality in the European continent, or are there cases where the combination of norms could produce unexpected "effects" that can slow down or even jeopardise progress in the fight to reduce air pollution.

It has to be emphasised that this analysis is not a criticism of the current European legislation framework, that is and will remain one of the most effective, advanced and successful tools to actively combat air pollution. On the contrary, the idea is to analyse specific situations or upcoming trends that could in principle fall outside the current normative net deployed so far to protect citizens. Clearly, the final goal is to provide information and factual evidence to inform the work to design and develop appropriate countermeasures.

3.2.1 Energy and industry

The energy and industrial sectors remain a major source of atmospheric pollutant emissions, primarily from stationary sources (see paragraph 2.1). Specific measures imposing stricter emission limits for energy production facilities and large industrial plants first entered in force in the EU in the 1980s and have been at the basis of the important improvements described in Chapter 2.

According to projections such a trend is expected to continue leading to a cleaner and cleaner sector. The additional push towards a more and more decarbonised and efficient energy system driven by climate policies is, in general, positively reinforcing such a trend. In a nutshell, increasing energy efficiency, decreasing power demand and decreasing the share of most polluting energy sources naturally leads to cleaner air. A similar positive trend is also expected for industrial emissions, following the widespread adoption of Best Available Techniques covering a wide range of industrial sectors.

Nevertheless, looking into more detail, other aspects are superimposed to these overall trends that could in principle slow them down or even worsen the problem on a local and/or sectorial scale.

It is worth mentioning that, generally speaking, possible issues are not related to insufficient abatement controls. On the contrary technological solutions for emissions control have been successfully deployed in the last decades in all sectors, including energy and industry and are now ensuring compliance with emission limits that are among the most restrictive in the world. In this context of strong controls, risks arise mostly from structural changes of the energy system in itself. The main issues identified are summarised in the following.

- Biomass combustion

The deployment pattern of renewable energies in the EU (Figure 6) shows how the different forms of bioenergy (solid biomass, biogas and biofuels) have become increasingly important in the last decades. Scenarios prepared for the renewable energy directive update show that such a trend is likely to continue in the near future (European Commission, 2016).

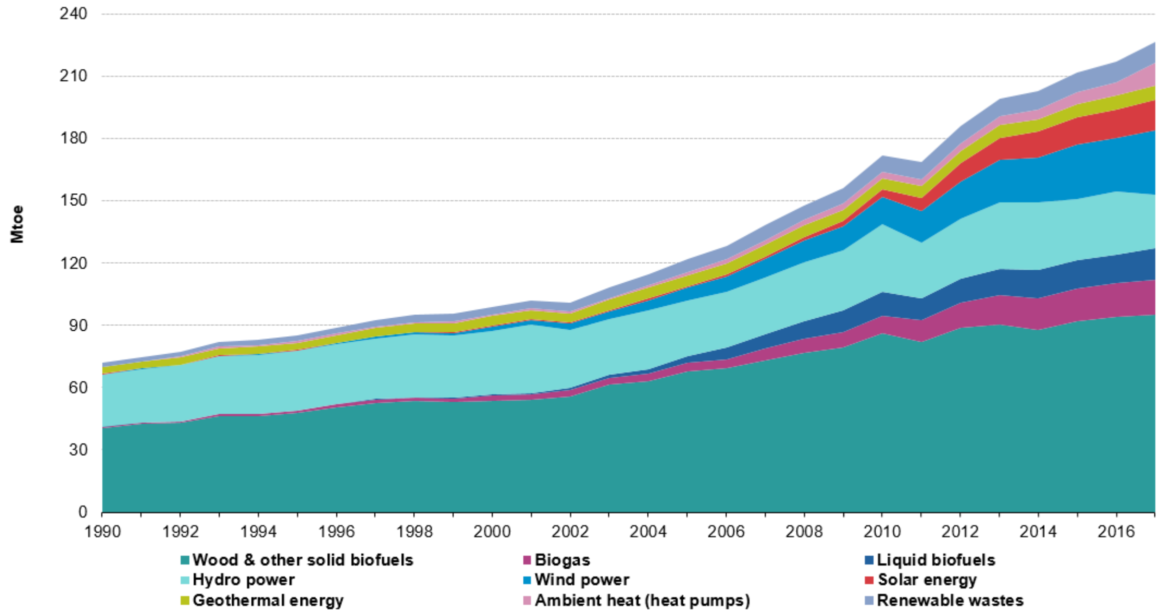


Figure 6 Primary production of energy from renewable sources, EU-28, 1990-2017 (Mtoe) Source: Eurostat

As far as large power and/or heating plants are concerned, emission limits for both fossil fuels plants and biomass have steadily decreased in the last decades thanks to successful deployment of emission abatement systems, increased efficiency and improved fuel quality. Nevertheless, if also considering air pollution, emissions from biomass combustion could be higher than for fossil fuel combustion. For instance, since the entry into force of the limits set in the Industrial Emission Directive, the dust emission limits for new biomass fed plants in the EU (Table 2) are higher by a factor of 4 than the limits for natural gas power plants and comparable (if not higher) than coal and oil plants of the same size.

Table 2 Current limits (mg/Nm^3) for dust emissions for power plants entering in operation after 7/1/2014 in the EU.

Plant size (MWt)	Solid Biomass	Gaseous fuels	Coal/lignite	Liquid fuels
50-100	20	5	20	20
100-300	20	5	20	20
> 300	20	5	10	10

Key message:

- Solid biomass combustion in large plants could emit a similar amount of pollutants to coal and oil and more than natural gas.

- Biogas and power to gas.

Biogas[23] production and use is increasing in the EU. Currently biogas is largely used for electricity or heat production in large plants and to a lesser extent in transport, in pure form or mixed with natural gas of fossil origin. Biomethane injection in the gas network also shows a positive trend following the improvement and the increasing cost-effectiveness of purification technologies (European Biogas Association, 2018).

Biogas generally produces lower GHG emissions than competing fossil fuels in both the transport and power sectors, however its advantage in terms of air pollution are less evident with a special concern arising from ammonia emissions in the digestate phase (Nicholson *et al.*, 2018) (Ghosh & Tomlinson, 2017).

Concerns have also been raised that increased use of the gas transmission and distribution network to accommodate the additional production of biomethane could worsen infrastructural fugitive emissions, a known source of GHG gases that the gas industry is currently actively evaluating and mitigating (MARCOGAZ, 2019).

It is also worth noting that transmitting and distributing biomethane is not the only way in which the gas system will possibly be involved in the decarbonisation of energy system. Indeed, excesses or untimely production of electricity from wind and solar sources can be transformed in to more storable and dispatchable energy in the form of natural gas or hydrogen, sometimes in combination with other production chains such as power-to-ammonia (Götz *et al.*, 2016). Again, these additional production patterns increase pressure on fugitive emissions from gas infrastructures, while the actual patterns of GHG and AQ emissions related to these innovative energy paths are mostly still to be investigated taking into account their whole supply chain and life cycle.

Key messages:

- Concerns have been raised that the need to accommodate increasing quantities of biogas in the existing gas infrastructures could result in losing control of fugitive emissions.
- A similar pressure could arise from the development of "power-to-gas" patterns fed by excess power production of intermittent renewables.
- In general, the full spectrum of "power-to-X"[24] production patterns would benefit from a more complete assessment of supply chain emissions.

- Power system flexibility

As for the power system, its increasing complexity, driven by decarbonisation needs, has created "effects" that could in principle slow down the actual adoption of emission free generation units: for instance the need for flexibility to compensate renewable variability could push traditional power plants out of optimal operational modes (Gonzalez-Salazar, Kirsten, & Prchlik, 2018). Effects on overall emissions of large power production facilities under increasing intermittent renewable penetration have not been systematically assessed, in the scientific literature to date.

[23] "Biogas" is a gaseous fuel produced from biomass feedstocks that can be used for production of electric power and heat. Biogas can be purified to biomethane, that can be used as automotive fuel or injected into natural gas network.

[24] Electricity conversion pathways that utilize electric power, allowing a suitable use of surplus production, are generally referred as "power-to-X" pathways.

In a system that needs to match intermittent supply with demand, power needs to be transported more extensively, increasing the likelihood of congestion and bottlenecks in the system. In principle, redispatching countermeasures intended to mitigate congestion could have an impact on GHG emissions, but at the moment there is little knowledge about the magnitude of such an effect and even less is known about possible consequences on air quality.

Finally, one has to remember that capacity mechanisms still allow gas and coal plants to be subsidised, although these subsidies are planned to be gradually restricted to less GHG emitting plants in the near future. As a consequence, the so-called "merit order" effect tends in some situations to keep less efficient power generation plants on the market. Although the impact of some of these power market features on GHG emissions have been studied, much less is known about their consequences on AQ emissions.

Key messages:

- The additional complexity and flexibility of the power system needed to accommodate increasing shares of intermittent renewables could lead to effects (ramping, congestion,..) that need to be evaluated from the air quality point of view.
- Similarly, the air quality impacts of power market features such as capacity mechanisms and merit order could be addressed.

- Democratising energy

Citizens Energy Communities (defined in Directive (EU) 2019/944 on common rules for the internal market for electricity) are a form of aggregation where citizens are expected to “take ownership” of the energy transition and participate actively in the market (Magnusson & Palm, 2019). Renewable energy communities have been recognised and regulated in the new renewable energy directive as legal entities whose goal is to provide environmental, economic or social community benefits through production of renewable energy. This form of aggregation, sometimes continuing and extending the experience of the rising phenomenon of "prosumers" is expected to induce a partial shifting of energy production from a centralised to a dispersed model, a shift whose consequences have been rarely analysed for the point of view of the air pollution emissions.

Key message:

- Consequences of moving from centralised to distributed generation need to be investigated in more detail as far as air pollution is concerned.

- BAT compliance and CCS deployment in industry and power generation

Although the Industrial Emission Directive generally imposes the use of appropriate Best Available Techniques (BATs) to emission sources, exceptions are possible. Member States are allowed to decide less stringent emission limit values where the application of BATs would result in “disproportionately higher costs” compared to the environmental benefits. The Court of Auditors (ECA, 2018) has focused one of its observation on this possibility of awarding exceptions noting that 15 Member States have adopted “Transitional National Plans” which allow higher emission ceilings until 2020 and some district heating plants have been granted special derogation until 2023. The European Commission has nevertheless reminded that the number of derogations actually granted by Member States is relatively low (Amec Foster Wheeler, 2018) and the Commission has to be informed of each derogation granted.

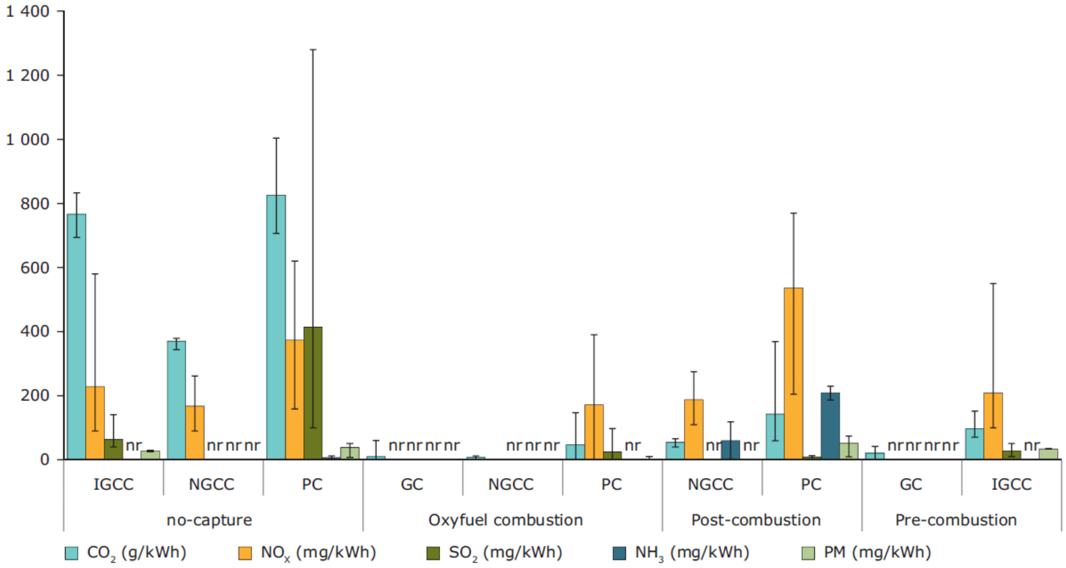


Figure 7 Emission rates of various pollutants for different conversion technologies with and without CO_2 capture. Source: (EEA, 2011) based on data from (Koornneef et al., 2010)

Another aspect needing attention in the case of large combustion plants, is the expected deployment of Carbon Capture and Storage (CCS) technologies as an effective countermeasure to the increase of GHG emissions. The use of CCS requires additional energy consumption, depending on the actual technique employed. Meta-analyses (Koornneef et al., 2010) have also shown that not all CCS technologies impact equally on the emissions of air pollutants from the plants where they are applied, leading to different abatement of pollutant emissions and in some cases even to increase in emissions (See Figure 7). The Carbon Capture and Storage BATs are examined in detail in (Lecomte et al., 2017) where effects on air pollutants are also discussed.

Key messages:

- Exceptions to BAT application have to continue to be monitored in order to remain a relatively small amount.
- The implication of Carbon Capture and Storage techniques for air pollution should be investigated further, in view of their projected deployment as an effective countermeasure to increasing GHG emissions.

3.2.2 Households and residential heating

- Biomass pathways for heating and cooling decarbonisation.

Apart from large plants, bioenergy, mostly in the form of solid biomass, is widely used in residential heating. Patterns for decarbonisation of the heating systems follow two main paradigms: electrification and increased renewable energy. Up to now, the latter has been by far the most successful with biomass and heat pumps playing the major role so far. The quota of renewable energy in heating and cooling reached 19.5% in 2017, compared with 10.4% in 2004. Figure 8 shows that biomass is mostly used for space heating in single houses, and to a lesser extent in multifamily houses, where its share amounts to more than twice electric heating and heat pumps. Unfortunately, the small scale of boilers involved in heating single houses makes reaching higher standards of efficiency and finally emission control more difficult. This decarbonisation pattern could thus lead to higher pressures for air pollution, although depending on the eventual penetration of emission-free technologies alternative to biomass burning such as heat pumps and solar thermal heating.

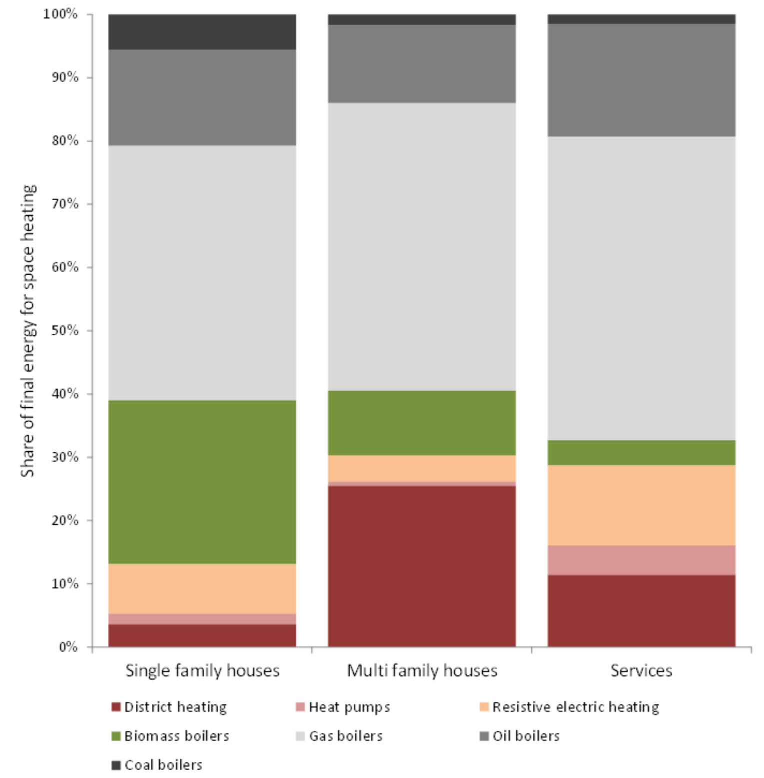


Figure 8 Shares of heating sources in different types of buildings in 2015. Source: JRC

Environmental risks may be associated to small and medium scale bioenergy plants (such as domestic heating systems, mostly due to the emission of pollutants from the biomass boiler, such as NO_x and SO_2, which are generally higher than natural gas alternatives. Furthermore, small-scale installations do not have (or have limited) flue-gas cleaning technologies. In this regard, technological advancements may help decrease NO_x and particulate matter emissions also from small-scale bioenergy installations. (Giuntoli et al., 2013)

In order to manage the increase in local air pollution due to bioenergy stoves some actions can be envisaged, such as limiting the amount of wood stoves in specific critical urban areas, promoting where possible larger, centralized installations where proper emission control measures can be installed, up to more targeted information campaigns on the correct use of wood stoves or promotion of pellet stoves). (Giuntoli et al., 2015)

On the other side, a decarbonisation pattern heavily relying on electrification will avoid the use of biomass but will displace the emissions production from individual heat producers/consumers to a more limited number of power producers, in similar way to what it is expected to happen in case of increasing electric cars penetration. In such a case, additional care should to be taken in order to avoid that extra electricity demand ends up in revamping the use of the most polluting power sources.

Key message:

- Biomass could be a key element in decarbonising residential heating systems, possibly resulting in higher pressures for the atmospheric environment.

- Energy poverty

Energy poverty arises from the combination of low income and poorly energy efficient housing and is part of the wider issues of social vulnerability. Social vulnerability is a known cause of exposure to health hazards driven by specific environmental risks. Vulnerable groups such as children, elder and inhabitants of low income areas are usually more severely exposed to threats originating from e.g., noise, air pollution and heat waves.

The relatively large share of the population suffering from energy poverty (See Figure 9), particularly in Southern and Eastern Europe has to be considered carefully when planning the decarbonisation of the heating and cooling sector.

Experience shows that otherwise there is the risk of worsening the socio-economic exclusion effects leading to energy poverty. In Eastern countries in particular, it has been shown that the removal of historical subsidies for fossil fuels without providing alternative support, triggered by market liberalisation and climate policies, has resulted in deep-rooted energy poverty, affecting to a larger extent the weakest population segments.

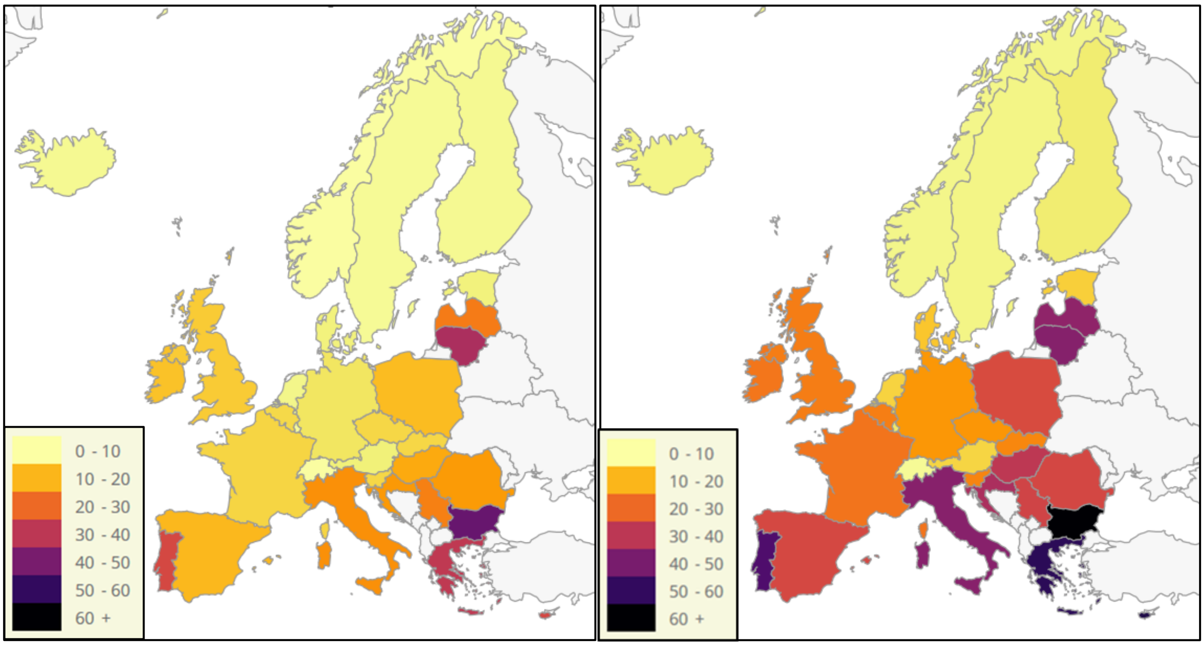


Figure 9 Share of population negatively answering the question "Can your household afford to keep its home adequately warm?" as a fraction of the entire population (left) and of the population belonging to the lowest income decile (right). Year: 2015 (Source: Energy Poverty Observatory).

Recent examples reported in (EEA, 2018c) also indicate that policies banning most polluting fuels need to be implemented taking into consideration the equity aspects to assure the affordability of the less polluting fuels. If not tackled, the presence of relevant population shares suffering from energy poverty additionally delays the uptake of sustainable heating solutions and leads to the continued use of very "dirty" combustion materials often coupled with old and inefficient stoves or fireplaces.

Key message:

- Energy poverty is present in Europe and could be a major cause of uncontrolled emissions.

- Assessing territorial policies from air quality perspective

Cohesion and urban policies make available an important amount of resources for pursuing objectives consistent with sustainable and inclusive urban development. Funded action could also shift/change the AQ issues in cities and outside even if not directly addressed, for instance triggering changes in population density and/or distribution, and the related changes in commuting habits.

As a general rule, several policies acting at the urban level could have consequences on air quality patterns too, even unintended. As an example, the JRC is performing an in-depth analysis on the impacts of Covenant of Mayors initiative (see paragraph 3.1.2) from the air quality point of view. Using a combination of data mining and modelling, the co-benefits for air quality of a wide range of energy saving measures originally designed for climate mitigation have been estimated (Monforti et al., 2018). Following such an example, a more systemic assessment of a large spectrum of territorial, cohesion and urban policies could be designed.

Key messages:

- Urban policies trigger structural changes in cities that could finally impact air quality.
- As an example, synergies and trade-offs between air quality and urban scale climate mitigation actions should be carefully analysed.

3.2.3 Transport and mobility

Passenger cars have historically dominated emissions in the transport sector, particularly in urban areas. In this regard, there is a big expectation for new passenger vehicles technologies: Battery electric vehicles and Hybrid Electric vehicles (HEV). For instance, Bloomberg New Energy Finance forecasts Electric Vehicles to hit 54% of new car sales by 2040 with decreasing importance of Plug-In Electric Vehicles (PHEVs)[25].

The same source foresees that electric vehicles will account for 33% of all the light-duty (LD) vehicles on the road in 2040. This transition is expected to lead to the coexistence

[25] https://www.greencarcongress.com/2017/07/20170706-bnef.html

of all LD vehicles, Internal Combustion Engines (ICE) and the new alternative powertrains for at least another 15-20 years.

Vehicle exhaust emissions are thus still a matter of concern as they are among the main contributors to urban air pollution and to climate change. Vehicles emit air pollutants such as NO_x, volatile organic compounds (VOCs), NH_3, and fine particles (R. Suarez-Bertoa et al., 2019) and also greenhouse gases —mainly CO_2, N_2O, and CH_4 (R. Suarez-Bertoa et al., 2019) (Wallington & Wiesen, 2014).

On 17 April 2019, the European Parliament and the Council adopted the EU Regulation 2019/631[26] setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU for the period after 2020. This new pieces of legislation (the EU's CO_2 limits for cars) could be seen as an incentive for car manufacturers to produce diesel cars – which is entirely logical from a climate change mitigation perspective, but creates tensions with air quality policy. Nevertheless the actual trend seen is to orientate the production of big cars (once Diesel) into hybrids (ICE gasoline and electric engines) to decrease the CO_2 and fuel consumption.

- Euro 6 vehicles: new catalysts systems and after-treatment technologies

In order to decrease regulated[27] emissions from vehicles exhaust, the automotive industry has introduced a series of different after-treatment systems in recent years[28]. The use of these after-treatments has resulted in substantial emissions of air pollutants by the transport sector, principally ammonia, nitrogen dioxide and/or GHGs (i.e. Nitrous oxide, N_2O) that are not yet regulated.

Ammonia has become a major reactive nitrogen species in petrol vehicle exhaust and is nowadays present in diesel exhaust. Important implications of NH_3 emissions have been already evaluated under US driving conditions with the conclusion that on-road emissions of ammonia should be recognised as a major contribution to particulate matter formation in urban regions (Fenn et al., 2018) (Ricardo Suarez-Bertoa, Mendoza-Villafuerte, et al., 2017).

Some recent publications (Ricardo Suarez-Bertoa et al., 2016) (Mendoza-Villafuerte et al., 2017) also show that Euro V heavy duty vehicles and Euro VI equipped with catalytic devices emit N_2O during on-road real driving operation. In house studies have akso shown that N_2O emissions, could account for approximately 2% of CO_2 equivalent emissions from Euro 6 diesel vehicles.

Key messages:

- There is concern that traffic-related ammonia emissions could reduce or even nullify benefits arising from policies targeting other urban ammonia emissions (mainly from the waste cycle).
- N_2O emissions, could account for approximately 2% of CO_2 equivalent emissions from Euro 6 diesel vehicles.

[26] https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en

[27] According to latest legislation in force, we refer to THC, CO, NO_x, PM and PN as regulated pollutants in LD vehicle exhaust

[28] Three-way catalyst (TWC), diesel-oxidation catalyst (DOC), diesel particulate filters (DPF), selective catalytic reduction (SCR), ammonia oxidation catalyst (AMOX), etc.

- Plug-in hybrid vehicles

Plug-in hybrid electrical vehicles (PHEVs)[29] are vehicles equipped with an internal combustion engine, an electric motor and a rechargeable electric energy storage system that can be directly charged from the electric grid. PHEVs represent a technical compromise between pure-electric vehicles (PEV) and the conventional vehicles. They offer drivers the same range as conventional vehicles while providing the environmental benefits of pure-electric vehicles (PEVs), such as the absence of exhaust pollutant emissions during electric operation and reduction of GHG emissions.

PHEVs are perceived as a clean alternative to conventional petrol and diesel vehicles (vehicles with just internal combustion engines) and consequently, these vehicles are usually presented as sustainable mobility alternatives that reduce vehicle emissions.

For this reason, these vehicles might soon be allowed to circulate in low-emission zones (LEZ) that have been defined aiming to improve urban air quality. However, pollutant emissions from Euro 6 PHEVs are quite similar to those measured from conventional Euro 6 petrol and diesel vehicles if those vehicles are not regularly charged. Potential emissions of all hybrid vehicles (PHEVs & PEVs) may also be larger during harsh winter temperatures (Ricardo Suarez-Bertoa et al., 2019) (Ricardo Suarez-Bertoa & Astorga, 2018)

Figure 10 RDE winter campaign on HEV, 2018. Sestriere (Italy) [Photo: VELA ®RSB]

- *Hybrid electrical vehicles and real driving emissions:*

Although Real Driving Emissions (RDE) legislation accounts for a large share of real-world driving circumstances, it excludes certain driving situations by setting boundary conditions (e.g., in relation to altitude, temperature or dynamic driving). The vehicles are now investigated in different on-road scenarios and exploring the emissions taking place when vehicles were tested outside the RDE boundary conditions and compared to tests performed using RDE routes.

- Hot and cold temperature effects are very relevant for electrified vehicles, Plug in HEV and PEV.

- High altitudes may affect emissions of vehicles with internal combustion engines, including HEV which also incorporate this engine.

[29] PHEV are also known in the European Union as "off-vehicle charge hybrid electric vehicles" - OVC-HEVs

Key message:

- Modern car technologies, including hybrids, and after-treatment systems designed for the new vehicles (Euro Euro6d, 6dTemp, and post Euro 6) can still be a source of air pollutants and GHGs and some of them are not yet regulated in EU (i.e. NH_3 and N_2O).

- *Electric vehicles expansion*

Transport and energy systems are increasingly intertwined but the question of how will additional electricity demand be met to fulfil the demand of increasing number of pure EV and Plug-in EV still remains open.

Electromobility has huge implications, both direct and indirect, for air quality. A direct impact is related to electric cars manufacturing. In principle one should look at electric vehicles production, use and dismissal using a 'life cycle analysis approach' (EEA, 2018b). Indeed, electromobility will have environmental impacts on the 'production phase' (Production of electric vehicles needs approximately 70% more primary energy than conventional vehicles) , 'in-use' (energy to run a car can be produced in different ways) and 'end-of-life' (as batteries should be recycled at the end of the life of the vehicle) (González & Prada, 2015). The production phase of, for example, Lithium ions batteries seems to generate several times more emissions of conventional pollutants (NO_x, SO_x and PM) than traditional lead acid batteries (Sullivan & Gaines, 2010).

The degree to which electromobility can support interoperability and energy storage while vehicles are parked, will also influence electricity demand. Several studies show that a significant deployment of EVs can indeed speed up the deployment of low carbon and low emission generation. As an example, a recent scenario developed by EEA assuming 80% of cars in 2050 were electric (EEA, 2016) showed that the increase in electric cars would lead to a reduction of CO_2 and air pollutant emissions (NO_X, SO_2 and PM) in the transport sector. Nevertheless, the study assumed that the extra electricity demand will be supplied by the energy mix projected for 2050 by the EU Reference Scenario 2013 that assumed, in turn, a share of energy consumption in transport sector by EV equal to 4%, a significantly lower amount than the one assumed by the EEA study itself.

Moreover, one should note that, even when running on power from renewable sources, electric vehicles would not be zero-emission vehicles, as they still generate non-exhaust emissions of particulate matter, for example, due to wear of tyres, brakes and roads, just like conventional vehicles. These emissions will remain and could even increase if the move to electromobility would trigger a rebound effect increasing road travel demand.

Finally, even if these vehicles are seen as a good alternative for individual mobility to reduce emissions in urban areas, the question still remains of where and how the energy needed will be produced. The EEA has been monitoring the progress in transport since 2000 through the Transport and Environment Reporting Mechanism (TERM) and in 2018. The TERM Report indicates the need to look at electric vehicles from a systemic perspective and to monitor the impact across life cycle stages. It is necessary to observe the production and integration of electric vehicles from life cycle and circular economy perspectives as well as to make EVs last and to promote intensive and possibly shared use of those vehicles. It will be also very important to conceive the design of these vehicles with reuse and recycling in mind.

The TERM report 2018 (EEA, 2018b) also alerts of the potential shift in pollution from local sources to background, from use to production. In order to better understand air quality impacts better data are needed on: electric vehicle use (incl. driving and charging behaviour), non-exhaust emissions in real driving conditions as well as end-of-life treatment of batteries.

Key messages:

- The expansion of electric vehicles could partially induce a shift in pollution from local sources to background and from use to production.
- Electric vehicles are not completely emission free, because of brakes, tyres and road abrasion.
- Look at electric vehicles from a systemic perspective including impact across life cycle stages, investigating the role of circular economy in reducing impacts, emphasising the importance of making EVs last & promote intensive & shared use and designing new vehicles with reuse and recycling in mind.

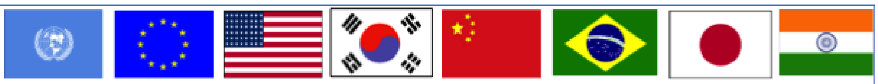
- Post Euro 6-VI vehicles and new emission standard legislation

The type-approval process of passenger cars in the European Union includes the fulfilment of environmental requirements including monitoring tailpipe emissions of hydrocarbons, carbon monoxide and dioxide, nitrogen oxides and particles (mass and number). The discussion on the topics to be addressed in a future step of emission legislation and standards post Euro 6-VI, both for Light and Heavy Duty vehicles has started in 2018. Progress in the scientific assessment for the next emissions standard (Euro 7) is expected during 2019 and 2020.

The JRC Centre has participated in the development of vehicle emissions legislation from the early stages of consultations, providing scientific evidences for emission standard limits for light duty and heavy duty vehicles, as well as motorcycles. Therefore, the output of the research performed in the last seven years contains data on various powertrain options (diesel, petrol, natural gas and plug-in hybrid). Laboratory measurements and on-road emissions of NO_x, NO_2, CO, PN and CO_2 from more than 100 recent cars are already available.

JRC will therefore have the capacity to assess the process and to provide a scientific based opinion about the future emissions legislation and implications for environment, of the best options for future vehicle's technologies in EU.

Considering the recent findings, the fact that new diesel cars (fulfilling Euro6dtemp emission standards) are not necessarily worse polluters than gasoline cars is a known issue (Platt et al., 2017). For instance, modern gasoline direct injection engines may have larger particulate emissions than modern diesel vehicles (equipped with Diesel Particulate Filter) and conventional (Port Fuel Injection) gasoline vehicles (R. Suarez-Bertoa et al., 2019).



NH_3	×	✓ HD	×	✓	×	×	×	×
N_2O	×	×	✓	×	✓	×	×	×
HCHO	×	×	✓	×	×	✓	×	×
NMOG*	×	×	✓	✓	×	×	×	×
HNCO	×	×	×	×	×	×	×	×

*Includes measurement of methanol, ethanol, formaldehyde and acetaldehyde

Figure 11 Overview of vehicle exhaust non-regulated pollutants in different regions (HCHO: Formaldehyde; NMOG: Non-Methane Organic Gases; HNCO: Isocyanic Acid)

Key messages:

- New EU emission standards should be technology neutral, fuel neutral and temperature neutral.
- Relevant non regulated pollutants should be considered in the assessment for post-Euro 6-VI.
- Need to analyse the reasons why other regions have already regulated some air pollutants and GHG which are not yet regulated in EU.

- *Biofuels in transport*

Biofuels, as long as they are sustainably produced, can play an important role in achieving decarbonisation targets in the transport sector (IEA, 2011). The potential of biofuels to substitute conventional fossil-based fuels has been analysed for example in maritime transport (OECD & ITF, 2018), aviation[30] and freight transport (IEA, 2017). However, the use of biofuels in combustion engines has no clear positive effects on air quality. Generally, emissions of PM, HC and CO are lower and NO_x higher (EEA & EMEP, 2016). This may become an issue in cities where local authorities encourage the use of biofuels for transport as a measure to combat climate change. The 7% maximum cap for first generation biofuels, although further confirmed in the agreed "Clean Energy for all Europeans" package, is not expected to change this picture as there is no evidence that second and third generation biofuels will emit fewer air pollutants.

The potential implications for emissions of air pollutants of innovative new fuel production technologies, including synthetic biofuels and those produced by genetically modified feedstock (plants/algae), as well as other new technologies, also needs to be considered.

It should be clear that, together with the search for new alternative energy sources, new challenges may arise when referring to the exhaust composition. All these new approaches will have different impacts on the exhaust and may reduce emissions of some pollutants while increasing, or having no effect on others.

[30] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/biofuels-aviation

Therefore, before blends of alternative fuels are made available in the market it is necessary to know if the emissions from such fuels, particularly toxic pollutants, will be lower, or at least the same as the fuel before its implementation (Ricardo Suarez-Bertoa, Clairotte, et al., 2017).

Vehicles using high ethanol content in fuel (up to 75%) have been studied by the JRC. In -use Flexi fuel vehicles using blends containing up to 85% of ethanol in gasoline (or 75% in winter fuel) have been tested. Legislation regarding control of pollutants in exhaust derived of the use of these blends with high content of ethanol is not available in EU. JRC has been working developed methodologies for analysis of non regulated pollutants in exhaust from these blends which can be now found in Global Technical regulation[31].

Key message:

- Before blends of alternative fuels become available in the market it is necessary to know if the emissions from such fuel will be lower, or at least the same as the fuel before its implementation. Environmental Impact Assessments should be applied.

- New trends of mobility & autonomous cars

Currently a limited number of studies focuses on the foreseeable impact of autonomous vehicles on air quality, and concerned have been expressed that the general concept of the clean autonomous vehicle could increase private car volumes at the expense of public transport and therefore contribute also to traffic congestion. Under this perspective, the possible introduction of high shares of autonomous vehicles, may impact negatively on the daily usage of transport means and consequently on AQ emissions.

More in general, with the combined effects of growing populations, rising incomes and demand of comfort in expanding cities, the demand for energy and transport will continue to grow. In the report "The Future of Road Transport" (Raposo et al., 2019) , aspects like the rebound effect (increase of private vehicle travel) are mentioned, but there is not any specific mention of air pollution/quality. Sustainable Integrated Assessments[32] (SIA) are necessary. SIA must include an overall economic, social, human rights and environmental analysis.

Finally, it is worth reminding the question of the second life of vehicles produced in Europe, which then end their active life in other, neighbouring regions, increasing the AQ problems in other areas (i.e. Eastern EU Member States or in neighbourhood countries of EU and Africa). One major issue is the reselling of obsolete European cars with no after-treatment systems to regions where the quality of fuels is very poor (high sulphur content).

Key messages:

- With the combined effects of growing populations, rising incomes and demand of comfort in expanding cities, the demand for energy and transport will continue to grow. New mobility opportunities such as autonomous vehicles must be considered in such a context.

[31] https://wiki.unece.org/display/trans/Latest+GTR+15

[32] Sustainable Impact Assessment (SIA) is a trade-specific tool developed for supporting mayor trade negotiations conducted under the aegis of the EU Commissioner for Trade. SIAs are a mayor tool for the conduct of sound, evidence-based and transparent trade negotiations. SIA must include an overall economic, social, human rights and environmental analysis.

- Acting from the perspective of individual sectors or locally does not help much to face future air quality, transport and societal challenges.
- Sustainable Integrated Assessments are necessary and must include an overall economic, social, human rights and environmental analysis.

3.2.4 Agriculture and rural development

As far as agriculture is concerned, ammonia is still an issue with 92% of ammonia emissions originating from agriculture. Until now, policies have failed to obtain the same level of reduction of ammonia as achieved for other pollutants. On the contrary, ammonia emissions in EU have shown since 2013 a slight but constant increase about 1% per year. (See Figure 12 and Figure 13)

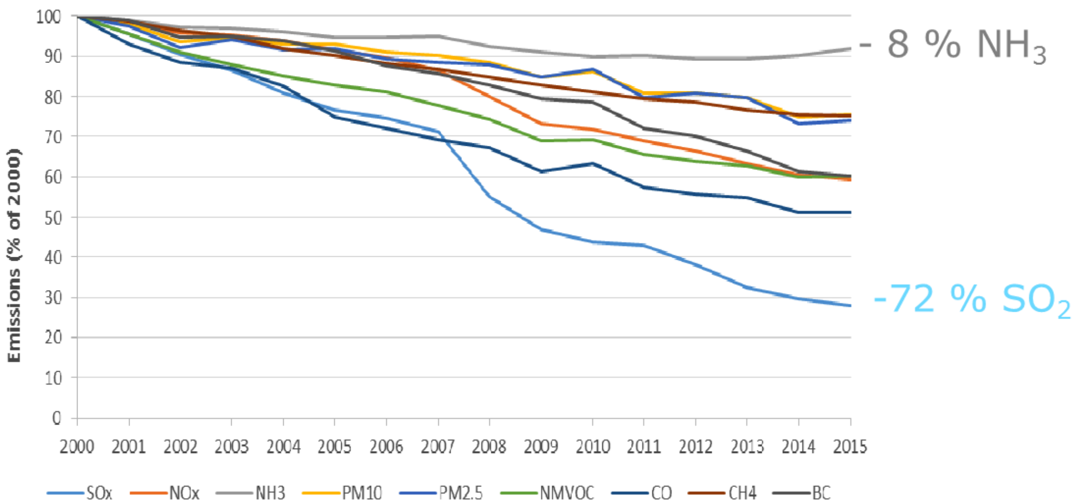


Figure 12 Normalised (year 2000 = 100) emissions trends as reported in the frame of the National Emission Ceilings Directive. Source: (European Commission, 2018b)

Ammonia emissions mostly originate from manure management, while a smaller share (about 20%) is related to inorganic fertiliser application. Part of the reason for the limited decrease in emissions, could be related to the fact that the economic structure of the European agriculture sector is also evolving, moving in the direction of fewer, larger farms, practicing more intensive agriculture. Currently, about 80% of the ammonia emissions in Europe come from farms with more than livestock 50 units, representing only 4% of all farms (Amann, Gomez-Sanabria, Klimont, Maas, & Winiwarter, 2017).

Agricultural practices and policies also affect (bio)methane emissions. In Europe, agriculture and waste management account for 76% of anthropogenic methane emissions (Van Dingenen et al., 2018). Methane is a precursor for global tropospheric background ozone. With other ozone precursors being mitigated, the relative contribution of methane to surface ozone is expected to increase over the coming decades (Turnock et al., 2018).

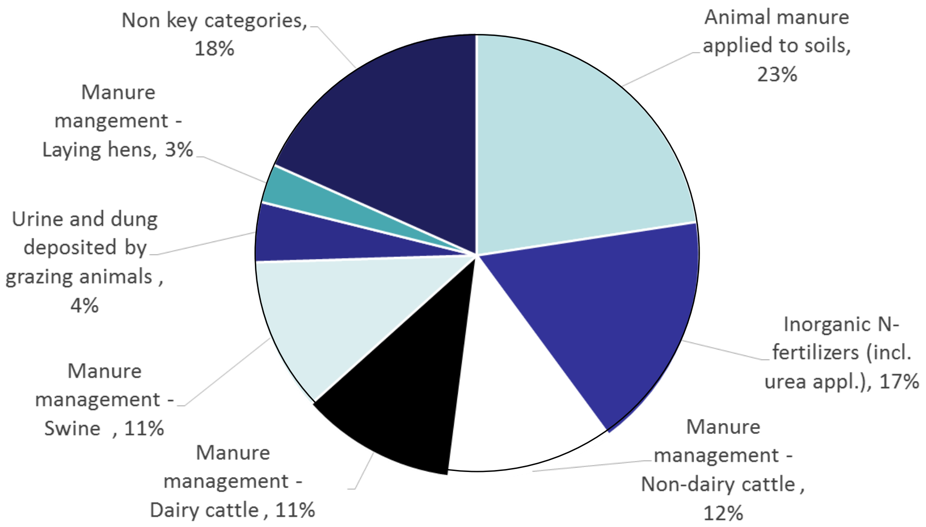


Figure 13 Origins of ammonia emissions from agriculture in the EU in 2016. Source: EEA inventory.

It is important to note that Member States enjoy a large degree of freedom in implementing the Common Agriculture Policy (see paragraph 3.1.3) in their territory, including the environmental constraints to be addressed. There is no strong evidence that member states with more air quality issues are actually paying specific attention to ammonia emissions minimisation when allocating resources related to the common agriculture policy. Given that ammonia is also an important constituent of $PM_{2.5}$, it is clear that countries with $PM_{2.5}$ problems and NH_3 abatement potential could exploit CAP funding to encourage reduced ammonia emissions. For this reason, awareness of both the issues related to ammonia and the opportunities available for its abatement should be properly raised.

Key messages:

- Ammonia emissions from agriculture have decreased slower than any other pollutants until 2012 and slightly increased since then.
- Agriculture plays a major role in methane emissions.
- It is not clear to what extent opportunities for Member States to use resources related to common agriculture policy are actually exploited to tackle ammonia emissions.

4 Directions for further insight

Addressing the challenges identified in the previous chapter requires further investigation of most of them. A robust quantification of the actual impacts of most of these challenges, both in terms of emissions and citizens' health is generally missing in the literature and when present a continental wide view is not usually provided. Although actual investigation of each challenge clearly goes beyond the scope of this report, in this chapter some first steps for future investigation are suggested.

4.1 Prioritising challenges

The challenges presented in the previous chapter differ from each other both in their potential scale and their foreseeable impact on citizens' health and on ecosystems, although these impacts are difficult to quantify. The most meaningful indicator to evaluate the different challenges against each other is probably *population exposure*, directly leading to health impacts and having the advantage of linking the overall amount of additional emissions (or impeded emission decreases) to actual demography. Such an indicator is for instance crucial to properly evaluate the impact of the emissions displacements foreseen in case of electric cars penetration.

The temporal scale of the challenges discussed is also quite diverse, with some challenges (e.g., energy poverty, urban ammonia emissions etc.) already creating effects today, while others (e.g., electric cars, autonomous vehicles etc.) are foreseen to create their potential impacts in the future.

With such a conceptual scheme in mind, the topics discussed in the previous chapter have been ordered along the two axes of relevance: population exposure, and urgency, measuring the time horizon.

Table 3 shows a first ideal grouping based on the very simple use of two classes for each axis, respectively "immediate" vs. "future" to express urgency, while "critical" vs. "relevant" identify the population exposure effect of the challenge.

Table 3 Conceptual framework for challenge prioritization.

	Future	**Immediate**
Critical	Electric mobility Decarbonisation of heating and cooling Power systems flexibility	Biomass and biofuels Energy poverty Ammonia emissions Transport inequalities Batteries & electric network
Relevant	Power-to-X Democratizing energy & transport	Rural development Territorial policies Power system flexibility Ammonia from catalysts

Clearly such a first classification is not yet complete and for instance does not consider the fact that an issue could be extremely relevant locally, but less important once investigated on the continental scale, energy poverty, mostly localised in Southern and Eastern Europe, being an example.

4.2 Research gaps

The tentative prioritisation scheme shown in Table 3 is based on the current knowledge collected through expert elicitation and literature analysis. This process has also indicated a number of research gaps that deserve to be discussed and that, once at least partially filled, could lead to a more robust priority setting.

From the point of view of *modelling*, more tailored analyses are needed. Modelling tools, both in the sectors of energy and transport, are generally well developed and allow a clear representation of several undergoing phenomena. Nevertheless, the number of studies that address the challenges identified are relatively small and often lack the generality needed to provide a robust factual base for policy decisions. For instance, the consequences of significant electric car penetration on the European grid are difficult to assess, as it involves putting together results that currently do not address the different aspects of the issue consistently (e.g., energy mix evolution, geographical displacement of emissions and along the value chain, impact on driving habits and transport demand).

Clearly, the reason for such a lack of integration to date should be looked at, from the point of view of the difficulty in building an integrated approach, not to mention the relevant amount of necessary data (or assumptions). Nevertheless, a first step towards a more integrated vision could consist of adding an air quality dimension to already existing scenarios, as it could be the case for scenarios addressing AQ consequences of ongoing changes in the heating and cooling sector, with a special focus on energy poverty.

A more tailored *monitoring* of the awareness of air quality aspects in resource allocation for territorial and rural development policies would be also extremely useful. As for urban dimension, following a path similar to the analysis of air quality consequences of the Covenant of Mayors initiative (Monforti-Ferrario et al., 2018), it would be very useful to set up a framework similarly addressing the consequences of actions targeting urban aspects other than air pollution (mobility, digitalisation, soil sealing, etc.). In the case of rural development, a more air quality focused examination of rural development plans and their actual deployment, could support the development of tailored suggestions, especially for those Member States where ammonia emissions are decreasing more slowly than expected.

In order to strengthen the links between transport sources in urban areas and ambient air quality, a targeted air quality modelling exercise focused on the pollutants related to urban smog (NO_2, NH_3, VOCs, CO, $PM_{2.5}$) could be useful. The work should cover different Member States and weather patterns, realistic fleet compositions and projections (different levels of penetration of Zero-EVs, PHEVs and gasoline/ diesel shares). The scenarios could run to the year 2030. It would also be worth intensifying the work on Real Driving Emissions in urban conditions (short trips, cold start engine, etc.) to produce better, more representative emission factors for urban and regional models on AQ.

Furthermore, the contribution of VOCs and non-regulated pollutants from vehicle emissions to the formation of Secondary Organic Aerosol (SOA) and urban pollution has seldom been studied in the EU, while receiving a lot of attention in other regions (US and recently also in China)**.** Fostering and connecting research groups who can provide questions and answers about the relation between sources (i.e. traffic, cooking, wood burning, etc.) and formation and evolution of SOA in the atmosphere is of vital importance (*knowledge management*). The final goal should be to find ways in which scientific evidences of the role of emissions in atmospheric processes could be an input to develop policies and mitigate SOA formation in urban areas of EU.

4.3 Tools for a wider vision

From Table 3, it is quite evident that most of the challenges identified for further investigation need to be addressed using a somewhat wider angle than traditionally taken for instance putting together and comparing technological and economical aspects or different steps in the life cycle of a product.

For this reason experts were elicited and literature sought to identify tools and methodologies that could provide support in filling the research gaps and addressing the challenges listed. In particular, such a mapping has focused on the scientific portfolio of the JRC and how it could be mobilised in this context.

- Life cycle thinking and analysis

A common feature of several of the potential challenges identified is the shift of pollution burden along the production chain, sometimes translating into a shift across spatial scales (e.g., from urban to regional in the case of electric vehicles, or from regional to local in the case of prosumers). In these cases, a life-cycle analysis approach is necessary to properly evaluate how environmental burdens, including atmospheric pollutant emissions, move up and down the supply chain, as well identifying those steps in the life cycle that are dominating the impact. Moreover, applying life-cycle thinking to new solutions/interventions/innovations may help identifying trade-offs, including those AQ. JRC has a very reputed and knowledgeable life-cycle analysis group already advanced in addressing similar issues (Sala et al., 2018).

- Technology monitoring and assessment

The Low Carbon Energy Observatory (LCEO)[33] collects world-class data, analysis and intelligence on developments in low carbon energy technologies and produces technology development and market reports, online database of future emerging technologies. The LCEO constitutes a reliable and recognised sources for any technology-based vision of future energy systems, although AQ aspects of the analysed technologies are not (yet) addressed. Similarly, the JRC Integrated Pollution Prevention and Control Bureau[34] maintains and updates the reference documents for Best Available Techniques (BAT) to be used as a legal basis for permits issuing for about 50.000 plants spanning all industrial sectors.

- Modelling

Modelling tools from the JRC portfolio have been and are being used to evaluate the interplay between climate and air quality at the global level in the frame of the Global Energy and Climate Outlook (GECO) activities[35] and are at the basis of perspective analyses discussed in the heating and cooling sector. Techno-economic assessments have also been applied for supporting LCEO activities while sectorial dispatching models are available both the electricity[36] and gas[37] sectors.

- Community of practices and stakeholder involvement at urban scale

JRC has an important role in relevant initiatives involving the local governance level, in particular through the Covenant of Mayors[38] and the Knowledge Centre for Territorial Policies[39], where *inter alia* JRC coordinates the Community of Practices on Cities and is developing a specific Urban Data Platform. These initiatives provide a unique opportunity for direct contact with decision makers ultimately responsible for local actions and funding allocation of great interest for building awareness around the challenges and obtaining on-field data.

[33] https://setis.ec.europa.eu/low-carbon-energy-technologies
[34] http://eippcb.jrc.ec.europa.eu/
[35] https://ec.europa.eu/jrc/en/geco
[36] https://ses.jrc.ec.europa.eu/power-system-modelling
[37] https://ses.jrc.ec.europa.eu/gas-and-power-modelling
[38] https://www.covenantofmayors.eu/
[39] https://ec.europa.eu/knowledge4policy/territorial_en

- *Composite indicators*

JRC has an advanced activity on Composite indicators, i.e., aggregations of observable variables that aim to quantify un-measurable concepts[40]. Such a framework is particularly helpful in describing a multi-faceted problem like that of "pressure on air" and gives the possibility of summarising and visualising multi-dimensional phenomena while still allowing one to go back to underlying data.

- *Foresight, behavioural insights and design for policy*

In the frame of its EU Policy Lab[41], the JRC makes available a pool of competences and worked experiences in the fields of foresight and participatory processes of special interest for "Pressure on Air". The activities of the Competence Centre on Foresight include Horizon Scanning - a process of discovering and monitoring emerging trends and events that might have significant future implications, while the Megatrends Hub is a systematic knowledge-management platform and an engagement tool for experts and policy-makers to help understand the impact of megatrends on the potential future developments in systemic and systematic way to support forward looking thinking. Both can be used through participatory sessions in the context of the project to imagine possible future developments.

[40] https://composite-indicators.jrc.ec.europa.eu/
[41] https://blogs.ec.europa.eu/eupolicylab/about-us/

5 Conclusions and outlook

The report presents a detailed discussion of some ongoing and incoming changes in a set of economic sectors and human activities known to emit relevant amounts of air pollutants in the European Union in order to evaluate their foreseeable consequences in terms of exposure and health impacts of atmospheric pollution.

Based on extensive literature screening and expert elicitation, a number of specific challenges needing more attention have been identified, mostly in the sectors of energy, transport and agriculture. Based on the knowledge gathered, challenges were classified using a simple prioritisation scheme taking into account their urgency and their overall impact (see Table 3 on page 35).

In order to complement the findings of a recent audit form the European Court of Auditors, the technical analyses in the report were complemented by an overview of sectorial policies, legislative frameworks and ongoing initiatives from the atmospheric pollution perspective.

A message that emerges is that almost all challenges identified for further investigation need to be addressed taking a more holistic approach than has been taken until now. Tools specifically designed for cross-sectors analyses such as Life Cycle Analysis, Techno-economic Modelling and Composite Indicators should be deployed in order to address issues that are, by definition, horizontal and multi-faceted.

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AC	Autonomous car
AQ	Air Quality
AQG	Air Quality Guidelines
BAT	Best Available Techniques
BC	Black Carbon
CAP	Common Agriculture Policy
CCS	Carbon Capture and Storage
CoM	Covenant of Mayors
DOC	Diesel Oxidation Catalyst
ECA	European Court of Auditors
EEA	European Environmental Agency
ERDF	European Regional Development Fund
ETS	Emission Trading System
EV	Electric Vehicles
GHG	GreenHouse Gases
HC	Hydrocarbons
HD	Heavy Duty
HEV	Hybrid Electric Vehicles
ICE	Internal Combustion Engines
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
LD	Light Duty
NECD	National Emission Ceilings Directive
NECP	National Energy and Climate Plan
NMVOC	Non-Methane Volatile Organic Compounds
OC	Organic Carbon
PEV	Purely Electric Vehicle
PHEV	Plug-In Hybrid Vehicle
PI	Positive Ignition
PM	Particulate Matter
PN	Particle Number
QA/QC	Quality Assessment/Quality Control
RDE	Real Driving Emission
RED	Renewable Energy Directive
THC	Total Hydrocarbons
TWC	Three Way Catalyst
WHO	World Health Organization

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