8th REPORT ON THE STATE OF THE ALPS

AIR QUALITY IN THE ALPS

ALPINE SIGNALS – SPECIAL EDITION 8

ALPENKONVENTION
CONVENTION ALPINE
ALPSKA KONVENCIJA
CONVENZIONE DELLE ALPI

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The preparation of the Eighth Report on the state of the Alps was coordinated by the French Presidency of the ad hoc Working Group and the Permanent Secretariat of the Alpine Convention.

The text has been drafted by the members of the ad hoc Working Group, with the support of the French Presidency and the Permanent Secretariat.

The Eighth Report on the state of the Alps, in all Alpine languages as well as in English, can be downloaded here: www.alpconv.org. All the maps can be browsed at: www.atlas.alpconv.org

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FOREWORDS

The concept of "pure Alpine air" recalls the idea of an environment untouched by human intervention. However, this is a simplification: the Alps - and thus the Alpine air - are exposed to meteorological phenomena, to chemical reactions in the atmosphere and to human activities. All these issues do not stop at the national borders and we need to tackle them through transnational cooperation. Moreover, it is important to remember that there is no threshold below which air pollutants do not represent a threat to human health: associating the Alpine arc only with pristine clean air risks underestimating the health risks that Alpine inhabitants are exposed to. It can also hinder the development of sound public policies.

All this clearly shows why it was crucial for the Alpine Convention to dedicate its Eighth Report on the State of the Alps to the topic of air quality. As an international treaty between the eight Alpine countries and the EU, bringing together an Alpine-wide network of policymakers, scientists and civil organisations, the Convention has served once more as the most appropriate arena to thoroughly research the current status of Alpine air quality, to identify the main specific sources of air pollutants in the Alpine arc, to showcase what is done at different policy levels and to put forward effective, practical recommendations to improve the quality of air. In a nutshell, the results of the analysis show that the air quality situation is good but can – and should – be improved. Moreover, it shows that challenges and risk factors do exist in the Alps, particularly in some areas and with reference to specific pollutants. Most importantly, the Report demonstrates that it is important to act together and to act now, in order to ensure the health and well-being of Alpine citizens and visitors!

I am therefore very grateful to the French Presidency of the Alpine Convention for choosing this topic, as well as to the international ad hoc Working Group that conducted such a detailed, up-to-date and thorough investigation of the situation, which paves the way to more precise and effective solutions at different administrative levels.

Alenka Smerkolj
Secretary General of the Alpine Convention

People rarely associate the Alps with pollution. Our mountains are often rightly perceived as breathing havens. They are considered to be in contrast with our cities, many of which are affected by pollution, primarily due to vehicles traffic emissions. But can we be assured that they provide pure air? What do we actually know about air pollution in the Alpine valleys? Is there still a need to improve the air in the Alps? What solutions might be available to do so?

During the 2019-2020 French presidency, the Alpine Convention addressed these issues in the Eighth Report on the State of the Alps. Specific data were collected, research into pollution mechanisms and their effects on health and nature was carried out, state-of-the-art findings on the state of the Alpine atmosphere were gathered and reported and, most importantly, good practices were identified.

The Report confirms that the quality of Alpine air is relatively good. Nevertheless, several Alpine valleys experience an excess of pollution. Generally speaking, the concentration of particles larger than 2.5 µm in diameter is too high when compared with the standards recommended by the World Health Organisation.

Depending on different areas and times of the year, wood heating, vehicle traffic and agriculture are the leading causes of this pollution. Local authorities and States have undertaken several initiatives to combat pollution. Some of these measures offer multiple benefits, including reducing greenhouse gas emissions and noise pollution.

The report closes its analysis with ten recommendations designed to further improve the air in the Alps, to protect their citizens and to attract visitors. I hope consideration will be given to these recommendations and that policymakers will draw on this array of options to develop measures that will allow them to respond to the public expectations concerning clean air, which is notably one of the premises for good health.

I would also stress that this Eighth Report on the State of the Alps is above all a collective effort. Each of the members of the Alpine Convention appointed highly qualified and motivated experts to support the patient work of collecting data and summarising the lessons it can provide. Leading experts have assessed the most recent scientific literature on sources of pollution and atmospheric transfer, as well as their impact on health and ecosystems. Throughout our meetings, many of which were videoconferences due to the sanitary situation, a sense of cooperation prevailed.

It has been an honour to coordinate this group; it gave me great pleasure to note the collaborative spirit shared by all, the relentless pursuit of compromise and, above all, the empathy we all shared. This is the spirit that makes the Alpine Convention great. I want to thank all the members of the group and the Parties to the Alpine Convention for their tireless support.

Éric Vindimian
Coordinator of the ad-hoc Working Group for the preparation of the RSA 8

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ABBREVATIONS, SYMBOLS AND FORMULAS

AEI	Average exposure indicator
AlpEnDAC	Alpine Environmental Data Analysis Centre
AQG	Air Quality Guidelines
As	Arsenic
AT	Austria
BAFU/FOEN	Swiss Federal Office for the Environment (*Bundesamt für Umwelt*)
BaP	Benzo(a)pyrene
BioCliS	Bioclimatic Information System
C_6H_6	Benzene
Cd	Cadmium
CH	Switzerland
CLRTAP	UNECE Convention on Long-range Transboundary Air Pollution
CNG	Compressed natural gas
CO	Carbon monoxide
DE	Germany
DLR	German Aerospace Center (*Deutsches Zentrum für Luft- und Raumfahrt*)
EC	European Commission
EEA	European Environment Agency
EU	European Union
EUSALP	EU Strategy for the Alpine Region
FL	Liechtenstein
FR	France
GAW	Global Atmosphere Watch programme
Hg	Mercury
HGV	Heavy goods vehicle
HULIS	Atmospheric humic-like substances
IARC	International Agency for Research on Cancer
IT	Italy
LEZ	Low Emission Zone
MC	Principality of Monaco
NEC	National Emission Ceilings
NH_3	Ammonia
Ni	Nickel
NMVOC	Non-methane volatile organic compounds
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
OAPC	Swiss Ordinance on Air Pollution Control
OCP	Organochlorine pesticides
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead
PCB	Polychlorobiphenyls
PERC	Perchlorethylene
PM	Particulate matter
PM_{10}	Particles of diameter smaller than 10 µm
$PM_{2.5}$	Particles of diameter smaller than 2.5 µm

POA	Primary organic aerosol
POP	Persistent organic pollutant
ppb	Parts per billion
SA	Secondary aerosol
SI	Slovenia
SO_2	Sulphur dioxide
SOA	Secondary organic aerosol
SOMO35	for ozone, the sum of means over 35 ppb (daily maximum 8-hour)
UFP	Ultrafine particles, of diameter smaller than 0.1 µm
UFS	Umweltforschungsstation (Environmental research station) Schneefernerhaus Zugspitze
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
US EPA	United States Environmental Protection Agency
VAO	Virtual Alpine Observatory
VOC	Volatile organic compound
WHO	World Health Organization
WMO	World Meteorological Organization
YLL	Years of life lost

AN OVERVIEW OF THE MOST COMMON POLLUTANTS IS PROVIDED IN ANNEX 1

EXECUTIVE SUMMARY

Legal regulations on air quality for Europe and for Alpine countries, as well as international conventions on air pollution, are stimulating measures to increase the knowledge of these phenomena, to understand their underlying mechanisms and their trends, and to take appropriate political action to improve air quality.

Although these large-scale regulations and agreements build a very useful framework, they are not customised to the Alpine situation. The Alps are, in general, an area of high air quality that benefits its inhabitants and its visitors: clean air is a commodity for the locals as well as a point of attraction for all the tourists who enjoy the Alpine landscapes and recreational activities. At the same time, it needs to be stressed that poor air quality is deleterious for human health. Air pollution is the most significant environmental risk factor for human health and has a negative impact on a large portion of ecosystems, as reported in the scientific literature.

The analysis of the data available from all the static monitoring stations in the Alps clearly shows that, for the most part, the levels of pollution are under the European Union (EU) regulated limits. Nevertheless, when air pollution in the Alps is measured against other quality objectives, such as those from the World Health Organization (WHO) for the protection of human health, the situation is different: for example, the measured concentration of fine particles with a diameter smaller than 2.5 µm ($PM_{2.5}$) is in some cases higher than the levels recommended by the WHO, although it has been recently decreasing. The same can be observed in some of the stations as regards the carcinogenic polycyclic aromatic hydrocarbon benzo(a)pyrene (BaP) attached to particles. Moreover, deposition of nitrogen linked to emissions of ammonia by agriculture exceeds the critical loads for some forests in the Alps. However, a trend analysis was conducted which shows that the situation has been generally improving over the last decade for all the considered pollutants except for ozone.

This report analyses the mechanisms of atmospheric pollution as described in recent scientific literature. Several research programmes have been carried out in the Alps in the last decade, and their results, published in the scientific literature, have been scrutinised to identify the sources of air pollution. In the Alps, pollutants are emitted, in particular, where traffic and cities are concentrated. Heating is often based on wood burning which is good for mitigating climate change but needs precautions to avoid emitting particulate pollution. Secondary aerosols (SA) from multiple sources, including agriculture, increase particulate pollution and nitrogen deposition on soils. Specific meteorological conditions are also present in the Alps. Most notably, temperature inversions prevent the vertical mixing of air masses so that pollution is sent downwards to the ground. Consequently, there are certain spots of high pollution levels in the Alps. In general, air quality could be improved to reach the very high standard requested by the Alpine Convention in its objective c: "drastically reduce the emission of pollutants and pollution problems in the Alpine region [...] to a level which is not harmful to man, animals and plants" (Alpine Convention, 2018).

The Report also lists several good practices and smart solutions implemented in the Alpine countries by regional and local authorities as well as by municipalities. Although not exhaustive, this set of smart solutions clearly shows that people in the Alps are actively engaged in improving the quality of their air. These measures range from heating systems to traffic management and mobility policies, from clean technology promotion to local regulations.

Lastly, and mainly stemming from these examples of smart solutions, the following set of recommendations is proposed to help policy makers to improve air quality in the Alps.

RECOMMENDATION 1

Support relevant organisations to:

- measure *in situ* fine particles and in particular benzo(a)pyrene coming from wood-burning heaters and boilers;
- inform the population about the health significance of wood-burning for heating.

RECOMMENDATION 2

Reduce domestic heating emissions by improving overall energy performance of buildings and renewing heating systems towards low emitters through support and guidance to all operators by:

- improving the energy performance of buildings;
- replacing old heavily polluting heating systems and boilers;
- substituting traditional fuels with a cleaner type.

RECOMMENDATION 3

After consultation and environmental evaluation, adopt regional and local mobility initiatives for passenger and freight transport favouring public transportation and active modes, coupling incentives with restrictions where a relevant impact on air quality is expected.

RECOMMENDATION 4

Promote clean mobility and zero-emission vehicles strategy, e.g., by using a balanced taxation and incentives system to internalise external pollution costs within real transport costs, and enhance the market signals in favour of clean mobility and zero-emission vehicles.

RECOMMENDATION 5

Promote the use of smart traffic management, e.g., speed limits, road pricing, favouring clean vehicles on Alpine motorways and tunnels to lower emissions, as well as:

- encourage the implementation of alternative transport technologies and combined transport;
- integrate public transport in multimodal mobility systems;
- incentivise modal shift of passenger and freight transport.

RECOMMENDATION 6

Support the development of good agricultural practices limiting the emissions of nitrogen compounds, like ammonia, and the open burning of green waste and slash in the Alpine region.

RECOMMENDATION 7

The Contracting Parties of the Alpine Convention are encouraged to set up air quality initiatives incorporating measures addressing their most relevant sources of air pollution like domestic heating, mobility, energy, industry and agriculture.

RECOMMENDATION 8

The Contracting Parties of the Alpine convention should liaise with neighbouring countries and regions to stimulate the reduction of transboundary pollutant transport in the geographic area of the Alpine Convention.

RECOMMENDATION 9

The Alpine Convention Contracting parties should:

- support the Air quality chapter of the EU Green Deal;
- strive to achieve WHO air quality guidelines.

RECOMMENDATION 10

Develop in-depth and specific studies on air quality in the Alps, especially where problems referring to ambient air quality are identified or expected from the monitoring of the situation, for studying the influence of the sources of air pollution, as well as on the related social and political issues.

1. INTRODUCTION AND OBJECTIVES

The Alps are the central mountain area in Europe. Fourteen million people live in the Alps and millions of tourists enjoy their fabulous landscapes, their cultural heritage, and recreational facilities as well as their clean air. The Alpine Convention covers 190,700 km² across eight countries including several cities of more than 100,000 inhabitants and its area is surrounded by major European cities. This report deals with air quality within the perimeter of the Alpine Convention as shown on the map in Figure 1.

Overall, the Alpine region has quite good levels of air quality. However, sources of atmospheric pollutants are present within the Alpine region, e.g. agglomerations and motorways as well as emissions from wood burning and industry. In addition, regional and long-range transported air masses might contribute to the pollution of Alpine air. Although some natural emissions are linked with atmospheric chemical phenomena, human activities are the major cause of the degradation of air quality in the Alps.

The particular orography of the Alps also results in a complex distribution and concentration of pollutants in the densely populated valleys. Valleys and foothills are a geographical and meteorological trap for atmospheric pollutants. Moreover, the Alpine region is an extraordinarily sensitive ecological system. Clean air in the Alps has a strong relevance especially for tourism, healthy recreational activities and for the protection of ecosystems. Therefore, analysing the quality of air in the

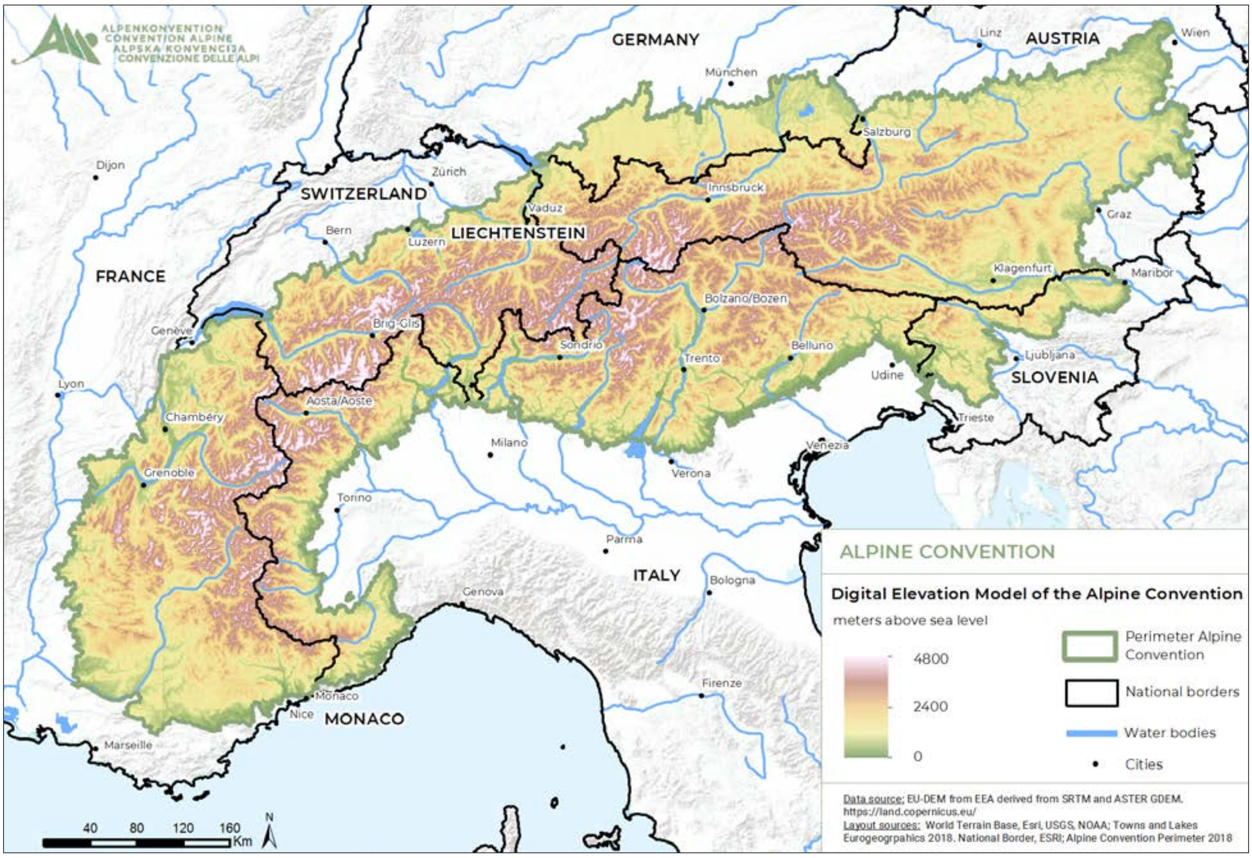

Figure 1: *Map of the Alpine Convention perimeter.*

Alps and improving it are seen as priorities by the Contracting Parties to the Alpine Convention.

In terms of health and of ecological conservation, the main pollutants are controlled by EU and Swiss regulations. Additionally, the European Member States and their partners, as well as Switzerland, are part of the Convention on Long-range Transboundary Air Pollution (CLRTAP) within which several protocols regulate further substances like polycyclic aromatic hydrocarbons (PAH), persistent organic pollutants (POPs), or heavy metals.

Following a proposal from the incoming French Presidency, the XV Alpine Conference (Innsbruck, AT, 4 April 2019) decided that the Eighth Report on the State of the Alps was to address the topic of air quality in the Alps. An ad hoc Working Group composed of experts from all Alpine countries was established to fulfil this task: over the following period, the Group drafted the present Report and submitted it to the XVI Alpine Conference (10 December 2020) that officially approved it. The French Presidency's proposal acknowledged that, since 2006 when the first Report on the State of the Alps dealt with transport and mobility, air quality had not been sufficiently addressed by the Alpine Convention. In addition to climate change, climate adaptation, the conservation of biodiversity and promoting a circular economy, a high quality of air is now a central objective of environmental and health policies. The scope of the Alpine Convention is to "pursue a comprehensive policy for the preservation and protection of the Alps by applying the principles of prevention, payment by the polluter (the 'polluter pays' principle) and cooperation" (Alpine Convention, 2018). Bullet c of the general obligations of the Convention (Art. 2) reads as follows: "prevention of air pollution: the objective is to drastically reduce the emission of pollutants and pollution problems in the Alpine region, together with inputs of harmful substances from outside the region, to a level which is not harmful to man, animals and plants".

Safeguarding the health of citizens is a major concern and the priority of air quality policies, although the impacts of air pollution on crops and ecosystems also remain important issues. Air pollutants are transported over long distances regardless of national boundaries and have a negative impact on human health and ecosystems: they are responsible, *inter alia*, for acidification, eutrophication, and ground-level ozone pollution. The Eighth Report on the State of the Alps deals with the five specific issues mandated by the XV Alpine Conference:

- provide an overview of air quality in the Alps, understanding the complex mechanisms underlying its degradation;
- list the relevant international, national, or local regulations;
- briefly inform on the health issues linked with air pollution as well as its impacts on ecosystems;
- identify good practices to improve air quality specifically in the Alps;
- formulate a set of recommendations to policymakers.

The regulatory framework is analysed in the first chapter of the text in order to identify the legal provisions laying down thresholds (limit values of concentrations in the air, target values, emissions limits, etc.) for air pollutant concentrations, monitoring regimes, reporting requirements and regulations for taking action in case of exceedances. The analysis highlights the formal reference environmental objectives to which present air quality reports and data must be compared.

However, expert groups using a combination of epidemiological, toxicological and exposure studies established that the negative impacts of air pollution on human beings occur well under the levels of legal requirements. For some pollutants such as particulates there is no evidence of a threshold below which no health effect is likely to happen. When the probability of effect increases in proportion to exposure concentration, quality objectives might conventionally be set to the concentrations inducing a probability of adverse effect of 1/100,000. This is also part of the reason why the WHO has formulated a set of Global Air Quality Guidelines (AQG) which are currently under review. The European Commission announced in its new European Green Deal (EC, 2019) that it will propose to *review the EU air quality standards to align them more closely with the WHO recommendations*.

Air pollution is defined as a mixture of gaseous, liquid and solid pollutants. Many of them, known as primary pollutants, are substances directly emitted into the atmosphere. On the other hand, secondary pollutants are formed by chemical reactions of precursors in the atmosphere including by the interaction with water or solar irradiation. Knowing which pollutants are present in ambient air and the underlying mechanisms of their emission, dispersion, formation, alteration and exposure is very important for a comprehensive understanding of the topic of air quality. The Report addresses these issues after the chapter covering the regulatory framework. The analysis carried out by the experts of the *ad hoc* Working Group is based on the results of several recent research projects dealing with air quality in the Alps.

An important chapter is dedicated to the analysis of the status of air quality in the Alps, using amongst others data from the European Environment Agency (EEA) database. The compilation of information and the data analysis have been carried out ensuring homogeneity in data collection and calculation. This chapter provides up to date information and maps of air quality in the Alps and on the trends of this pollution. It confirms that air quality has gradually been improving in the Alps and that legal limit values are generally being met. It also shows that more protective quality targets are still not reached, especially regarding $PM_{2.5}$.

The Report then provides an overview of relevant research projects and observatories for air quality in the Alps and analyses the issues that might arise in the future.

The identification of good practices is another important contribution of the Working Group, which has labelled them *smart solutions*. Thus, the following chapter shows examples of measures implemented in the Alps to address, at several political levels, the issues raised in the first parts of the text.

In its final part, the Report lists several recommendations on the topic of air quality in the Alps, based mainly on the smart solutions, in an attempt to address all the issues highlighted in the text.

2. AMBIENT AIR QUALITY REGULATORY FRAMEWORK

This chapter provides an overview of the legal framework by presenting the relevant existing legislation concerning air quality in the Alpine area. It focuses on ambient air quality and mainly refers to European Union (EU) legislation and similar regulations in Alpine Convention Member States that are not part of the EU.

2.1 EUROPEAN UNION LEGISLATION

The regulatory framework on air quality in the Alpine Convention area is to a considerable extent determined by EU legislation. Since the early 1970s, the EU has been developing a legal framework to improve air quality.

The EU's Clean Air Policy is based on three main pillars:

- Ambient air quality standards in the form of limit values and target values set out in the Ambient Air Quality Directives as regards concentration levels of pollutants in the ambient air with the aim to protect human health and the environment as a whole.
- Overall national emissions of certain air pollutants are addressed in the National Emission Reduction Commitments Directive. This Directive outlines *inter alia* the requirements e.g. for the national emission inventories, the national emission reduction commitments for five key pollutants and the national air pollution control programmes to ensure compliance with these commitments.
- Emission and energy efficiency standards for key sources of air pollution, including vehicle emissions, products and industry. These standards are set out in EU legislation targeting e.g. industrial emissions, emissions from power plants, vehicles and transport fuels, as well as the energy performance of products and non-road mobile machinery.

2.1.1 AMBIENT AIR QUALITY DIRECTIVES

The main instruments in the first pillar of the EU air quality framework are two directives setting ambient air quality standards: Directive 2008/50/EC and Directive 2004/107/EC as last amended by Commission Directive (EU) 2015/1480. These Directives build on previous legislation gradually developed since the early 1980s. They establish ambient air standards for a range of pollutants including ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$)[1] and nitrogen dioxide (NO_2) as well as arsenic (As), cadmium (Cd), mercury (Hg), nickel (Ni) and polycyclic aromatic hydrocarbons[2] (Directive 2004/107/EC). Together, they provide the current framework[3] for the improvement of air quality in the EU and set standards to be achieved across the EU for 13 air pollutants (see Table 1). Since the air quality challenge is far from being solved[4], the current legal framework has recently been subject to a Fitness Check[5] focusing on the period from 2008 to 2018.

1. PM_{10} are particles of size smaller than 10 µm; the size of $PM_{2.5}$ is smaller than 2.5 µm.
2. https://www.niehs.nih.gov/health/topics/agents/air-pollution/.
3. The Framework Directive and the first three daughter directives were consolidated into a single Directive in 2008.
4. Infringement proceedings have been taken up against several Member States.
5. Further information can be found online: https://ec.europa.eu/environment/air/quality/aqd_fitness_check_en.htm. As an overall result of the Fitness Check the air quality standards have been found instrumental in driving concentrations downward and in reducing exceedance levels. However, there is potential for improvement with regard to two points in particular: EU air quality standards are not fully aligned with well-established health recommendations (and they also do not feature an explicit mechanism for adjusting air quality standards to the latest technical and scientific progress), and there have also been substantial delays by Member States in taking appropriate and effective measures to meet the air quality standards or to at least try to keep the exceedance period as short as possible.

POLLUTANT	AVERAGING PERIOD	CONCENTRATION	LEGAL NATURE	COMMENTS
AIR QUALITY STANDARDS FOR THE PROTECTION OF HUMAN HEALTH				
PM_{10}	1 day	50 µg/m³	Limit value	Not to be exceeded on more than 35 times per calendar year
	Calendar year	40 µg/m³		
$PM_{2.5}$	Calendar year	25 µg/m³	Limit value	
		20 µg/m³	Exposure concentration obligation	Average exposure indicator (AEI)[6] in 2015 (2013-2015 average)
		0-20% reduction in exposure	National exposure reduction target	AEI in 2020, the percentage reduction depends on the initial AEI
Ozone (O_3)	Maximum daily 8-hour mean	120 µg/m³	Target value	Not to be exceeded on more than 25 days per year, averaged over 3 years
		120 µg/m³	Long-term objective	
	1 hour	180 µg/m³	Information threshold	
		240 µg/m³	Alert threshold	
Nitrogen dioxide (NO_2)	1 hour	200 µg/m³	Limit value	Not to be exceeded on more than 18 times per calendar year
		400 µg/m³	Alert threshold	To be measured over 3 consecutive hours over 100 km² or an entire zone
	Calendar year	40 µg/m³	Limit value	
Benzo(a)pyrene (BaP)[7]	Calendar year	1 ng/m³	Target value	Total content in the PM_{10} fraction
Sulphur dioxide (SO_2)	1 hour	350 µg/m³	Limit value	Not to be exceeded on more than 24 times hours per calendar year
		500 µg/m³	Alert threshold	To be measured over 3 consecutive hours over 100 km² or an entire zone
	1 day	125 µg/m³	Limit value	Not to be exceeded on more than 3 times per calendar year
Carbon monoxide (CO)	Maximum daily 8-hour mean	10 mg/m³	Limit value	
Benzene (C_6H_6)	Calendar year	5 µg/m³	Limit value	
Lead (Pb)	Calendar year	0.5 µg/m³	Limit value	Total content in the PM_{10} fraction
Arsenic (As)	Calendar year	6 ng/m³	Target value	Total content in the PM_{10} fraction
Cadmium (Cd)	Calendar year	5 ng/m³	Target value	Total content in the PM_{10} fraction
Nickel (Ni)	Calendar year	20 ng/m³	Target value	Total content in the PM_{10} fraction
AIR QUALITY STANDARDS FOR THE PROTECTION OF VEGETATION				
O_3	AOT40[8] accumulated over May to July	18,000 µg/m³ • h	Target value	Averaged over 5 years
		6,000 µg/m³ • h	Long-term objective	
Nitrogen oxides (NO_x)	Calendar year	30 µg/m³	Critical level	
SO_2	Calendar year and winter (10/1 to 03/31)	20 µg/m³	Critical level	

Table 1: *Air quality standards for the protection of human health and vegetation, as given in the EU Ambient Air Quality Directives (EEA, 2019).*

6. *AEI: based upon measurements in urban background locations established for this purpose by the Member States, assessed as a 3-year running annual mean.*
7. *BaP (Benzo(a)pyrene) is regarded as the lead substance for polycyclic aromatic hydrocarbons with carcinogenic potential.*
8. *AOT40 is an indication of accumulated O_3 exposure, expressed in µg/m³/h, over a threshold of 40 ppb. It is the sum of the differences between hourly concentrations > 80 µg/m³ (40 ppb) and 80 µg/m³ accumulated over all hourly values measured between 08:00 and 20:00 (CET).*

The Ambient Air Quality Directives were adopted with the aim of laying down measures aimed at[9]:

- defining and establishing the objectives for ambient air quality designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole;
- assessing ambient air quality in Member States based on common methods and criteria;
- obtaining information on the ambient air quality to help combat air pollution and nuisance and to monitor long-term trends and improvements resulting from measures taken at all relevant levels of governance;
- ensuring that information on air quality is made available to the public;
- maintaining air quality where it is good and improving it in other cases;
- promoting increased cooperation between Member States in reducing air pollution;
- setting up Air Quality Plans to achieve compliance with ambient air limit values in the shortest possible time in the case of exceedances.

European legislation on air quality is built on several principles to achieve the overarching goal of minimising harmful effects on human health and on the environment as a whole. To monitor the pollutant concentrations and the compliance with applicable ambient air quality standards, Member States must establish zones and agglomerations throughout their territory and classify them according to prescribed assessment thresholds to determine the applicable method for assessing air quality: measurements, modelling and/or other techniques of objective estimation. In this regard, the Air Quality Directives lay down common methods and criteria for siting sampling points. The location of those sampling points is aimed at the protection of human health, vegetation and natural ecosystems. Member States are required to report to the European Commission on the air quality data collected (see Chapter 5).

Where levels exceed limit or target values, Member States must establish an air quality plan addressing the sources responsible to ensure compliance with the related limit or target value. In the event of limit value exceedances, these plans need to set out appropriate measures to ensure that the exceedance period can be kept as short as possible. In addition, information on air quality must be disseminated to the public.

2.1.2 NATIONAL EMISSION REDUCTION COMMITMENTS DIRECTIVE

The main legislative instrument in the second pillar of the EU clean air framework is Directive (EU) 2016/2284 on the reduction of national emissions of certain atmospheric pollutants (often still referred to as the NEC Directive[10]), repealing Directive 2001/81/EC. By addressing overall national emissions of five key air pollutants, the NEC Directive aims at achieving the objectives of EU air policy to cut the health impacts of air pollution by half in 2030 compared to 2005 and to reduce environmental impacts.

To this end, Member States report national inventories of past emissions and projections of emissions for the future years. This reporting is fully consistent with the reporting guidelines under the Convention on Long-Range Transboundary Air Pollutants (CLRTAP) presented in Chapter 2.4.1.

These emission inventories are used to monitor and analyse the air pollution situation and to check compliance with the national emission reduction commitments that have been set for 2020-2029 and for 2030 and beyond, respectively. The reduction commitments for 2020-2029 correspond to the commitments that have been taken by the EU Member States under the 2012 revised Gothenburg Protocol and the CLRTAP, while the NEC Directive also establishes more ambitious reduction commitments to be reached by 2030.

The NEC Directive also requires Member States to establish, implement and regularly update a National Air Pollution Control Programme[11] which sets out measures that will be taken by Member States to ensure compliance with the emission reduction commitments for 2020-2029 and for 2030 and beyond (Annex II of Directive (EU) 2016/2284).

Finally, the NEC Directive also requires Member States to monitor impacts of air pollution on ecosystems, by ensuring a network of monitoring sites

9. As per Article 1 of the Ambient Air Quality Directive 2008/50/EC.
10. The National Emission Ceilings Directive.
11. The NAPCPs can be found online: https://ec.europa.eu/environment/air/reduction/NAPCP.htm.

and reporting on key indicators with a view to providing information that will support the efforts of ensuring that air pollution does not contribute to concentrations above the critical loads and levels in the various ecosystem types in the EU.

2.2 NATIONAL REGULATIONS IN AUSTRIA, LIECHTENSTEIN, MONACO AND SWITZERLAND

In general, Switzerland, Monaco and Liechtenstein apply rules similar to those foreseen by the EU Ambient Air Quality Directives. Air pollutants are regulated by the Swiss Ordinance on Air Pollution Control[12] (OAPC), which is based on the Federal Act on the Protection of the Environment. The Ordinance (status 2018) defines air quality standards for air pollutants according to the 2005 WHO recommendations, which are stricter for some air pollutants than the current limit values set by the EU clean air framework, as shown in Table 2 below.

For EU Member States, Article 193 of the Treaty on the Functioning of the European Union allows Member States, as regards legal acts adopted pursuant to its Article 192 in the framework of EU environmental policy, to maintain or introduce more stringent protective measures if they are compatible with EU Treaties. For instance, the Austrian Federal Law on Ambient Air Quality implementing the Ambient Air Quality Directives made use of this provision and continued to set stricter national limit values for NO_2, PM_{10} and BaP, as shown in Table 2 below. These standards are based on impact-related limit concentrations that were developed by the Austrian Academy of Sciences in the 1970s and 80s.

Within its ambient air quality framework, the Principality of Monaco, on the basis of common methods and criteria, currently compares air quality data to European Air Quality Directives limit val-

POLLUTANT	AVERAGING PERIOD, LEGAL NATURE	APPLICATION	CONCENTRATION	COMMENTS
PM_{10}	1 day, limit value	Switzerland, Liechtenstein	50 µg/m³	Not to be exceeded on more than 3 days per year
		Austria		Not to be exceeded on more than 25 days per year
		All other countries		Not to be exceeded on more than 35 days per year
	Calendar year, limit value	Switzerland, Liechtenstein	20 µg/m³	
		All other countries	40 µg/m³	
$PM_{2.5}$	Calendar year, limit value	Switzerland, Liechtenstein	10 µg/m³	
		All other countries	25 µg/m³	
NO_2	0.5 hour, limit value	Switzerland, Liechtenstein	100 µg/m³	Not to be exceeded on more than 18 hours per year
		Austria	200 µg/m³	
	1 hour, limit value	All other countries	200 µg/m³	Not to be exceeded on more than 18 hours per year
	Calendar year, limit value	Austria, Switzerland, Liechtenstein	30 µg/m³	
		All other countries	40 µg/m³	
BaP	Calendar year, limit value	Austria	1 ng/m³	

Table 2: *Comparison of Air Quality Standards for particulate matter, nitrogen dioxide and Benzo(a)pyrene in the Alpine region.*

12. OAPC, SR 814.318.142.1. Online: https://www.admin.ch/opc/en/classified-compilation/19850321/index.html#app7ahref0.

ues and alert thresholds for the pollutants PM, O_3, NO_x, SO_2 and CO, with a long-term WHO target for 2030.

2.2.1 NO_2

For NO_2, there are differences not only in the thresholds but also in their averaging period. The limit values for the annual mean concentration vary between 30 µg/m³ (Austria[13], Switzerland and Liechtenstein) and 40 µg/m³ (all other EU Member States). As regards short-term thresholds, Switzerland and Liechtenstein lay down a half-hourly limit value of 100 µg/m³ with 18 exceedances allowed. In Austria, a 200 µg/m³ limit value is laid down for the half-hourly mean, whereas in all other EU Member States the EU limit value for the one-hourly mean of 200 µg/m³ applies. Differences also exist regarding the number of exceedances allowed for short-term limit values per year for NO_2: other EU Member States allow, in accordance with the Ambient Air Quality Directive, 18 exceedances of the one-hourly limit value per calendar year whereas in Austria the half-hourly limit value must not be exceeded.

2.2.2 PARTICLES

For PM_{10}, the annual air quality standards in Switzerland and Liechtenstein are set at an annual average of 20 µg/m³, in line with WHO guidelines, and at an annual average of 40 µg/m³ in EU Member States. The limit value for the daily mean of PM_{10} is set at 50 µg/m³ for all countries in the Alpine arc; however, the number of allowed exceedances per year varies between three days in Switzerland, 25 in Austria and 35 in all other EU Member States.

For $PM_{2.5}$, the upper limits of air quality standards are set at 10 µg/m³ (annual average) in Switzerland in line with the WHO guidelines and at 25 µg/m³ (annual average) in the EU Member States.

2.3 AIR QUALITY PLANNING

According to the EU Air Quality Directive, air quality plans must be prepared for the case of ambient air quality limit values being exceeded, with suitable measures to ensure compliance in the shortest possible time. The responsibility for preparing the plans differs across Member States. For example, in Bavaria it is the responsibility of the district governments (regional authority), while the competent authorities for air quality planning and implementation are the regional administrations in Italy and the provincial governments in Austria.

2.4 INTERNATIONAL CONVENTIONS, AGREEMENTS AND COORDINATION

International organisations, national and local authorities, NGOs and other stakeholders have started to take action given the increasing awareness of the effects and rising costs of air pollution (see Chapter 1). In particular, the United Nations Economic Commission for Europe (UNECE), the WHO and the United Nations Environment Programme (UNEP) have presented global actions to address air pollution.

2.4.1 UNECE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION[14]

The UNECE Air Convention (or CLRTAP) deals with the protection of the human environment against air pollution and the gradual reduction and prevention of air pollution, including long-range transboundary air pollution, and was adopted in 1979. It has been extended by eight protocols dealing with different air pollutants, the latest protocol[15] being a multi-effect, multi-pollutant instrument designed to reduce acidification, eutrophication and ground-level ozone. For its parties, this protocol sets limit values for several main emission sources and establishes national emission reduction commitments for five main pollutants. These reduction commitments correspond to the 2020-2029 reduction commitments of the EU NEC Directive.

The Air Convention provides access to emission, measurement and modelling data as well as information on the effects of air pollution on ecosystems, human health, crops and materials. Moreover, it functions as an important legal framework

13. A remaining margin of tolerance of 5 µg/m³ applies as of 1.1.2010.
14. Also referred to as "Air convention". Online: https://www.unece.org/env/lrtap/welcome.html.html.
15. 1999 Protocol on the abatement of acidification, eutrophication and ground-level ozone (Gothenburg Protocol) as amended 2012.

for a number of task forces, centres and International Cooperative Programmes that provide research and scientific assessments on relevant air quality issues.

2.4.2 WHO GUIDELINES

The WHO works on global standards in environmental quality and has developed Air Quality Guidelines that were published in 1987 and revised in 1997 and 2005. The rationale underlying those AQGs is explained in Chapter 4.1. Table 3 summarises the values proposed by WHO (currently under revision) to reduce the effects of air pollution on human health and natural ecosystems.

For the 2013 review of European Air Quality policies, the European Commission addressed a number of questions[16] to the WHO to support the review process. The answers to these questions were formulated within the projects "Review of evidence on health aspects of air pollution" and "Health risks of air pollution in Europe"[17]. As a result of these projects, the WHO launched a review of its air quality guidelines[18] in 2016. According to the latest report from the WHO/UNECE joint Task Force on Health[19], the review includes $PM_{2.5}$, PM_{10}, NO_2, O_3, SO_2 and CO. The systematic review of evidence on health effects from these air pollutants was the basis for the second phase of the update process, namely to derive numerical guideline exposure values, set interim targets and other recommendations. This second phase took place during 2020, and the new AQG will be published in 2021.

In 2018, the First WHO Global Conference on Air Pollution and Health took place in Geneva[20]. The Conference launched the Geneva Action Agenda to Combat Air Pollution (WHO, 2018), which includes the implementation of solutions to reduce burning in any form, strengthening action to protect the most vulnerable populations (i.e. children), support

POLLUTANT	AVERAGING PERIOD	AQG	REFERENCE LEVEL	COMMENTS
PM_{10}	1 day	50 µg/m³		99th percentile (3 days per year)
	Calendar year	20 µg/m³		
$PM_{2.5}$	1 day	25 µg/m³		99th percentile (3 days per year)
	Calendar year	10 µg/m³		
O_3	Maximum daily 8-hour mean	100 µg/m³		
NO_2	1 hour	200 µg/m³		
	Calendar year	40 µg/m³		
BaP	Calendar year		0.12 ng/m³	
SO_2	10 minutes	500 µg/m³		
	1 day	20 µg/m³		
CO	1 hour	30 mg/m³		
	Maximum daily 8-hour mean	10 mg/m³		
Benzene	Calendar year		1.7 µg/m³	
Pb	Calendar year	0.5 µg/m³		
As	Calendar year		6.6 ng/m³	
Cd	Calendar year	5 ng/m³		
Ni	Calendar year		25 ng/m³	

Table 3: *AQG and estimated reference levels. When no AQG has been set, reference levels are estimated by assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100,000 (EEA, 2019).*

16. *http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/health-aspects-of-air-pollution-and-review-of-eu-policies-the-revihaap-and-hrapie-projects/key-questions-for-guidance-of-eu-policies.*
17. *http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/health-aspects-of-air-pollution-and-review-of-eu-policies-the-revihaap-and-hrapie-projects.*
18. *http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/update-of-who-global-air-quality-guidelines.*
19. *http://www.unece.org/fileadmin/DAM/env/documents/2019/AIR/EMEP_WGE_Joint_Session/ECE_EB.AIR_GE.1_2019_17-1909805E.pdf.*
20. *https://www.who.int/airpollution/events/conference/en/.*

to cities in improving urban air quality, enhanced joint action between the financial, health and environmental sectors to enable specific actions to improve air quality and to mitigate climate change, and continuing the joint effort for harmonised air pollution monitoring.

In the context of the EU Green Deal, the European Commission has announced its intention to strengthen the provisions relating to the monitoring and modelling of air quality, as well as the creation of air quality plans. The Commission will also put forward a proposal to align the EU air quality standards more closely with the WHO recommendations COM/2019/640.

2.4.3 OTHER UN ACTIVITIES

The United Nations Environment Assembly adopted two resolutions in 2014[21] and 2017[22] and a ministerial declaration in 2019[23] that call on Member States to take significant action to address air pollution and to improve air quality globally. The ministerial declaration builds on these resolutions and commits to improving national environmental air monitoring systems and technologies and to encouraging national environmental data management capacities. It also requests that UNEP enhances cooperation and information-sharing at all levels among its Member States to address transboundary air pollution.

21. Resolution 1/7 on Air Quality (https://wedocs.unep.org/bitstream/handle/20.500.11822/17135/UNEA1_Resolution7AirQuality.pdf?sequence=1&%3BisAllowed=).
22. Resolution 3/8 on Preventing and reducing air pollution to improve air quality globally (https://papersmart.unon.org/resolution/uploads/k1800222.english.pdf).
23. Ministerial Declaration: Towards a pollution-free planet (https://papersmart.unon.org/resolution/uploads/k1800398.english.pdf).

3. DESCRIPTION OF ATMOSPHERIC POLLUTANTS AND PROCESSES IN THE ALPS

The Alpine region's air quality and its spatial-temporal variability are the complex result of emissions as well as local and mesoscale meteorology and topography. The mountain heights in the entire region vary from medium-tall to high, with many Alpine valleys of different shapes that are often narrow and relatively long. The large differences in altitude between the valley floors and the mountain peaks result in extremely steep slopes. Most of the roughly 14 million inhabitants of the Alpine region live in the valleys, where the main roads and motorways are located: this means that anthropogenic emissions in the Alps are primarily confined to valleys. The spatial distribution of emissions within valleys is determined (a) by the distribution of the resident population and (b) by the presence of motorways that concentrate supra-regional traffic. About 45% of the total Alpine population lives in municipalities with fewer than 5,000 inhabitants (Price M.F. *et al.*, 2011), and thus more than half of the inhabitants live in or close to mid-size towns or in the very few larger cities.

3.1 METEO-CLIMATIC PROCESSES

A number of meteorological processes have to be considered when interpreting air pollution (and deposition) in the Alps:

- long-range transport (>100 km) of pollutants emitted outside the Alps to the Alpine region, lifting and transport of air masses, increased deposition by topographically or orographically induced precipitation;
- transport of pollutants from lowlands in the vicinity of the Alps into valleys and uphill;
- diurnal valley-wind and slope-wind circulation which transports and dilutes pollution within valley systems;
- atmospheric dispersion conditions, triggered by vertical temperature distribution;
- complex interactions of ozone transport, formation and depletion on different spatial and temporal scales.

Air pollution related dynamics also depend on the width and length of valleys and on their orientation with respect to the synoptic winds[24].

3.1.1 THE METEOROLOGY OF THE ALPS FAVOURS ATMOSPHERIC POLLUTION

Typical weather situations in the Alps follow seasonal patterns. Significant differences can be found between summer and winter seasons affecting the movements of air masses, the type and intensity of primary emissions and the phenomena leading to the formation, transport, dilution and depletion of pollutants.

Eight highly diverse climatic regions within the European Alps have been identified (Sturman A., Wanner H., 2001): the *high Alpine* region characterised by cold and humid weather; the *continental high Alpine*, generally drier; *southwestern Alps*, *northern foothills*, and *western Alpine foreland* all influenced by warm air masses from the Mediterranean south, with generally humid winters and dry summers; the *inner Alpine valleys* characterised by continental dry climate; the *northern and eastern Alpine foreland* with continental climate and rainy summers; the *southwestern foothills* with rainy transition seasons (Egger I., Hoinka K.P., 1992).

24. Synoptic winds are created by pressure differences disregarding of any effect related to relief or convection (e.g. the föhn wind).

The horn-shaped barrier of the Alps frequently contributes to generating three different cold wind systems formed by complex blocking and channelling effects: the Mistral in the western Rhone valley, the Bise between Jura and the Alps on the North, and the Bora on the Adriatic coast ESE of the Alps (Tibaldi S., Buzzi A., Speranza A., 1990). Moreover, advective weather situations caused by macro-scale wind, which is itself caused by large pressure systems, leads to the northern and southern Foehn.

Another important feature of the Alpine environment is the thermally generated local winds, particularly under weak pressure gradients (Sturman A., Wanner H., 2001). During summer, the mixing layer evolves rapidly during the day, due to strong insolation allowing the locally produced pollutants to be rapidly diluted and mixed.

During winter (and less frequently in autumn) weather regimes of calm wind associated with extensive high pressure are quite frequent (e.g. Diemoz H. *et al.*, 2019a). Such conditions lead to atmospheric stability: temperature inversions persist for several days, strongly affecting the air quality as a low mixing layer height combined with low vertical mixing under the inversion reduces the dispersions and dilution of pollutants (Figure 2). It is to be noted that when occurring in

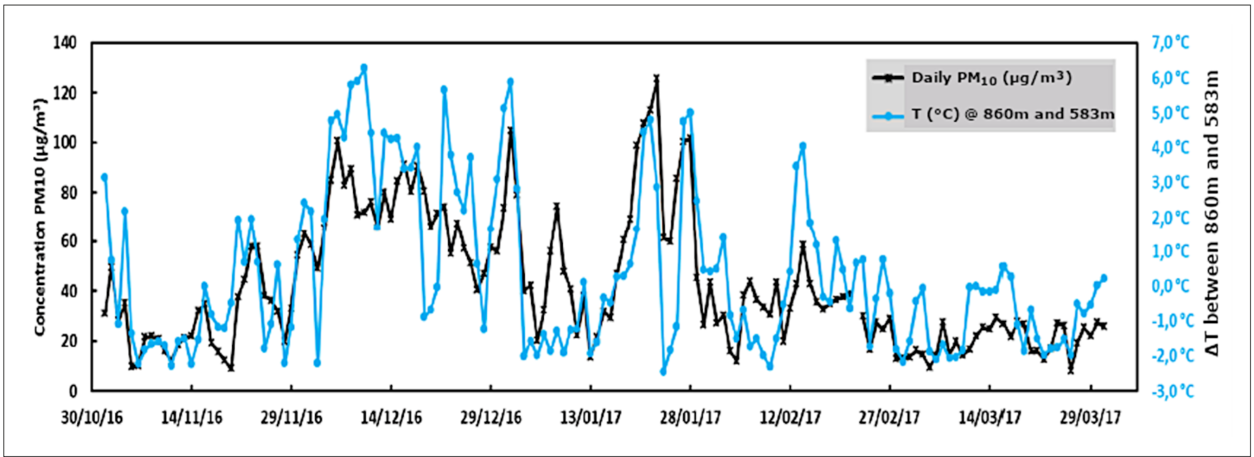

Figure 2: *Correlation between temperature difference at two altitudes and PM_{10} in the Arve valley (Favez O. et al., 2017a). The blue line shows the difference of temperature between the altitudes 583 m and 860 m in Celsius (right side of the graph) and the black line reports the daily average PM_{10} concentration within the valley (in µg/m³, on the left-hand side). The two lines vary together, suggesting that higher differences in temperature between the bottom and the top of the valley correlate with higher PM_{10} pollution.*

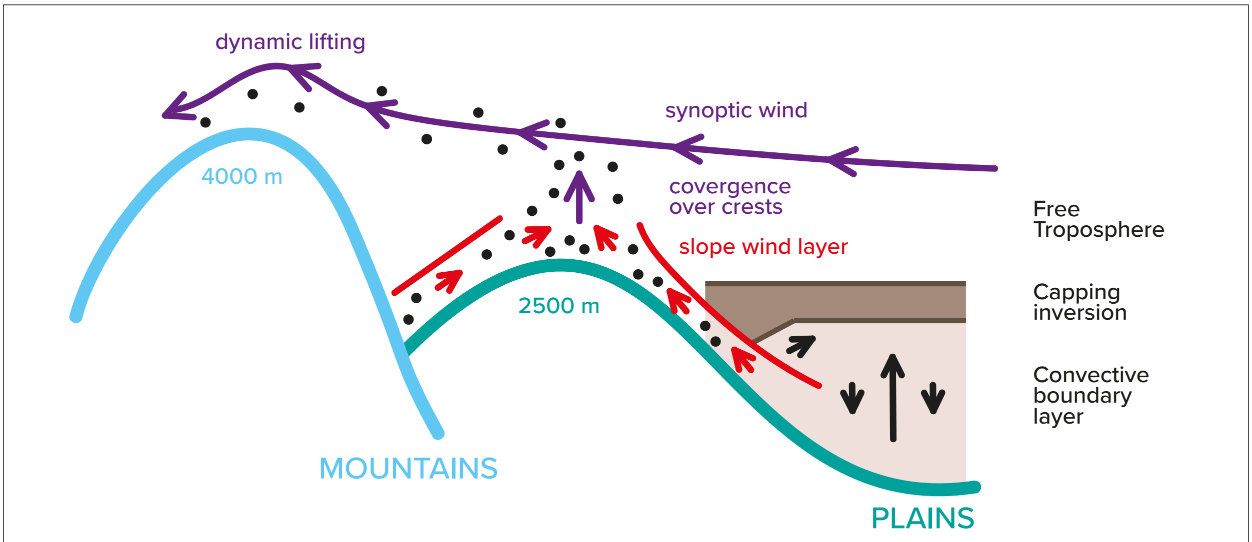

Figure 3: *Schematic view of the processes transporting polluted boundary layer air from adjacent plains and valleys up to the level of the highest Alpine peaks. Pollutants can enter the free atmosphere from there (Adaptation. Courtesy of Seibert P. et al., 1996).*

the Alpine region, an inversion taking place at 800 m above sea level could correspond to less than 200 m above the valleys, making the phenomena particularly critical in terms of the accumulations and concentrations of pollution recorded in the near-ground atmosphere of the valleys. Furthermore, if the ground is snow-covered, the air can remain stably stratified throughout the whole day and even for several consecutive days. During the day, the lower layers usually become well-mixed but often a persisting inversion in the valley prevents complete vertical mixing (Heimann D. *et al.*, 2007; ALPNAP report Ch.4).

A prolonged condition of atmospheric stability, with stable ground-based layers of cold air persisting over the valley floor, is characterised by a strongly stratified temperature inversion. This causes the suppression of the vertical mixing of pollutants and leads to an accumulation of pollutants in the lower troposphere (Chemel C. *et al.*, 2016). In the Alpine region, the valleys are mostly characterised by atmospheric stability. This, in addition to the presence of many emission sources, causes significant secondary aerosol air concentrations in valleys.

As shown in Figure 3, under typical mountain valley diurnal patterns of air mixing, strongly polluted air layers are observed in the morning on the val-

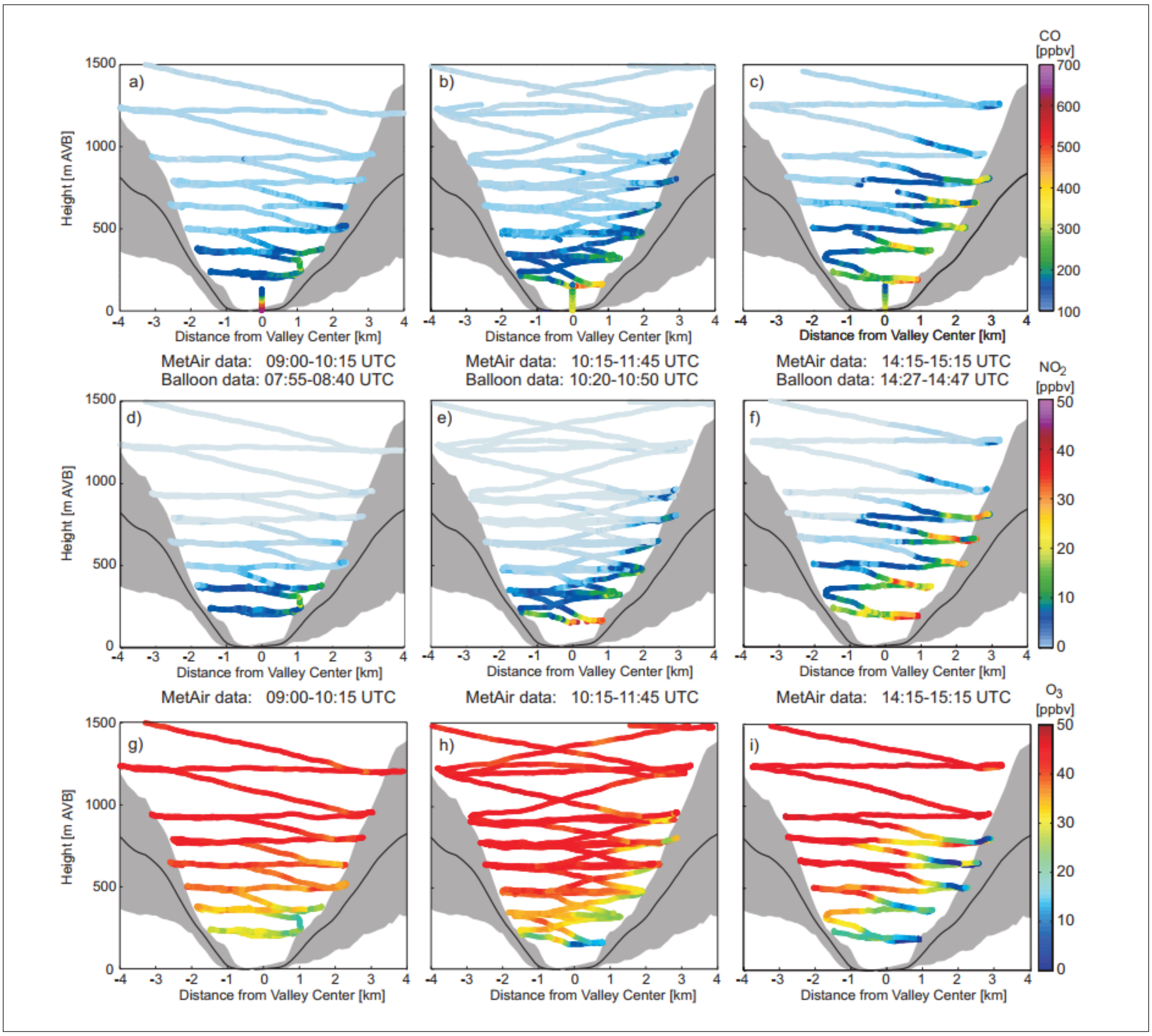

Figure 4: *Concentration trends of CO, NO_2 and O_3 in wintertime in the Inn Valley in relation to their distributions over time and space.*
The three rows report respectively the distribution of CO, NO_2 and O_3 concentrations in the Inn Valley (Tyrol, AT) on 1 February 2006, in the morning (first column), before noon (second column) and in the afternoon (third column). The view is looking at the valley towards south west. The sunny side is thus on the right-hand side (courtesy of Schnitzhofer R. et al., 2009).

ley floor due to winter atmospheric stability, while slope winds start around midday allowing vertical air exchange. As a result, pollutant concentrations on the valley floor decrease in the afternoon while pollution levels along the sunny side of the valley up to 1,300 m above the valley body increase (Schnitzhofer R. *et al.*, 2009).

In Figure 4 the concentration trends of CO, NO_2 and O_3 in wintertime are shown in relation to their distributions over time (from early morning to afternoon) and space (along a transect from valley to mountain top). The sunny side of the mountain is displayed on the right-hand side of the figures. For CO and NO_2, a progressive increase of concentration (colour scale shifting towards yellow-red, corresponding to higher values) is observed along the mountain sunny side, from early morning to afternoon. Correspondingly, on the same side (and in the valley), the O_3 concentration decreases. This is due to the formation reaction (titration) of NO_2 from freshly emitted NO and O_3, a reaction which consumes O_3 and NO to build up NO_2.

3.1.2 OZONE REGIMES

Of specific concern during the summer are photochemical pollutants, especially ozone. Generally, the processes that strongly affect variation in ozone concentration are long-distance transport by advection, vertical mixing, ozone formation triggered by UV radiation and dry deposition. A

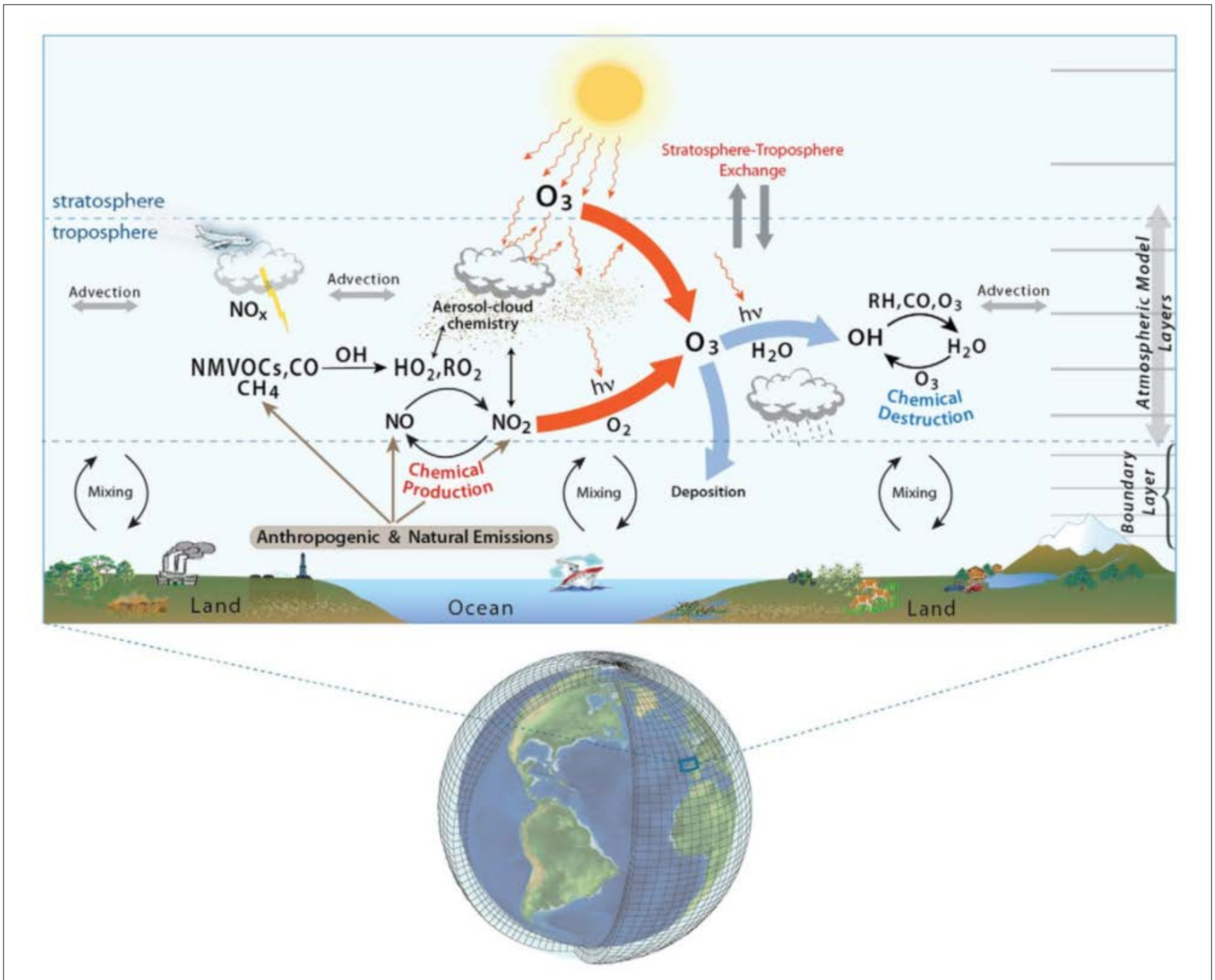

Figure 5: *Schematic of chemical and physical processes responsible for tropospheric ozone.*
Physical processes include transport by advection, convection, turbulence, and boundary layer mixing, as well as temperature, humidity, cloud cover, sun angle/latitude and time of year. Chemical processes include photochemical ozone production and destruction, aerosol-cloud interactions, wet and dry deposition and precursor emissions from anthropogenic and natural sources. Ozone precursors undergo similar physical processes to ozone itself. (Courtesy of Young P.J. et al., 2018).

general overview of the main mechanisms driving ozone production and destruction is reported in Figure 5.

Alpine background ozone concentration levels are mainly determined by mesoscale transport and ozone formation in the boundary layer from precursor emissions in central Europe – with regionally high contributions from, for instance, the Po basin and southern Germany and some areas in the east, and with a high share from the continental and hemispheric background (Wotawa G. *et al.*, 2000; Wierzbicka A. *et al.*, 2005).

On a sub-regional scale, ozone levels and their temporal pattern are triggered by the diurnal circulation pattern (valley and slope wind circulation, see Figure 4 and Section 3.1.1). The presence of anthropogenic precursor emissions, as well as biogenic volatile organic compounds (VOC) (such as terpene, isoprene, and others) in nearby valleys may also have a major impact on ozone levels. The relationships between precursor availability, temporal and spatial pattern and ozone formation/depletion chemistry have been shown to be complex and non-linear. Different studies showed that ozone production was partially affected by the presence of VOCs and NO_x (Mazzuca G.M. *et al.*, 2016 and reference therein). For example, terpene and isoprene can significantly contribute to ozone production due to the reaction with hydroxyl radical (Derognat C. *et al.*, 2003): the impact of biogenic isoprene and terpene emissions on photochemical species levels has been addressed in several studies (German Environment Agency, 2019). For instance, a study carried out in the Grenoble area showed a strong contribution (about 59%) of biogenic VOC to non-methane volatile organic compounds (NMVOC). Owing to the deciduous and pine forests in mountains surrounding the town, biogenic emissions could in fact play a role in ozone pollution, particularly during extremely dry conditions such as during heat waves (Chaxel E. and Chollet J.P., 2009). This is an important feature showing the need for a local understanding of the most important processes in order to correctly address the abatement strategies.

Peak ozone concentrations occur around noon since the formation in the plumes adds up to an already high background ozone level from intensive mixing. In the late afternoon, the valley wind weakens progressively: the atmosphere becomes stable and ozone concentrations decrease due to titration of ozone by the nitric oxide accumulated in the surface layer and due to dry deposition. Although background ozone is largely due to mesoscale phenomena, local sources of precursors can occasionally play a significant role in the observed ozone daily cycle.

Global warming may lead to more frequent future occurrences of heat waves. These events are characterised by persistent temperatures and soil dryness, with high temperatures at night and the soil canopy becoming drier and drier during the episode. Evidence of the possible effect of rising temperature on increased ozone concentrations has been derived by modelling simulations. A study simulating a 1° C temperature increase in the model found the atmosphere dynamics almost unchanged. Therefore, it was assumed that the ozone increase was due to chemistry kinetics. Authors particularly observed that high temperatures trigger radical formation, which accelerates ozone production, except in town centres where ozone titration by NO predominates (Chaxel E., Chollet J.P., 2009).

3.1.3 LONG-RANGE TRANSPORT OF AIR MASSES

Long-range transport can advect polluted air masses to the Alps, where lifting triggers the vertical distribution of pollutants along the mountain transect.

Persistent organic pollutants (POPs):

The advection of air masses through long-range transport is considered in the literature to be the main factor contributing to the quantity of POPs found at high mountain sites in air, snow, water and soil. The upper reaches of mountains may retain POPs owing to the cold temperatures found at such high altitudes (Finizio A. *et al.*, 2006). Organic pollutants in remote Alpine forest sites in Austria, Germany, Italy, Slovenia and Switzerland have been monitored within the MONARPOP project (Offenthaler I. et al., 2009; Weiss P. *et al.*, 2015). It was found that the concentrations of PAHs in spruce needles and soil were higher than the corresponding emissions in the Alpine area, indicating that the Alps are a sink for PAHs advected from surrounding areas.

In alpine systems, forests may represent an important compartment, able to intercept the movement of POPs towards higher altitudes and retaining them in the organic matter of rich forest soils (McLachlan M.S. *et al.*, 1998; Wania F. *et al.*, 2001; Meijer S.N. *et al.*, 2003). Vegetation acts as an intermediate compartment for the exchange of POPs between the atmosphere and soils (Jaward F.M. *et al.*, 2005).

Particulate matter:

The impact of long-range transport on the concentration and composition of ambient PM in European high altitude background sites was also investigated within the CARBOSOL project. In an air mass trajectory analysis, episodes with impact from emissions produced by fossil fuel and biomass burning processes from the Baltic countries, Belarus, western regions of Russia and Kazakhstan were found to contribute to elevated levels of PM components in spring and autumn (Salvador P. *et al.*, 2010).

In addition, the Alpine region is also close to the Po valley basin, where contributions of air masses enriched with secondary inorganic (ammonium sulphate and nitrate) and organic aerosol are observed (Diemoz H. *et al.*, 2019b). The phenomenology of recurrent episodes of wind-driven arrival of aerosol layers in the north-western Italian Alps was thoroughly investigated using an integrated multiple-site, multiple-sensor measurement dataset with modelling tools (Diemoz H. *et al.*, 2014; Diemoz H. *et al.*, 2019a; Diemoz H. *et al.*, 2019b) focusing on the Aosta Valley. Favourable conditions for the development of the advections occur on over 50% of days on average (based on three years of observations); particularly during the cold season, synoptic winds flow mainly from the east (Po basin) to the west. Under these conditions, the mass concentrations of PM_{10} can increase up to a daily average of 80 µg/m³. Advected particles within the accumulation mode (particles between 0.07 and 1 µm) contributed predominantly to increased mass concentrations. Chemical analyses reveal an increase in secondary inorganic fraction, composed by nitrate, sulphate and ammonium, confirming their likely origin (i.e. Po valley).

3.1.4 CLIMATE CHANGE EFFECT ON AIR QUALITY IN THE ALPS

Climate particularly influences the ecosystem but also the exchange processes with the atmosphere (emissions and deposition). Climate change will affect the distribution of air masses, mixing and vertical structure of the atmosphere, and the kinetics of its chemistry. For the moment, the information and evidence on how climate change will influence air quality, and thus also human health, are still limited. Climate change is expected to change regional-scale transportation, ventilation of Alpine valleys and the vertical mixing due to changing climate and vegetation zones on the slopes of Alpine valleys. While this will affect all atmospheric constituents, different air quality indicators are subject to more specific impacts due to climate change.

NO_x, especially NO_2, is expected to decrease in line with the reduction in anthropogenic NO_x emissions associated with changes in the traffic and energy sectors (see Section 3.2.2). Potentially changing radical chemistry with impacts on the lifetime of NO_x is considered to be less relevant (see below).

Concerning ozone, we know of two counteracting features with an as of now unclear trend. On the one hand, due to the reduction of anthropogenic NO_x emissions, we expect reduced regional and local photochemical production of ozone, which is mostly NO_x-limited. On the other hand, lower NO emissions yield lower titration losses and thus higher levels of ozone in the vicinity of emission areas. Furthermore, an increased occurrence of heat waves associated with droughts is expected to reduce the ozone deposition velocity due to higher stomatal resistance of the water-stressed vegetation (Lin M. *et al.*, 2020). Further aspects like changing radical chemistry due to UV, pollutant level, and kinetic changes, are only speculations and cannot yet be estimated reliably. Overall, it is important to monitor the ozone system with precursors and transport changes during climate change.

PM will also be affected by climate change. Rising temperatures in wintertime will reduce the PM emissions related to heating. The changing composition and distribution of vegetation on the slopes of the Alpine valleys, the rising temperatures and the longer vegetation periods will alter and may enhance biogenic VOC emissions and contribute to higher levels of secondary organic aerosol (SOA).

3.2 SOURCES

The main sources of air pollutants in the Alpine region are linked to local anthropogenic activities; dominant among them are biomass burning and road traffic (Price M.F. *et al.*, 2011).

Other local sources include agriculture, and, at a limited number of sites, industry, power plants or district heating plants. In addition, biogenic VOC emissions, like those from forest canopies, may be significant in some parts of the Alps. Moreover, atmospheric dynamics and processes, particularly long-range transport and atmospheric stability, interact critically with the sources due to the specifically Alpine topography.

Investigating the responsibility of each source of air pollution is key for developing air quality policies focused primarily on the causes of pollution.

For instance, regarding particulate matter, the contribution of biomass burning to PM_{10} in many of the Alpine sites is comparable to (or even higher than) the contributions from road traffic (Gianini M.F.D. *et al.*, 2012). This aspect is shown in Table 4, where results from source apportionment studies and projects focused on the Alpine region are reported for valley sites, showing the quantitative contributions (in percent of PM_{10} mass) of the three main sources contributing to PM mass, namely biomass burning, vehicular traffic and secondary aerosol.

Year (season(a))	Site (Country)	Valley or area	Contribution to PM_{10} (in % of PM mass)			References
			Biomass burning %	Traffic %	Secondary aerosol %(b)	
2008 (w)	Erstfeld (CH)	Erstfeld	21 - 30	15 - 30	15 - 25	Ducret-Stich R. E. *et al.*, 2013a Project funded by the Swiss Federal Office for the Environment
2008 (s)	Erstfeld (CH)	Erstfeld	8 - 15	13 - 15	35 - 40	Ducret-Stich R. E. *et al.*, 2013a Project funded by the Swiss Federal Office for the Environment
2010 (y)	Lanslebourg (FR)	Maurienne	57	31	9	Projects Lanslebourg 2010-2014 (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2010 (y)	Lescheraines (FR)	Auvergne-Rhone-Alpes	58	6	n.a.	PARTICUL'AIR (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2010 (y)	Grenoble (FR)	Auvergne-Rhone-Alpes	42	10	n.a.	FORMES (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14	Air RA (FR)	Auvergne-Rhone-Alpes	21	2	~ 20	AERA (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (w)	Chamonix (FR)	Arve	70	5	15	Favez O. *et al.*, 2017a; SOURCES Project Report
2013-14 (s)	Chamonix (FR)	Arve	10	5	35	Favez O. *et al.*, 2017a; SOURCES Project Report
2013-14 (w)	Marnaz (FR)	Arve	64 - 71	4 - 8	8 - 12	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (s)	Marnaz (FR)	Arve	< 3	8	30 - 35	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (w)	Passy (FR)	Arve	66 - 74	4 - 8	12 - 15	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (s)	Passy (FR)	Arve	< 3	5 - 10	40 - 50	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (w)	Chamonix (FR)	Arve	57 - 62	3 - 14	18 - 21	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)
2013-14 (s)	Chamonix (FR)	Arve	5 - 10	7 - 12	38 - 43	DECOMBIO (in: Favez O. *et al.*, 2017a; SOURCES Project Report)

Table 4: *Contribution of biomass burning, traffic and secondary formation of aerosols to PM_{10} concentration in some Alpine valleys. (a) Winter = w; Summer = s; Annual = y. (b) SA is reported as the sum of all inorganic and organic components available from each study.*

3.2.1 BIOMASS BURNING

Biomass has been used for centuries for cooking, heating and warm water production in the Alpine regions. Over the past two decades, the use of biomass was favoured to replace fossil fuels and to stimulate the local economy. Legal, financial and institutional incentives increased the share of biomass in the energy mix of the domestic sector as well as the energy sector (power generation and district heating). On the other hand, wood heating systems are responsible for deforestation in some regions and are a source of emission of particulate matter, black carbon, VOC and PAH (e.g. BaP). The importance of biomass burning as a source of gaseous and particulate pollutants has been shown in many studies, indicating that in the Alpine region it is the predominant source of carbonaceous aerosols during the cold season. Indeed, wood burning in domestic stoves is widespread as the principal or additional source of residential heating (Szidat S. *et al.*, 2007; Gilardoni S. *et al.*, 2011; Pietrodangelo A. *et al.*, 2014; Piot C., 2011; Herich H. *et al.*, 2014). To reduce the adverse effects of biomass burning, a legal framework has been put into place, including limit values for small scale appliances in the domestic sector, medium and large size district heating plants and power plants.

Recent nationwide statistics of the particulate emissions from wood-burning stoves show diverse figures. In Austria for instance both PM_{10} and $PM_{2.5}$ emissions declined respectively by 30% and 40% between 1990 and 2017, while emissions from the domestic sector reduced by 32-34%. In Switzerland, PM_{10} and $PM_{2.5}$ emissions from wood-burning stoves decreased by about two-thirds between 1990 and 2018 as shown in Figure 6 while energy consumption decreased by 30%. The decline was achieved by a mix of measures, including awareness raising, support schemes, technology development and legal instruments. Within Austria however, there are differences between provinces: for example, in Tyrol and Vorarlberg (two Austrian provinces in the Alpine region) the decline of emissions in the domestic sector was not as pronounced as in other Austrian provinces. Although PM emissions generally decreased during the past ten years, the relative

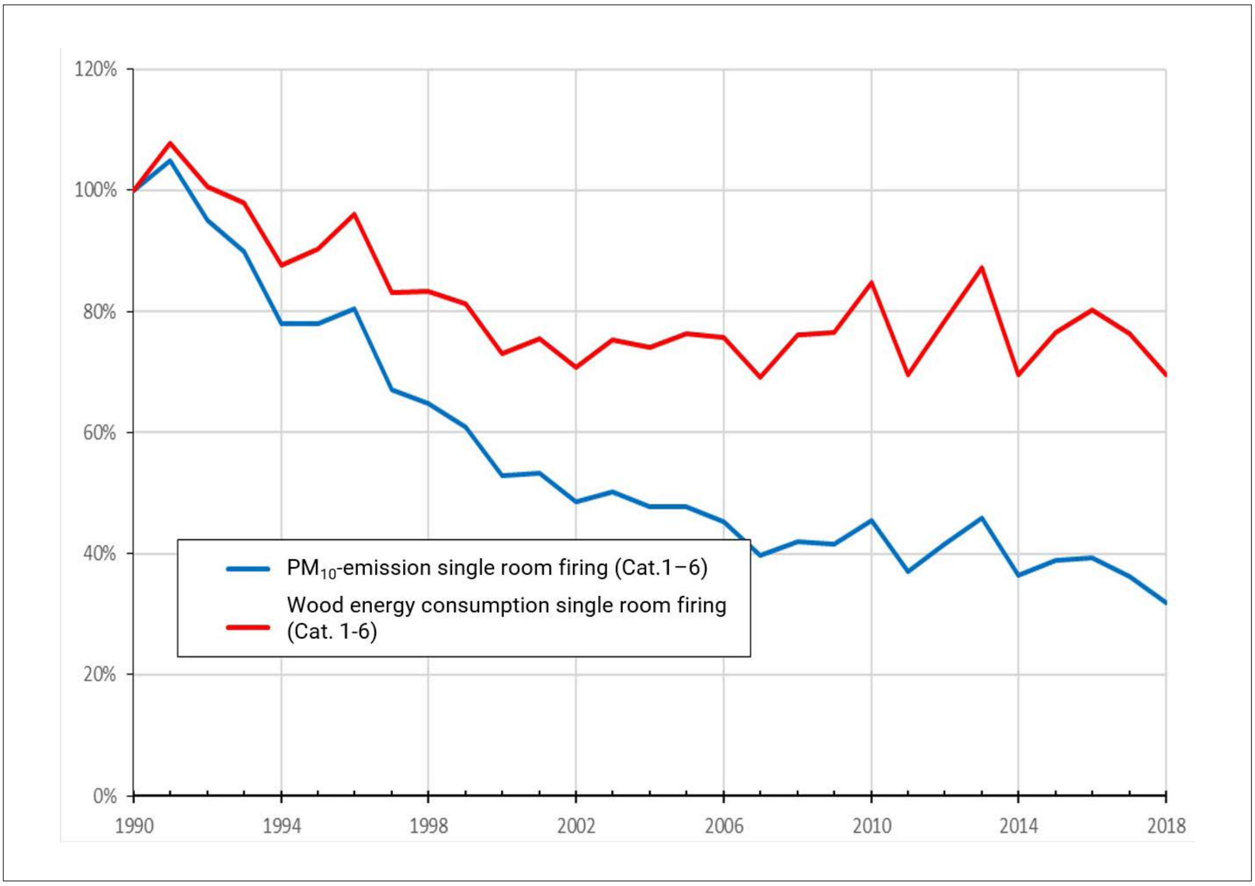

Figure 6: *Evolution of the emissions of single room fire stoves in Switzerland.*

contribution from biomass burning to total emissions in the Alpine regions needs to be further investigated.

Emissions from biomass burning are strongly enriched with organic species and metals (Zhang W. *et al.*, 2014; Pietrodangelo A. *et al.*, 2014; Hasan M. *et al.*, 2009; Wierzbicka A. *et al.*, 2005; Avakian M.D. *et al.*, 2002; Lighty, J.S. *et al.*, 2000), the first in both gaseous and particulate phases, the second mainly in the particulate phase (metals). All particulate components of biomass combustion fumes (organics, metals and, to a lesser extent, elemental carbon and mineral particles) fall within the fine ($PM_{2.5}$, PM_1) or ultrafine (UFP: smaller than 100 nm) size of airborne PM and can therefore be inhaled and reach the deepest tracts of the respiratory system. The combustion efficiency of residential stoves where biomass burning occurs is therefore critical to the goals of protecting human health.

In a study carried out in a semi-rural area in Italy, 30–70% of the PAHs in ambient air PM_{10} were identified as coming from wood combustion in autumn and winter (Van Drooge B.L. and Ballesta P.P., 2009). In the heating period, the contribution of wood combustion to PM_{10} mass can sometimes increase by more than 80% during the night. This is consistent with results from Augsburg (Bavaria, Germany) where peak concentrations of wood combustion related PAHs were found at night, highly correlated with Levoglucosan, a common tracer for wood combustion aerosols in ambient PM (Schnelle-Kreis J. *et al.*, 2010; Elsasser M. *et al.*, 2012; in Belis C.A. *et al.*, 2014). It is very difficult to attain a complete chemical speciation of organic components in emissions from biomass burning due to the large variety of families of organic compounds that can be present. Recently, Stefenelli G. et al. (2019) carried out the chemical speciation of the organic components in emissions from different wood combustion stoves[25]. Nevertheless, the contribution of the combustion of biomasses to the content of elemental carbon in airborne PM is not negligible.

In 2014, a study compared concentrations of elemental carbon, organic carbon and PM from different studies: 23 measurement sites, mostly in the Alpine region, were considered for the years 2005-2010. The highest average concentrations of elemental carbon from wood burning were observed at the sites of Cantù (IT), Chamonix (FR), Graz (AT), Ispra (IT), Lanslebourg (FR), Lescheraines (FR), Milan (IT), Passy (FR) and Sondrio (IT). Most of these sites are directly located in Alpine valleys, whereas the stations Cantù, Graz, Ispra and Milan are at the foothills of the Alps. High concentrations of elemental carbon also occurred at the sites Ebnat Kappel (CH), Grenoble (FR), Magadino (CH), Moleno (CH), Roveredo (CH), Zagorje (SI) and Zurich (CH). All sites, except Zurich, are in Alpine or pre-Alpine valleys where inversion layers could lead to high concentrations of PM (Herich H. et al., 2014).

Table 5 summarises emission factors for selected fuel technologies used for the Austrian national inventory of air emissions. Use of gas oil, LPG or gas in modern technologies results in medium emissions of NO_x, very low emissions of $PM_{2.5}$, SO_2 and NMVOC and no emissions of BaP. Coal burning is accompanied by high releases of all pollutants. Emissions from wood burning technologies strongly depend on the technology and biomass used: the lowest emissions are achieved by modern pellet boilers. However, technologies are on the market for burning mixed-fuel wood and wood chips, which show lower emissions compared with older systems. It should be noted for example, that by installing small electrostatic precipitators, emissions of $PM_{2.5}$ could be further reduced. However, it must also be taken into account that such end-of-pipe technologies determine increased costs for investment and operation.

Switzerland, Austria and Germany have already introduced legislation to minimise pollutant emissions of biomass combustion and there are existing strong regulations for wood firing systems depending on their size. The limit values summarised on Table 6 should help reduce the PM emissions in the affected areas.

Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establish-

25. *Fumes typically include a complex mixture of low-volatile non-methane organic gases (see section 3.3.3.2), brown carbon (primary organic aerosol [POA]) and black carbon. Main families of organic compounds identified in the POA are furans, single-ring aromatic hydrocarbons (SAHs), polycyclic aromatic hydrocarbons (PAHs), humic-like substances (HULIS) and oxygenated aromatic species. Furans are emitted through cellulose pyrolysis, SAHs and PAHs are generated from incomplete combustion (especially from flaming wood), and oxygenated aromatics are mainly emitted through lignin pyrolysis. The remaining part of fumes is rich in oxygenated organic gases, which act as precursors in the atmospheric formation of secondary organic aerosol (SOA), as described in section 3.2.3 HULIS are a major component of brown carbon, and play a key role in the atmospheric processes (e.g. acting as cloud condensation nuclei, ice nuclei, aiding hygroscopic growth, etc.) in the radiative exchanges (high absorption of U.V. light) and in the health effects of ambient PM, due to cellular oxidative stress action (Fang T. et al., 2019; Tuet W. et al., 2019).*

ing a framework for the setting of ecodesign requirements for energy-related products entered into force on 1 January 2020 for biomass combustion systems (such as pellet heating systems). EU Regulation 2015/1185 requires that it will apply to smaller wood heating systems known as "solid fuel local space heaters" from 1 January 2022. Through this Directive, the minimum requirements in the EU Member States are strictly standardised. However, the results will depend on the different control and inspection regimes. It makes a big difference whether measurements are performed on-site or on the test bench and who performs the measurement (i.e. self-declaration by the manufacturer or competent, independent laboratory). Implementing the ecodesign Directive needs to be accompanied by effective market control regimes otherwise it will allow cheaper and more polluting stoves to enter the market.

3.2.2 ROAD TRANSPORT

Road transport is an important source of gaseous (NO_2, VOCs) and particulate pollutants. PM from vehicle emissions is principally composed of elemental carbon and PAHs, and, according to the WHO[26], diesel exhaust is proven to be carcinogenic. In addition, the road circulation of vehicles contributes to the PM_{10} mass by fine and coarse dust released by abrasion of brakes and tyres and by resuspension of road dust.

The impacts and emissions from motor vehicle traffic not only affect the main transit routes and urban roads in the valleys, but also the peripheral routes connecting small villages and many off-road routes reaching semi-natural mountain areas at high altitudes. Figure 34 (Chapter 7) shows the location of the main transport routes through the Alps. Besides the permanent settlements of people

Fuel technology	$PM_{2.5}$	NO_x	NMVOC	BaP	SO_2
	kg/TJ	kg/TJ	kg/TJ	g/TJ	kg/TJ
Gas oil: Blue burners with low temperature or condensing technology	1.2	33.1	0.17	0.0	0.5
Forced-draft natural gas burners	0.2	36.6	0.20	0.0	0.3
LPG stoves	1.8	51.0	2.00	0.0	6.0
Coal stoves	122.4	132.0	333.30	33.4	543.0
Wood stoves and cooking stoves	118.4	106.0	583.59	121.0	11.0
Mixed-fuel wood boilers	113.8	122.1	422.99	29.8	11.0
Forced-draft wood boilers	40.0	80.0	325.00	0.2	11.0
Wood chip boilers with conventional technology	80.0	107.0	432.40	8.4	11.0
Wood chip boilers with oxygen sensor emission control	44.0	80.0	78.00	0.6	11.0
Pellet stoves	24.0	60.0	39.00	10.0	11.0
Pellet boilers	15.2	60.0	32.50	0.6	11.0

Table 5: *Emission factors for selected fuel technologies used for the Austrian national inventory on air emissions (per terajoule of energy produced). Note: distinction between fuel technologies varies across countries, so a direct comparison of national sets of emission factors may lead to misinterpretations.*

26. WHO-IARC 2012: Diesel engine exhaust carcinogenic (https://www.iarc.fr/wp-content/uploads/2018/07/pr213_E.pdf).

Country	Solid fuel space heater	Limit values at 13% Oxygen	
		CO [mg/m³]	PM
European Union Regulation (EU) 2015/1185 Beginning 01.01.2022	Open fronted	2,000	50
	Closed fronted	1,500	40
	Closed fronted using pellets	300	20
	Cookers[(a)]	1,500	40
Austria[(b)]	Open fronted	640	120
	Closed fronted	640	120
	Closed fronted using pellets	640	120
	Cookers		
France Voluntary Requirements of the label *Flammeverte* - new appliances since 01.01.2020	Open fronted	1,250	
	Closed fronted	1,500	40
	Closed fronted using pellets	250	30
	Cookers	1,500	40
Germany BimSchV Stufe 2 - new appliances since 01.01.2015	Open fronted	1,250	40
	Closed fronted	1,250	40
	Closed fronted using pellets	250	20/30
	Cookers	1,500	40
Italy[(c)] DM 7 November 2017, n. 186 Already in place, contains requirements to be applied on a voluntary basis	Open fronted	1,500 - 1,250 - 650	40 - 30 - 25
	Closed fronted	1,500 - 1,250 - 650	40 - 30 - 25
	Closed fronted using pellets	364 - 250 - 250	40 - 30 - 15
	Cookers	1,500 - 1,250 - 650	40 - 30 - 25
Liechtenstein	Open fronted	1,500	75
	Closed fronted	1,500	75
	Closed fronted using pellets	500	40
	Cookers	3,000	90
Monaco	Open fronted	Not applicable	Not applicable
	Closed fronted	Not applicable	Not applicable
	Closed fronted using pellets	Not applicable	Not applicable
	Cookers	Not applicable	Not applicable
Slovenia	Open fronted	1,250	40
	Closed fronted	1,250	40
	Closed fronted using pellets	400	30 - 20[(d)]
	Cookers	1,500	40
Switzerland[(e)]	Open fronted	1,500	75
	Closed fronted	1,500	75
	Closed fronted using pellets	500	40
	Cookers	3,000	90

Table 6: *Comparison of the existing emission values of wood heating systems with the future requirements of the Energy related Products Directive (ErP) 2009/125/EC in conjunction with regulation (EU) 2015/1185.*

(a) 'cooker' means a solid fuel local space heater, using solid fuels, that integrates in one enclosure the function of a solid fuel local space heater, and a hob, an oven or both to be used for preparation of food and which is sealed to a chimney or fireplace opening or requires a flue duct for the evacuation of products of combustion; (b) the Austrian Emission Limit Values refer to the initial measurement; for type approval, stricter emission limit values apply; (c) Data for Italy regulated by a label system with separate values for 3-star, 4-star and 5-star labels; (d) First value for direct heat, second for heat to fluid; (e) For Switzerland, the Ordinance on Air Pollution Control; Annex 4 Number 212 applies. From 1.1.2022, the requirements of EU Regulation 2015/1185 for the placing on the market of such installations will also apply (see Annex 1.19 EnEV).

living there, many tourists reach these locations along off-road mountain tracks by private car (Alpine Convention, 2007) during both winter and summer months, e.g. for skiing and for trekking activities (e.g. Blasco M. *et al.*, 2006, 2008; Nascimbene J. *et al.*, 2014). Measurements taken by mobile stations in and near villages and valley roads identify traffic as the dominant source of ultrafine particles by number, especially those smaller than 50 nm, while biomass burning is the main source of the mass of UFP (Weimer S. *et al.*, 2009).

Studies in the literature reveal that, while wood burning is of comparable importance in many Alpine valleys, motor vehicle emissions become substantial only in locations with very high traffic flows (Szidat S. *et al.*, 2007; Gianini M.F.D. *et al.*, 2012; Zotter P. *et al.*, 2014). The most common form of passenger transport in these areas is the private car: this is a concern in the Alpine region since it is expected to increase in the near future (Alpine Convention, 2007). In addition, the trans-Alpine freight traffic along the Alpine valleys has a significant impact on air quality since it adds to the regional and local inner-Alpine transport of goods (Heimann D. *et al.*, 2007). Alpine sites in the valleys are indeed increasingly influenced by traffic exhausts (Ducret-Stich R.E. *et al.*, 2013a; Ducret-Stich R.E. *et al.*, 2013b). Many studies show the substantial increase of concentrations of traffic-related air pollutants such as NO_2, elemental carbon and particles in the ambient air next to motorways or main roads in villages. People living near roads show statistically significant increases in respiratory symptoms very much associated with exposure to pollutants (Ducret-Stich R.E. *et al.*, 2013b; Hazenkamp-von Arx M.E. *et al.*, 2011).

The complex topography of the Alps means that the transport infrastructure is limited to only a small number of corridors along valleys and across passes where traffic emissions are concentrated. Considering that many villages and towns in the Alps are also clustered along the valleys, especially those with major motorways and railway lines (Heimann D. *et al.*, 2007), the impact of road traffic is likely to affect a large part of the Alpine population.

Electrification of vehicles by sectors (city logistics), ongoing hybridisation and a diversification of different technologies/alternative fuels/propulsion systems are processes already taking place. Overhead power lines for the sector of electric heavy goods vehicles (HGV) along flat sections could be installed. Diesel trucks will still have a mid-term future by optimising engines and exhaust filter cleaning systems (see Chapter 7.3.4). Therefore, improvements of air quality in Alpine valleys can be expected, particularly if the transport of trucks by rail can be further increased.

3.2.3 TRANSBOUNDARY POLLUTION

Some studies available in the literature deal with the impact of the coal industry outside Europe. Only one publication reports results dealing with Europe (Valverde V. *et al.*, 2016). Coal combustion can be a source of SO_2, NO_2, PM and heavy metals (mercury, lead, arsenic and cadmium) and of course carbon dioxide (Global energy monitor, 2019). These emissions might be transported over a long range.

Many European countries have announced their willingness to ban coal from their energy production sources. This corresponds to 48% of the EU carbon budget. As of 2020, among the Alpine Convention members, Austria, Liechtenstein, Monaco and Switzerland have no coal power plants in 2020; France announced a ban by 2022; Germany will phase-out its coal plants at the latest by 2038, and Italy intends to phase-out coal by 2025. Slovenia operates the new 600 MWe 6th unit of the Šoštanj coal power plant, built in 2016 and foreseen to operate until 2054.

After a careful review of the scientific literature, none of the currently published air pollution and source apportionment studies focusing on areas of the Alpine region report contributions by coal power plants to the measured air pollution. According to the scientific literature, therefore, these facilities have a negligible or no impact at all on air quality in the Alpine region.

Although no specific cause for concern emerges from this analysis, pollution conveyed over long distances is an important topic which is addressed by the Alpine Convention on long-range transport of atmospheric pollution. The use of observations, emissions surveys and modelling like those run by the Virtual Alpine Observatory presented in Chapter 6.4 is important to understand the mechanisms that might trigger transportation of pollutants and provide an early warning to policymakers and the public on air quality issues.

3.2.4 SOURCES OF PRECURSOR SPECIES FORMING SECONDARY AEROSOL

Precursors of SA are gaseous species (e.g. ammonia (NH_3), SO_2, NO_x, VOCs) that undergo chemical reactions and gas-to-particle conversion, forming particulates directly in the atmosphere. Biomass burning and road traffic (Sections 3.2.1 and 3.2.2) are among the main sources emitting SA precursors. Other key sources of precursors in the Alpine region include agriculture and forest canopies. In addition to emission sources, the critical factor driving SA formation is atmospheric stability (Section 3.1.1): it aids chemical reactions to continue forming particles and to increase concentrations in the ambient air (Hao L. *et al.*, 2018).

The chemical composition of SA reflects the season-related predominance of different sources of precursors and the different physical and weather conditions favouring their formation reactions in the atmosphere. SA is a major component of airborne PM in the Alpine region, in both winter and summer periods, due to two main factors: increased emissions from primary anthropogenic sources (mainly traffic and domestic heating) during wintertime, and increased emissions from biogenic sources (forest canopies) during the summer. Both inorganic and organic species make up the SA composition.

Atmospheric formation of inorganic SA (mainly ammonium, nitrate, sulphate) is due to anthropogenic sources emitting NH_3 (agriculture), NO_x and SO_2 (traffic, domestic heating, biomass burning) as precursors. At the same time, atmospheric formation of organic SA (a mixture of many different families of organic species) is due to both anthropogenic (mainly biomass burning, traffic) and biogenic (forest canopies) sources emitting VOCs as precursors (Rouvière A. *et al.*, 2006; Srivastava D. et al., 2019; Stefenelli G. *et al.*, 2019).

3.2.4.1 Inorganic Secondary Aerosol

Inorganic SAs are mostly composed of ammonium nitrate during winter and of ammonium sulphate in the summer, depending on the chemical equilibria among these species (Squizzato *et al.*, 2013). Typical contributions of inorganic SAs in the total PM_{10} mass in valley sites of the Alps region range between 5-15%, as observed in Aosta (Diemoz H. *et al.*, 2019a), Chamonix and Grenoble (Weber S. *et al.*, 2019), Lanslebourg (Besombes J.L. *et al.*, 2014) and other valleys, but in some cases contributions of up to 30% are observed (Favez O. *et al.*, 2017a). The weight of inorganic SA to PM mass strongly depends on concentrations of ammonium (and its precursor, ammonia). Ammonium air concentrations in Alpine valleys range roughly between 0.1-0.5 µg/m^3: within this range, the highest values are observed during autumn and winter (Favez O. *et al.*, 2017a; Diemoz H. *et al.*, 2019a). Similar values for ammonia are also found in the air of Alpine sites. Thimonier A. *et al.* (2019) compared measurements of ammonia in the ambient air in Switzerland for the years 2000 and 2014 at different Alpine pasture sites and in two open fields with intensive agriculture: Lausanne and Vordemwald. Concentrations were below 1 µg/m^3 at Alpine pasture sites, and between 2-4 µg/m^3 at intensive agriculture sites, with no meaningful differences from 2000 to 2014. Since ammonium (and its precursor, ammonia) primarily derives from agricultural activities, these values reflect a generally low impact of agriculture on air quality in the Alpine region, as previously reported (Lighty J.S. *et al.*, 2000; Price M.F. *et al.*, 2011).

Ammonium concentrations in areas strongly impacted by agricultural activities, such as the Po Valley, are far higher: between 5–30 µg/m^3 and averaging 5-15 µg/m^3 (e.g. Larsen B.R. *et al.*, 2012); similar ranges were also reported for ammonia in ambient air at farming settlements in Austria and Bavaria (Löflund M. *et al.*, 2002). However, the same authors found a rapid decrease of ammonia concentrations within a radius of 500 m from the settlements, suggesting that a rapid removal and dilution of ammonia occurs, and that the NH_3 burden therefore remains only localised.

3.2.4.2 Secondary Organic Aerosol

During the winter in the Alpine region, organic species of SA are formed from the emissions of biomass burning and traffic VOCs, whereas in the summer, organic species of SA are formed from forest canopies which emit large amounts of VOCs due to the higher ambient temperature. In general, once emitted, VOCs undergo oxidation reactions with atmospheric oxidants such as hydroxyl radicals (OH), ozone (O_3) and nitrate radicals (NO_3-) to form secondary particulates.

Rouvière A. *et al.* (2006) analysed the fumes from pine wood combustion in the Chamonix valley, where most of the vegetation is composed of coniferous trees. Analytical results indicate the presence of aromatics (benzene, toluene, xylenes), alkanes (heptane, octane, nonane) and terpenes (isoprene, limonene, α-pinene). As mentioned, the composition of SOA is very complex, and a comprehensive detection of all organic families in the SA is hard to obtain. Nevertheless, Squizzato et al. (2013) were recently able to distinguish different source contributions to SOA and to identify the differences in chemical composition and quantity at a rural background site in the Paris region. Of these contributions, at least two originated from biomass burning emissions, and another was linked to traffic, altogether representing about 15% of the total SOA; the latter is found to represent about 75% of total organic aerosol.

The role of biogenic emissions on SOA formation in Switzerland and Italy in 2003 was investigated by Andreani-Aksoyoglu S. *et al.* (2008). Model simulations suggested that the contribution of biogenic SOA (formed from the precursors emitted by trees) to total SOA was rather high, about 80% in northern Switzerland. In this area, the biogenic contribution comes from the Norway spruce forests, due to their abundance and to high monoterpene emissions. Meanwhile, the contribution to SOA from biogenic emissions was found to be substantially lower in southern Switzerland (about 40%) where monoterpene emissions are lower, and in the polluted area in northern Italy (Milan: 15–25%) where anthropogenic sources contribute much more to SOA formation than vegetation. Similarly, SOA of biogenic origin was found in the range of 10-30% of total PM_{10} mass at Marnaz, Chamonix and Passy by the DECOMBIO Project (Favez O. *et al.*, 2017a).

It is worth noting that only recently have source apportionment studies demonstrated that the contribution of organic species to total SA composition is generally comparable to that of inorganic species (Favez O. *et al.*, 2017a; Srivastava D. *et al.*, 2019). However, while sources and atmospheric reactions forming inorganic secondary particulate species are widely acknowledged, which supports decisions on abatement measures to be undertaken to prevent high pollution episodes, the same aspects are still largely unknown for the formation of organic secondary particulate species. In particular, knowledge should be increased concerning both the chemical profiles of VOCs sources (namely: which VOCs species are mainly emitted by which sources), and the atmospheric reactions forming secondary species from VOCs (especially during night-time chemistry, e.g. with nitrate radical).

One important result of the SOURCES project for air quality policies is that it enables sources of pollution to be allocated to the global PM_{10} concentrations in ambient air so that pollution can be reduced at its origin. As an example, Figure 7 clearly shows the importance of biomass burning in French Alpine valleys. Although this study does not show a great contribution of nitrate and sulphate rich particles linked with intensive agriculture, this does seem to be important in other regions and needs to be carefully checked in the Alpine areas of intensive agriculture.

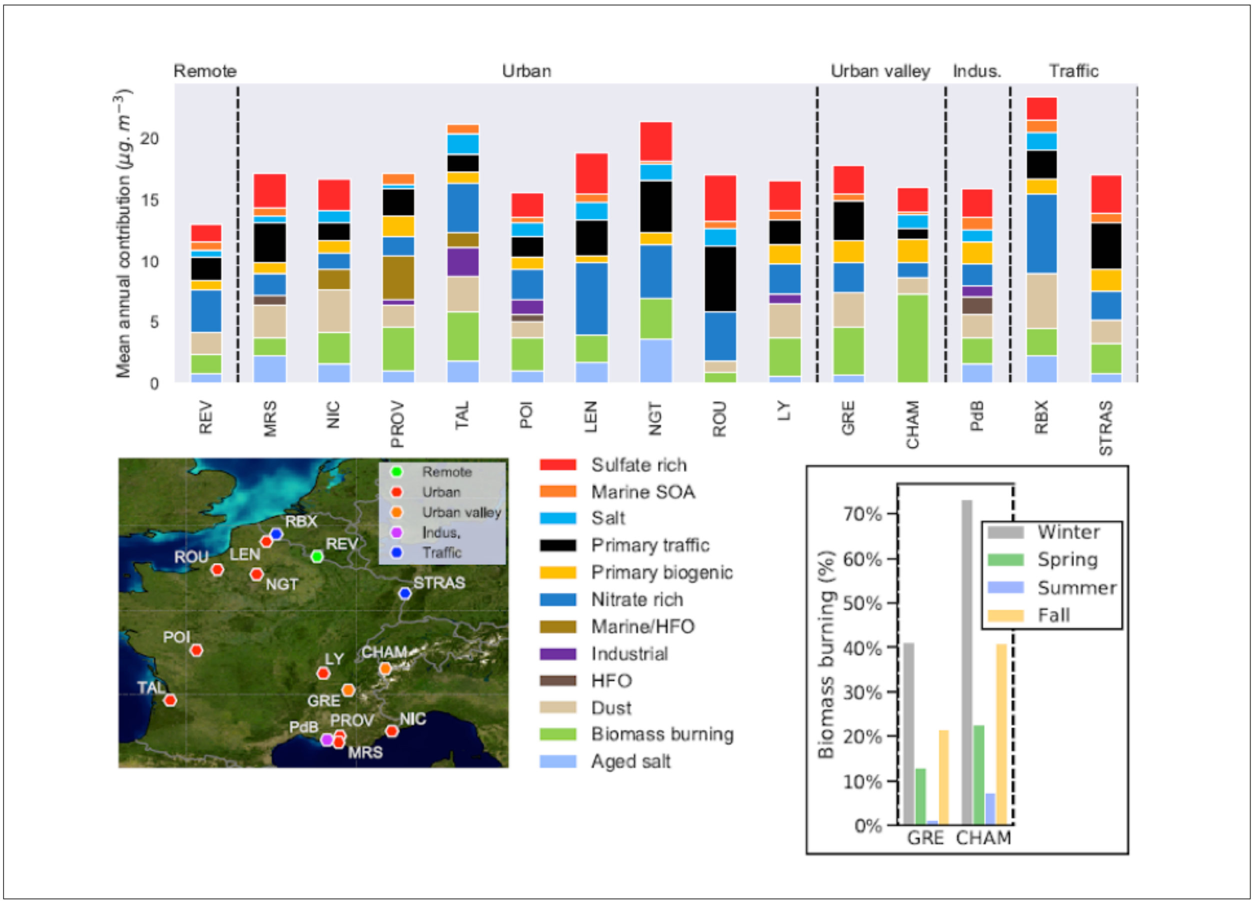

Figure 7: *Results from the "SOURCES" project showing the contributions from PM_{10} sources in different locations in France. The graph on the top shows the significant contribution of biomass burning in the two Alpine locations Grenoble (GRE) and Chamonix (CHAM) compared to other locations (the other acronyms of city names can be found in the reference). HFO means Heavy fuel oil, Sulphate rich means containing SO_4^{2-}, Nitrate rich means containing NO_3-, dust is a mix of terrigenous aerosols and mineral particles linked to human activities (e.g., building works, resuspension due to road transport, etc.). The lower right graph shows the seasonal variations in the biomass burning source in Grenoble and Chamonix revealing the impact of biomass burning in winter (Weber S. et al., 2019).*

4. EFFECTS OF AIR POLLUTION

The most important air pollutants with respect to health effects are particulate matter ($PM_{2.5}$, PM_{10}), NO_2, and ozone. Other pollutants of concern are black carbon, PAHs and other families of organic compounds (furans, HULIS, oxygenated aromatics) and heavy metals as part of PM. Scientific evidence for various adverse health effects is based on epidemiology, toxicology, and controlled human exposure studies. In order to assess the burden of adverse health effects linked to air pollution, the WHO developed Air Quality Guidelines based on expert evaluation of the scientific literature (see Table 3).

4.1 AIR POLLUTION EFFECTS ON HUMAN HEALTH: MORTALITY

Mortality due to air pollution is assessed by epidemiological studies. The estimates provided by such calculations can vary widely between different studies depending, *inter alia*, on the methods chosen for exposure assessment, on the mathematical functions used which relate the level of exposure to air pollution to the effect on mortality while taking different factors into account, and on the level of exposure at which the minimum risk was observed (baseline scenario).

The estimates of reduced life expectancy due to air pollution range from several weeks to a few years, depending on the methodology of the study and on the region considered. Worldwide estimates average the mortality effect of air pollution over all regions (e.g. rural areas, polluted cities), so their explanatory power is limited.

Worldwide, air pollution is estimated by the Health Effects Institute to reduce life expectancy by 20 months for children born today (Health Effects Institute, 2019). In Europe, air pollution is the largest environmental health risk (EEA, 2019). The European Environment Agency (EEA) estimated for 2016 the number of years of life lost (YLL) attributable to $PM_{2.5}$, NO_2 and O_3 exposure. Information about years of life lost for 41 European countries is summarised in the EEA's 2019 Air quality report. These calculations are based on annual population weighted mean concentrations of 14.4 µg/m³ for $PM_{2.5}$ and 16.3 µg/m³ for NO_2. In the case of ozone, the SOMO35 (sum of means over 35 ppb[27] [daily maximum 8-hour]) with 3,811 µg/m³ per day was used. In total, for Europe, 4.22 million YLL are attributable to $PM_{2.5}$, 707,000 to NO_2, and 160,000 to ozone. The averages of YLL per 100,000 inhabitants in all Europe are 900, 100, and 30 respectively for $PM_{2.5}$, NO_2, and ozone. Some newer publications estimate figures twice as high (Lelieveld J. et al., 2020).

4.2 AIR POLLUTION EFFECTS ON HUMAN HEALTH: MORBIDITY

Although mortality due to air pollution is important, morbidity – which indicates the set of diseases caused or exacerbated by air pollution – plays a crucial role in decreasing the quality of life of people, sometimes from childhood onwards.

The adverse health effects of air pollution are the consequences of different pathophysiological mechanisms. Firstly, there is the direct toxicity of pollutants to cells and genetic material. They also have indirect effects via inflammatory processes, oxidative stress and weakening of the body's defence mechanisms. All these processes act on the cardiovascular and respiratory systems and other organs, leading to reduced heart rate variability,

27. *Parts per billion.*

increased blood pressure and coagulability, progression of atherosclerosis, reduced respiratory capacity, increased bronchial reactivity, in some cases abnormal cell growth, reproductive disorders, child development disorders, neurological and metabolic disorders. These adverse effects depend on the type of exposure, the deepness of the penetration of pollutants into the lungs and on the oxidising and irritant nature of the pollutants[28].

The clearest evidence of the effects of air pollutants on health are in the respiratory system due to the direct contact of the pollutant with the human body through inhalation. Thereafter, systemic inflammation and oxidative stress caused by lung inflammation could induce further adverse health effects such as cardiovascular diseases and cancer. The only health effects described in the following sections are those for which a causal or likely to be causal relationship was concluded by the United States Environmental Protection Agency (U.S. EPA).

Ozone, nitrogen dioxide and sulphur dioxide are irritant gases with oxidation capacity and have adverse health effects, increasing the risks of lung diseases, asthma and bronchitis. Across the different size fractions of PM, the most substantial scientific evidence for adverse health effects is for $PM_{2.5}$. Generally, for most health effects and exposure to PM_{10}, $PM_{2.5}$ and ultrafine particles, there are several limitations and uncertainties across scientific disciplines complicating the interpretation of evidence (U.S. EPA, 2019). Nevertheless, recent research studies evidence the role of organic species of POA and SOA (see sections 3.2.1 and 3.2.4.2) in the PM in generating endogenous reactive oxygen or nitrogen species that are directly responsible for cellular oxidative stress in lung tissues. It is also generally observed that the endogenous generation of reactive oxygen or nitrogen species in cells is mediated by heavy metals included in the PM (Fang *et al.*, 2019; Tuet *et al.*, 2019).

There is a likely causal relationship between respiratory effects and short-term (daily mean) $PM_{2.5}$ exposure, including exacerbation of asthma, worsening of chronic obstructive pulmonary disease, and combined respiratory-related diseases. Evidence from epidemiologic studies indicates associations between long-term (annual mean) $PM_{2.5}$ exposure and asthma development in children, asthma prevalence in children, childhood wheeze, and pulmonary inflammation (U.S. EPA, 2019).

For cardiovascular effects, the U.S. EPA concludes a causal relationship between short-term $PM_{2.5}$ exposure and cardiovascular-related emergency department visits and hospital admission, particularly for ischemic heart disease and heart failure. Long-term $PM_{2.5}$ exposure can be the cause of a variety of cardiovascular diseases (causal relationship), including atherosclerotic plaque progression, decreased cardiac contractility and output, and changes in blood pressure.

There is also a likely causal relationship between long-term $PM_{2.5}$ exposure and a range of nervous system effects including neuroinflammation and oxidative stress, neurodegeneration, cognitive effects (cognitive function decrements, dementia), and effects on neurodevelopment. Both experimental and epidemiologic evidence are well substantiated and coherent, supporting a pathway involving neuroinflammation in specific regions of the brain (U.S. EPA, 2019).

Regarding cancer, there is a likely causal relationship with long-term $PM_{2.5}$ exposure. Recent experimental and epidemiologic evidence indicates genotoxicity, epigenetic effects, and carcinogenic potential of $PM_{2.5}$ exposure, along with strong epidemiologic evidence for increases in the risk of lung cancer incidence, particularly in never-smokers (U.S. EPA, 2019). In 2013, the International Agency for Research on Cancer (IARC), a specialised agency of the WHO, classified ambient air pollution as carcinogenic to humans (WHO Europe, 2013b) since there is sufficient evidence that exposure to air pollution causes lung cancer. PM_{10} and $PM_{2.5}$ were evaluated separately by IARC and also classified as carcinogenic.

Scientists have recently been discussing the impact of air pollution on the spread and fatality of COVID-19. Two ways of impact are discussed: the spread of the virus through fine particles and a higher mortality due to former impairment of the lungs of people living in highly polluted areas. Whereas the first hypothesis is widely rejected, the second is still unclear and has to be further investigated; many research projects throughout the world are in fact currently addressing this issue.

28. Agence Santé publique France, Sylvia Medina, June 2019, presentation to the RSA8 Working group.

4.3 AIR POLLUTION EFFECTS ON HUMAN HEALTH IN THE ALPINE REGION

The relationship of traffic air pollution, perception of exhaust fumes and behavioural impact or symptoms of illnesses was investigated in 1995 in two surveys with 1,989 adults and 796 children in 13 small Alpine communities in Tyrol (AT) by means of questionnaire responses and air pollution measurements. Among the symptoms, feelings of fatigue/exhaustion/low mood/nervousness and irritation of the eyes and stomach aches showed a significant association with the rated air quality. Children in the traffic-exposed areas spend less time outdoors and the reported perception of car fumes was significantly associated with recurrent colds, chronic bronchitis and an index of hyperreactive airways (Lercher P. *et al.*, 1995).

A cross-sectional study with 1,839 adults from 10 communities along the Swiss Alpine motorway corridors was performed in 2005 to investigate the impact of traffic exhausts on respiratory symptoms. Associations were found between living close to a motorway and wheezing without a cold and chronic cough. The symptoms reached background levels in populations living 400 to 500 m away from the motorway (Hazenkamp-von Arx M.E. *et al.*, 2011).

In a comprehensive three-year project (2005-2007), the ALPNAP consortium collected and described up-to-date science-based methods to observe and predict air and noise pollution along trans-Alpine transport corridors and to assess the related effects on health and well-being. Combining data of population with an air dispersion model, maps of the distribution of exposed populations were obtained. The use of exposure-response functions subsequently allowed the health effects to be quantified and their distribution on the territory examined (Heimann D. *et al.*, 2007).

A study on air pollution, mortality and life expectancy in the Arve valley in the French Alps

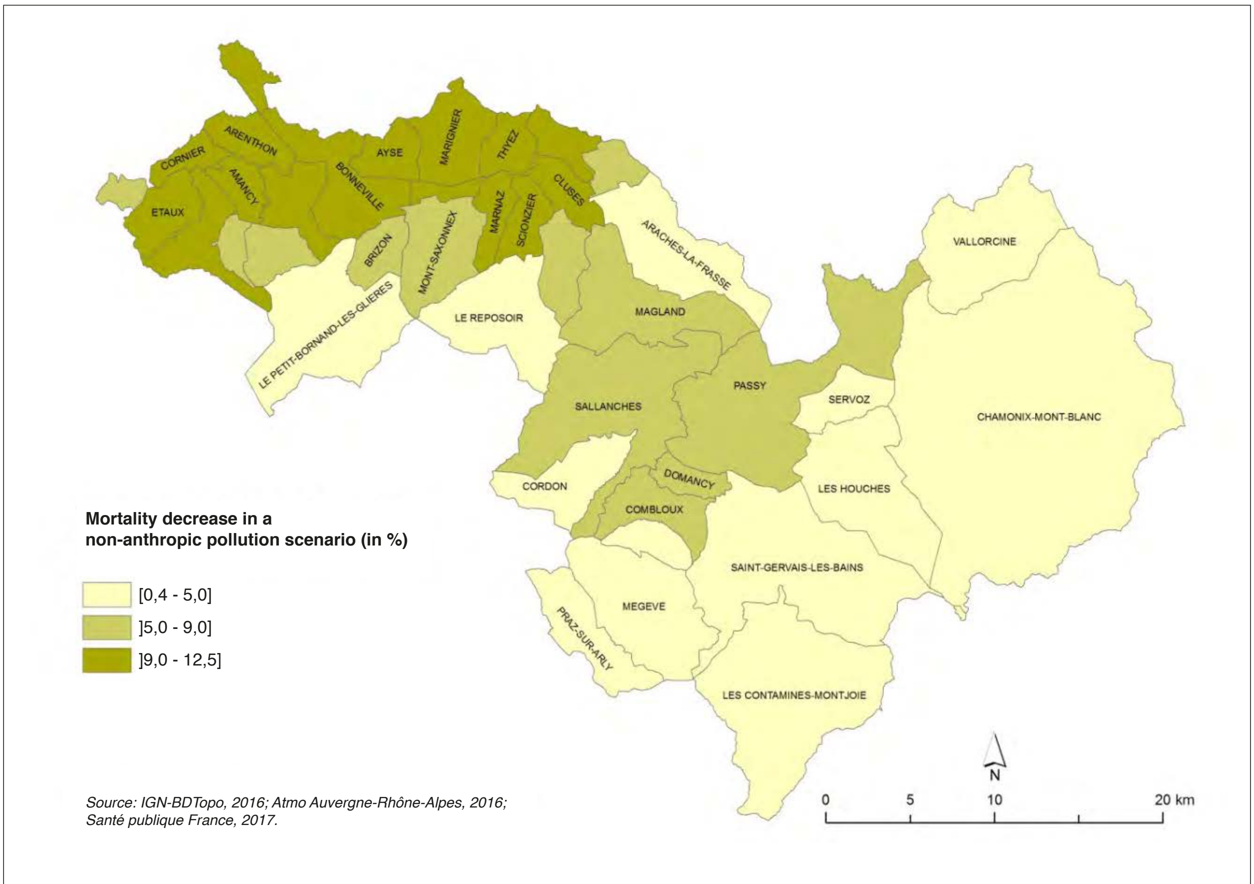

Figure 8: *Map of expected mortality decrease in a non-anthropic pollution scenario in the different communes of the Arve valley (Pascal M. et al., 2017).*

was performed in 2017 by Santé publique France (Pascal M. *et al.*, 2017). This valley has unfavourable topographical and climatic conditions, with marked seasonal variations and frequent air pollution peaks in winter. The study focused on $PM_{2.5}$ as a tracer of pollution for which enough evidence is available to assess mortality risk; $PM_{2.5}$ pollution is widespread in the Alps as shown in Chapter 5.2. It modelled sequentially: meteorology of the valley, emissions from transport, industry and domestic activities, dispersion and chemical transformation of pollutants, and finally average exposure of people to particles at the community scale. Data on non-accidental mortality of people over 30 was collected in the same area. A classical log-linear model (see Chapter 4.1 above) linking mortality to exposure to $PM_{2.5}$ could be established. It was therefore possible to infer the decrease of mortality as a function of the decrease of $PM_{2.5}$. Policy-makers now have the possibility to use the model to test several policy options that can anticipate their benefits in terms of mortality or life expectancy (Figure 8).

The study concluded that $PM_{2.5}$ air pollution in the valley has an impact of the same magnitude as in other medium-sized city areas in France, representing 8% of total mortality. This impact is very significant albeit lower than the one observed in the most polluted large cities in France (13%). Should $PM_{2.5}$ concentrations be reduced by 30%, the increase in average life expectancy would reach five months. A new collaborating project between local Swiss and French partners has just started in the Grand Genevois region to evaluate the health effects and costs of air pollution.

4.4 AIR POLLUTION EFFECTS ON ECOSYSTEMS

Air pollution also has serious impacts on ecosystems and biodiversity. The concept of critical load[29] is used to assess the exposure of terrestrial and aquatic ecosystems to the deposition of air pollutants above the threshold of deleterious effect (Nilsson J. *et al.*, 1988).

SO_2 seems to no longer be a problem in Europe: by 2010, sulphur deposition was 90% less than it had been in 1980 and was below its critical load. However, ozone, NH_3 and nitrogen oxides (NO_x) have the most damaging effects on fauna, plants, water and soil, while toxic metals (such as arsenic, cadmium, lead, nickel and mercury) and POPs present significant risks as they can remain in the environment and some can accumulate through the food chain (EEA, 2019).

The atmospheric deposition of nitrogen combines with the nitrogen leaching from soils and causes eutrophication of rivers and lakes, thus impairing biodiversity. Paerl H.W. (2003) showed that atmospheric deposition of nitrogen can reach 60% of the total addition of nitrogen in the sea. Ozone, as a powerful oxidant, interacts with plant cells to reduce growth and disturb reproduction, thereby damaging forests, crops and grasslands.

NO_x acidifies soils, lakes and rivers. Ammonia and nitrogen oxides affect ecosystems via eutrophication (an excessive accumulation of nitrogen nutrients) and acidification via transformation in the air into nitrous acid that falls back to the soil with precipitation. The impact on biodiversity is important. Nitrogen deposition has been proven to decrease species richness of grasslands by 50% in Atlantic Europe when nitrogen deposition reaches 30 kg/ha/year (Stevens *et al.*, 2010). The 2016 CLRTAP report states that "the useful steps taken to reduce emissions of nitrogen compounds to date have been insufficient to provide conditions in which ecosystems can begin to recover from eutrophication and that further reductions are necessary" (Maas R., Grennfelt P., 2016).

The nitrogen pollution in the Alps is not often specifically addressed in scientific literature. It might depend on local situations in intensive agricultural areas. However, a comprehensive study of nitrogen deposition in Switzerland between 1990 and 2010 has been carried out and was published in 2016 (Rihm B. *et al.*, 2016). It shows that the nitrogen critical load is exceeded in most of the country, although a slow recovery seems to be occurring (Table 7). A map of nitrogen critical load exceedance in Switzerland is provided in Figure 9.

An experimental study showed that there might be only a slow recovery of grassland ecosystems

29. *Critical load: a quantitative estimate of exposure to deposition of one or more pollutants, below which significant harmful effects on sensitive elements of the environment do not occur, according to present knowledge. Exceedance of a critical load is defined as the atmospheric deposition of the pollutant above the critical load.*

when nitrogen deposition ceases (Bowman W.D. *et al.*, 2018). In this study, only one nitrophilic species showed recovery to its prior level nine years after the experimental deposition was stopped. Such a result highlights the need for an improvement of the policies against atmospheric pollution by NO_x and NH_3 in order to prevent biodiversity loss.

Ecosystem	Area km²	1990	2000	2010
Raised bogs	52	100 %	100 %	98 %
Fens	188	91 %	82 %	76 %
Dry grassland (TWW)[(a)]	200	81 %	62 %	49 %
Forest	10,290	99 %	96 %	95 %

Table 7: *Exceedance of critical loads of nutrient nitrogen in different protected ecosystems in Switzerland in 1990, 2000 and 2010. (Rihm B. et al., 2016). (a) TWW: Trockenwiesen und -weiden (dry meadows and pastures).*

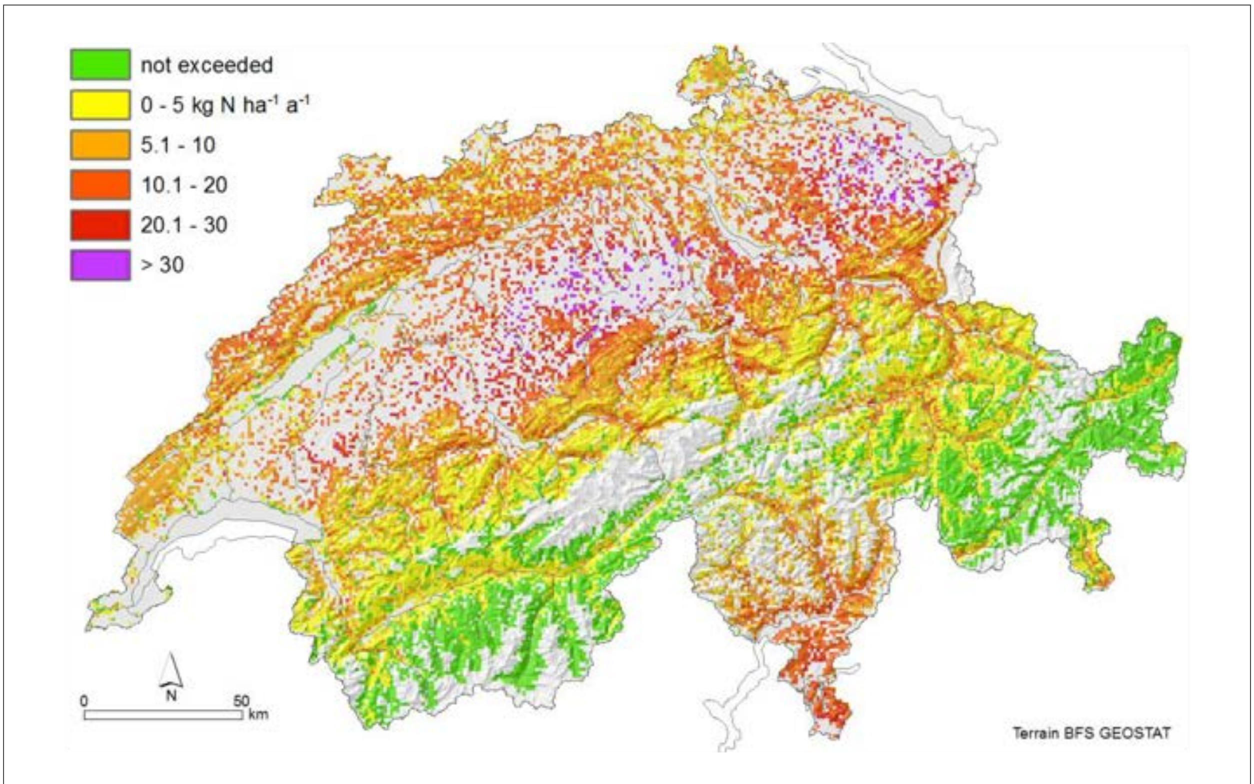

Figure 9: *Maximum exceedance of critical loads in Swiss forests and (semi-)natural ecosystems by nitrogen depositions in 2010 per km². (Rihm B. et al., 2016).*

5. STATE OF THE AIR QUALITY IN THE ALPS

In this chapter, data from regular measurements are used to provide an overall picture of the status of air quality in the Alpine region. The spatial distribution of the monitoring stations operated by the countries in the Alpine region is analysed in relation to their geography and their surrounding environment. The concentrations of pollutants in recent years are then assessed by comparing the annual statistics with the European air quality standards and WHO guidelines referred to in Sections 2.1 and 2.4.2 of this Report. Looking at the longer term, the evolution of concentrations is examined through trends analyses.

5.1 SOURCE OF DATA

Station metadata and concentration statistics for Austria, France, Germany, Italy, Slovenia and Switzerland were retrieved from the European Air Quality Portal managed by the EEA, which gathers the official air quality data from Member States and other EEA member and co-operating countries.

Station metadata for Liechtenstein were provided by the Office of Environment of the Principality of Liechtenstein and corresponding statistics were downloaded from the Ostluft website (www.ostluft.ch). Station metadata and concentration statistics for Monaco were provided by the Government of the Principality of Monaco (Department of the Environment).

As supplementary information, data on the cantonal and municipal monitoring networks of Switzerland were obtained from the Swiss Federal Office for the Environment (BAFU) and corresponding statistics were downloaded from the BAFU website. Unless expressly stated, only stations and statistics from the Swiss state network are represented.

5.1.1 GEOGRAPHICAL DISTRIBUTION: OVERVIEW

234 monitoring stations operating during the 2016-2018 period were identified in the Alpine region for measuring the following pollutants: PM_{10}, $PM_{2.5}$, NO_x including NO_2, SO_2, C_6H_6 (benzene), O_3, Pb, BaP, Ni, As, CO, Cd. As displayed in Table 8, two-thirds of these stations are located in suburban or urban environments and one-third in rural environments.

Type of area	Number of stations	Percentage (%)
Rural (unspecified)	38	16.2
Rural remote	11	4.7
Rural regional	19	8.1
Rural near city	10	4.3
Suburban	72	30.8
Urban	84	35.9

Table 8: *Distribution of the 234 monitoring stations according to the type of area.*

Figure 10 illustrates their geographical distribution, together with that of 39 additional stations belonging to the local Swiss monitoring networks and operating in the same period. Of all these stations, 14% and 8% are located at altitudes higher than 1,000 m.a.s.l. and 1,500 m.a.s.l. respectively.

Adapting an existing methodology[30], it has been estimated that approximately 86% of the stations displayed in Figure 10 are situated in valleys (Figure 11).

It is important to know that mobile measurement campaigns and passive sampling methods (NO_2,

30. To determine which stations lie in valleys, the methodology proposed by A. Simcox, D. Morse and G. Hamilton, 2016 (https://www.arcgis.com/home/item.html?id=646ebe715800410d9e5c02aa3653546d) was adapted to the European situation. Valleys (areas that are lower than their neighbours) were extracted from a Digital Elevation Model (European Digital Elevation Model EU-DEM - version 1.1, 25 m resolution) by finding the local average elevation within a given radius, subtracting the actual elevation from the average, and selecting areas where the actual elevation was below the average. The landscape was sampled at five scales (circles of 1, 2, 4, 7 and 11 km radius) to take into account the diversity of valley shapes and sizes. Areas selected in at least three scales were designated as valleys.

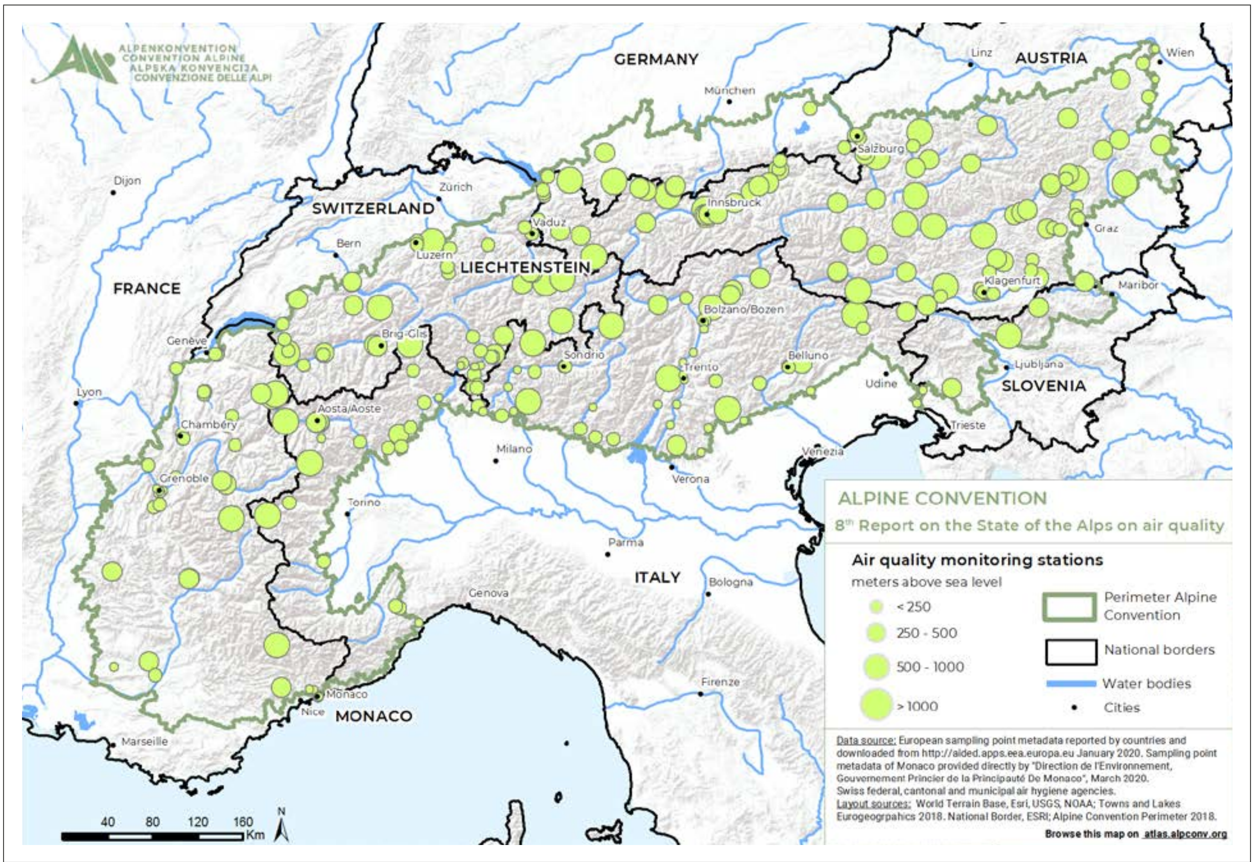

Figure 10: *Geographical distribution of the monitoring stations operating in the period 2016-2018 in the Alpine region, adding the stations from the Swiss cantonal and municipal monitoring networks for the same period*[31].

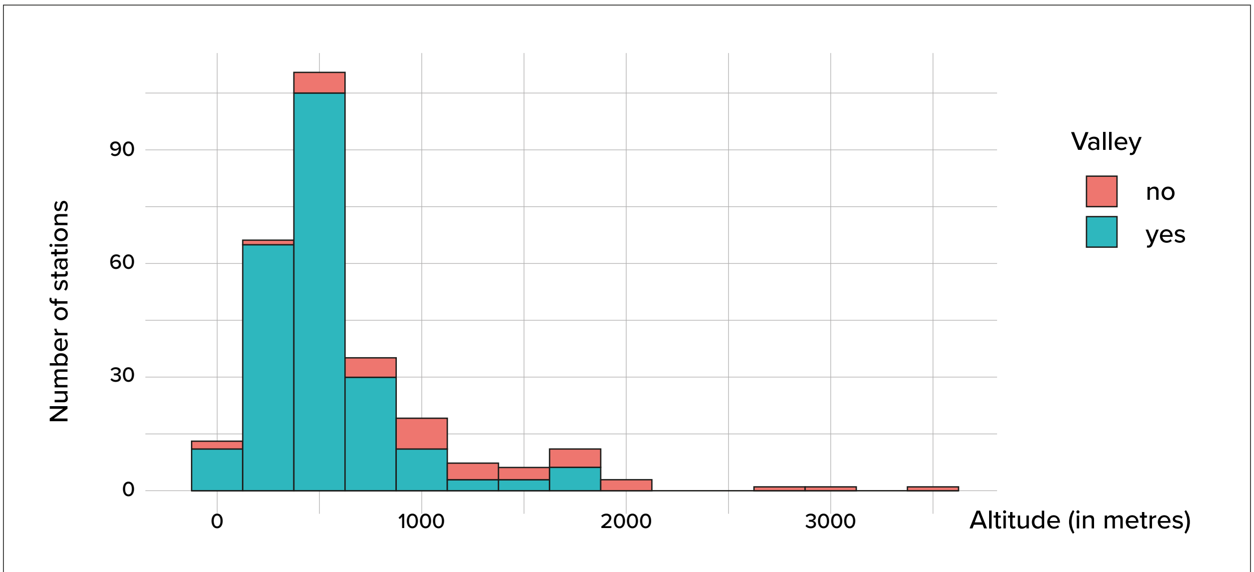

Figure 11: *Histogram showing the distribution by altitude of the monitoring stations in the Alpine region, including the stations from the Swiss cantonal and municipal monitoring networks, operating in the 2016-2018 period.*

31. *The Swiss sampling points of cantonal and municipal monitoring networks are presented only on this map. The following maps rely on official EEA data.*

Country	Pollutant	Station classification						
		Rural	Rural near city	Rural regional	Rural remote	Sub-urban	Urban	Total
Austria	NO_2	12	1	10	2	31	20	76
	PM_{10}	10	0	6	1	22	19	58
	$PM_{2.5}$	1	0	0	1	4	8	14
	O_3	11	2	12	7	19	7	58
	BaP	4	0	0	0	5	8	17
	Heavy metals	2	0	1	0	1	1	5
France	NO_2	0	1	0	1	5	22	29
	PM_{10}	0	3	0	1	5	22	31
	$PM_{2.5}$	0	2	0	1	1	9	13
	O_3	0	2	2	2	5	15	26
	BaP	0	1	0	1	1	4	7
	Heavy metals	0	0	0	1	0	2	3
Germany	NO_2	0	2	1	1	2	2	8
	PM_{10}	0	1	1	1	1	1	5
	$PM_{2.5}$	0	1	0	0	2	1	4
	O_3	0	1	1	1	2	1	6
	BaP	0	0	0	0	1	0	1
Italy	NO_2	12	2	0	1	18	29	62
	PM_{10}	9	1	0	0	15	27	52
	$PM_{2.5}$	2	1	0	0	7	14	24
	O_3	15	2	0	1	14	18	50
	BaP	3	0	0	0	9	12	24
	Heavy metals	2	0	0	0	6	6	14
Liechtenstein	NO_2	0	0	0	0	1	0	1
	PM_{10}	0	0	0	0	1	0	1
	O_3	0	0	0	0	1	0	1
Monaco	NO_2	0	0	0	0	0	5	5
	PM_{10}	0	0	0	0	0	2	2
	O_3	0	0	0	0	0	2	2
	Heavy metals	0	0	0	0	0	2	2
Slovenia	PM_{10}	0	0	0	0	1	0	1
	O_3	2	0	0	0	0	0	2
	Heavy metals	0	0	0	0	1	0	1
Switzerland	NO_2	4	0	0	0	2	2	8
	PM_{10}	4	0	0	0	2	2	8
	$PM_{2.5}$	2	0	0	0	0	1	3
	O_3	4	0	0	0	2	1	7
	BaP	1	0	0	0	0	1	2
	Heavy metals	4	0	0	0	0	1	5

Table 9: *Air quality measurement stations in the Alpine Convention perimeter.*

NH_3, benzene, toluene, ethylbenzene, xylene) are implemented by some countries on a temporary or long-term basis in order to supplement permanent monitoring sites and obtain a more detailed description of air quality. They have not been considered in this analysis which mainly relies on information available through the EEA website.

5.1.2 GEOGRAPHICAL DISTRIBUTION PER POLLUTANT

In this section, the spatial distribution of the monitoring stations is examined by pollutant, according to station classification (Table 9).

Note that the station type, which characterises the main source of influence, is pollutant specific. NO_2, O_3 and PM_{10} have the highest density of measurement points, as illustrated in Figure 12. Those points are distributed over the whole region except for highly mountainous or less densely populated areas, and their number remains stable across the years examined (2016 to 2018). Whereas ozone is mostly measured in rural or (sub)urban background areas, NO_2 and PM_{10} monitoring also targets traffic-oriented sites and, to a lesser extent, industrial sites. Ozone precursor substances listed by Air Quality Directive 2008/50/EC are measured at one urban background site in Grenoble. The complete set of maps per pollutant and per year (2016, 2017, 2018) is available online at http://www.atlas.alpconv.org.

More sparse but still fairly extensive monitoring of $PM_{2.5}$ and BaP is also carried out throughout the Alpine region, mainly at urban or suburban background locations. In addition, measurements of PAHs other than BaP are reported for several monitoring sites in France and Italy.

Carbon monoxide and benzene are infrequently monitored, which is consistent with the low concentration levels observed for those pollutants (see Section 5.2.2) resulting in the possibility offered by European directives to implement less stringent assessment methods (indicative measurements, modelling, objective estimation). The situation is almost the same for SO_2 although a larger number

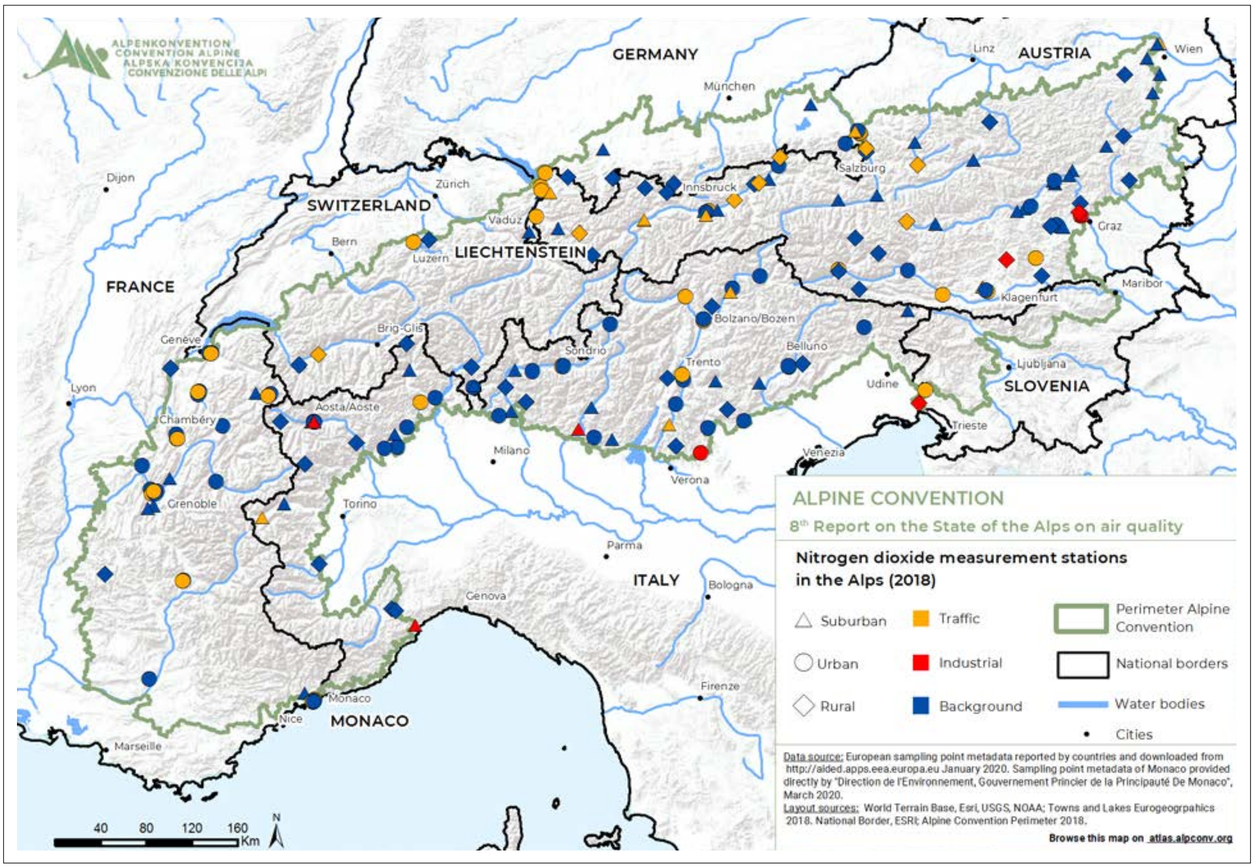

Figure 12a: *Map of measurement stations for nitrogen dioxide in the Alps.*

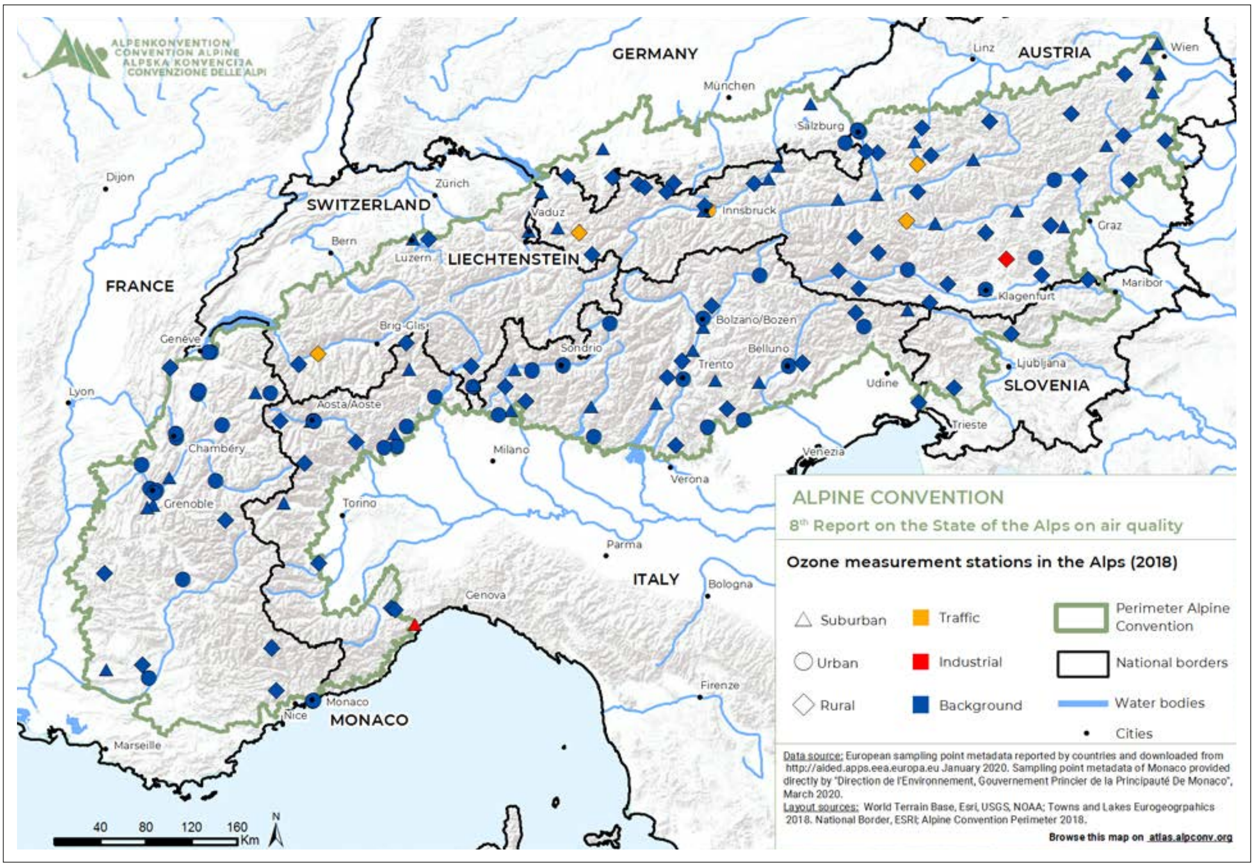

Figure 12b: *Map of measurement stations for ozone in the Alps.*

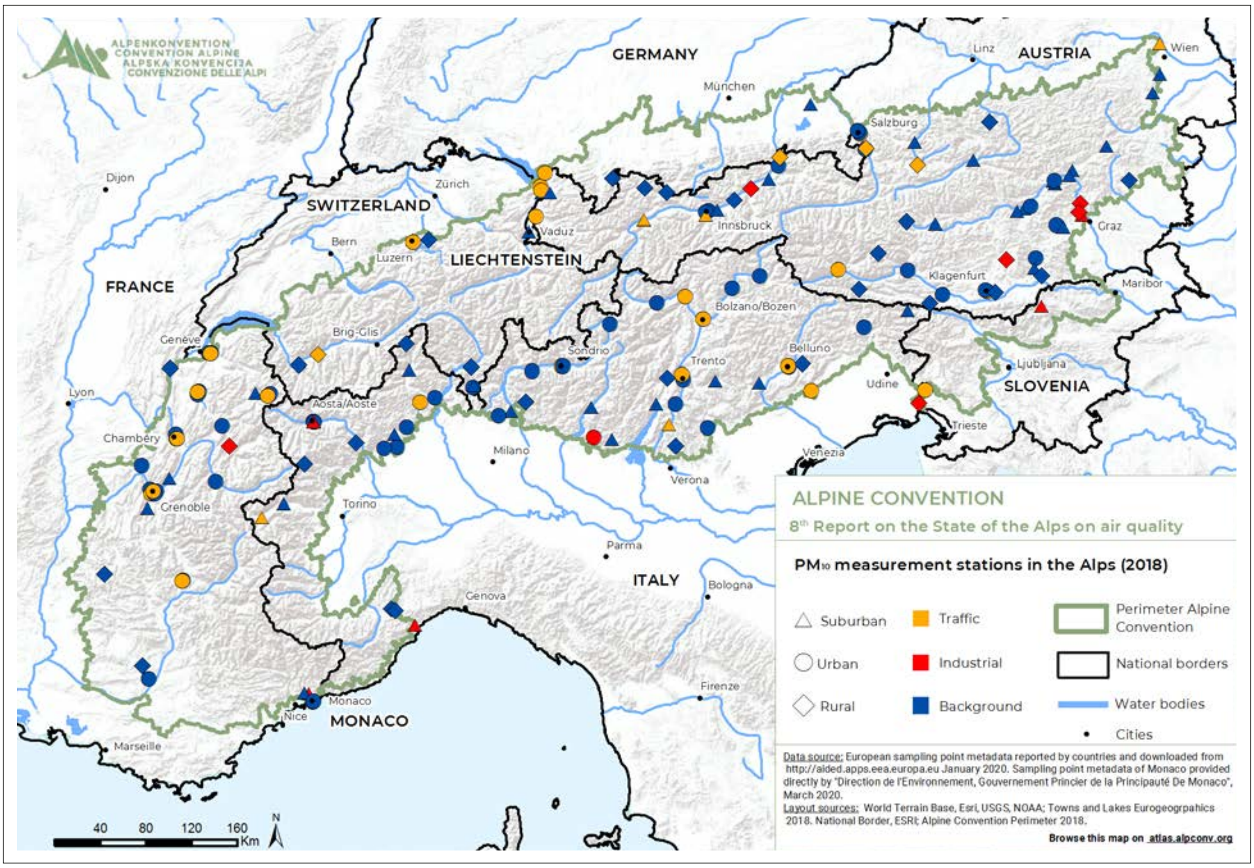

Figure 12c: *Map of measurement stations for PM_{10} in the Alps.*

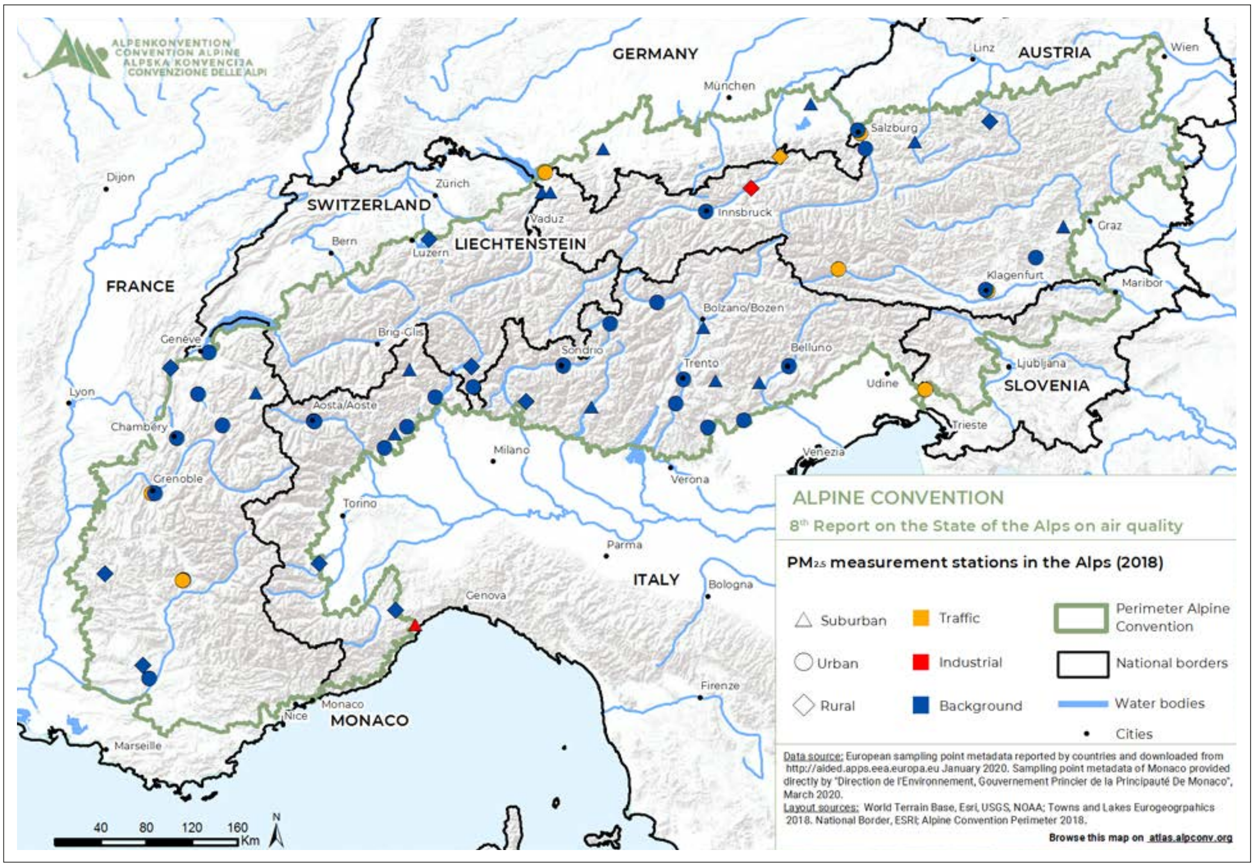

Figure 12d: *Map of measurement stations for* $PM_{2.5}$ *in the Alps.*

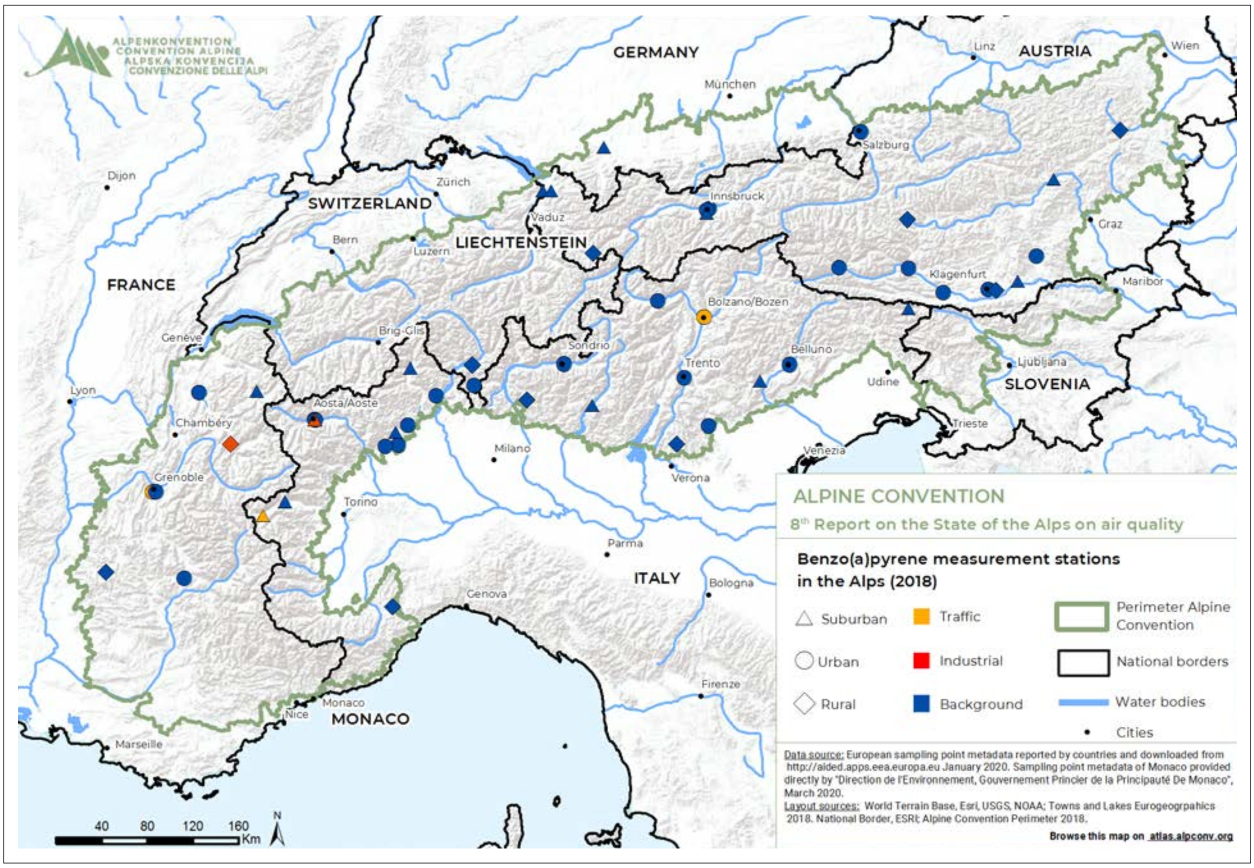

Figure 12e: *Map of measurement stations for benzo(a)pyrene in the Alps.*

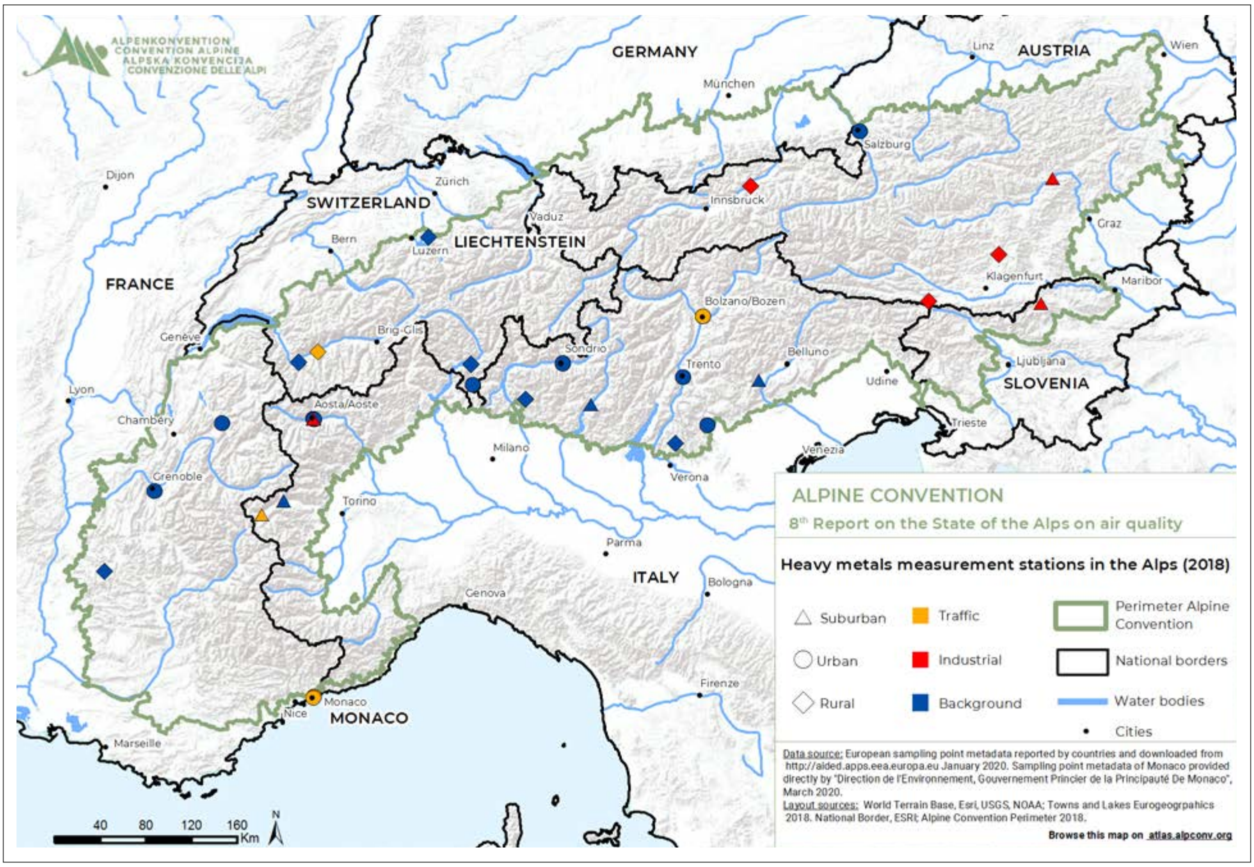

Figure 12f: *Map of measurement stations for heavy metals in the Alps.*

of stations continue to operate in some areas (in the Austrian and Italian parts of the region).

Heavy metals also fall into the category of pollutants that have low concentration levels compared to the thresholds set by the EU and have reduced monitoring. They are generally measured at background locations, except for Austria where their measurements are mainly oriented towards industrial sites. Additional monitoring of all these pollutants is also part of the Swiss local networks.

Other measurements are carried out at high altitude measurement stations as part of research-oriented programmes. They are not the subject of this chapter and information about this activity can be found in Section 6.2.

5.2 STATUS OF CONCENTRATIONS

5.2.1 COMPARISON WITH EUROPEAN ENVIRONMENTAL OBJECTIVES AND WHO GUIDELINES

This comparison is based on the sources of statistics mentioned in the introduction to this chapter. Available statistics from the Swiss local networks are considered as additional material to supplement the results. The complete set of graphs is available online (www.atlas.alpconv.org). The concentrations presented here are compared to the limits from Directive 2008/50/EC, which is the regulatory basis in the EU (see Chapter 2.1), and with the WHO air quality guidelines established to protect human health (see Chapter 2.4.2).

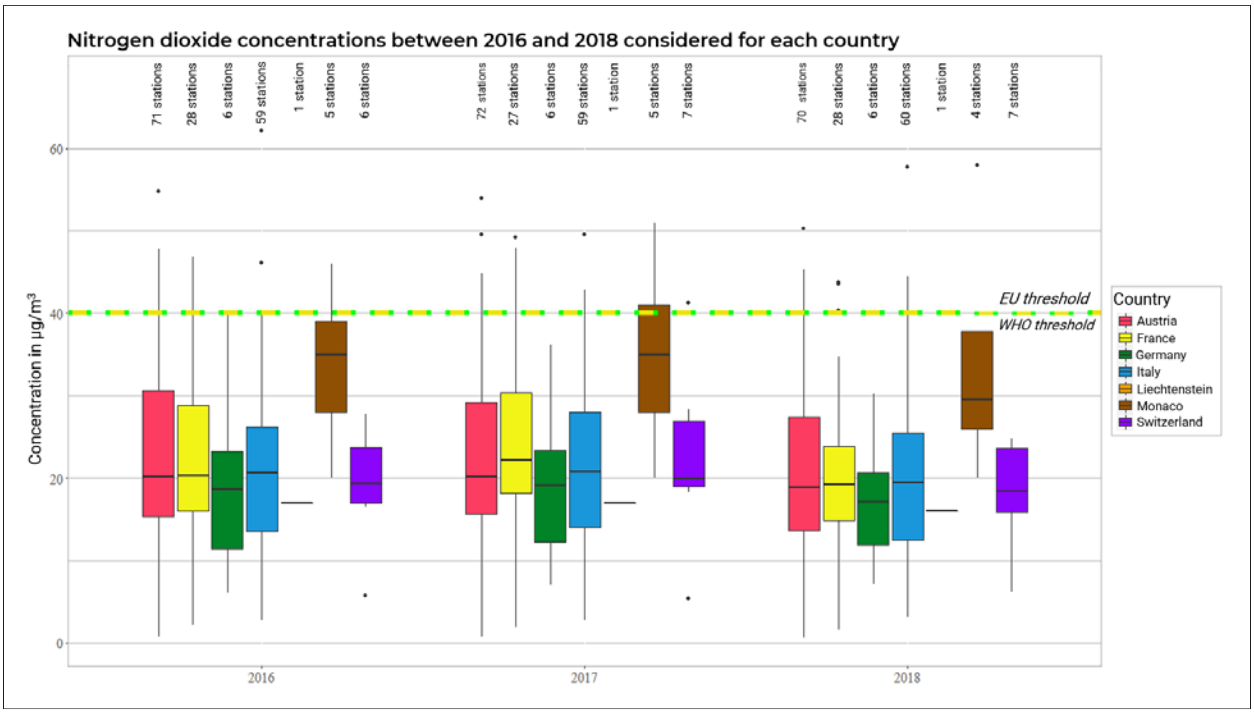

Figure 13: *Distribution of NO_2 annual mean concentrations in 2016, 2017 and 2018 in the Alpine region.*
The yellow dotted line represents the annual limit value of the EU Directive (2008/50/EC) and the green dotted line the WHO-Guideline for the protection of human health. The bottom and top of each coloured box represent the first and third quartiles, the horizontal line inside the box represents the median and the extremities of the vertical lines represent the lowest and highest values excluding outliers. The dots are single values outside the distribution.

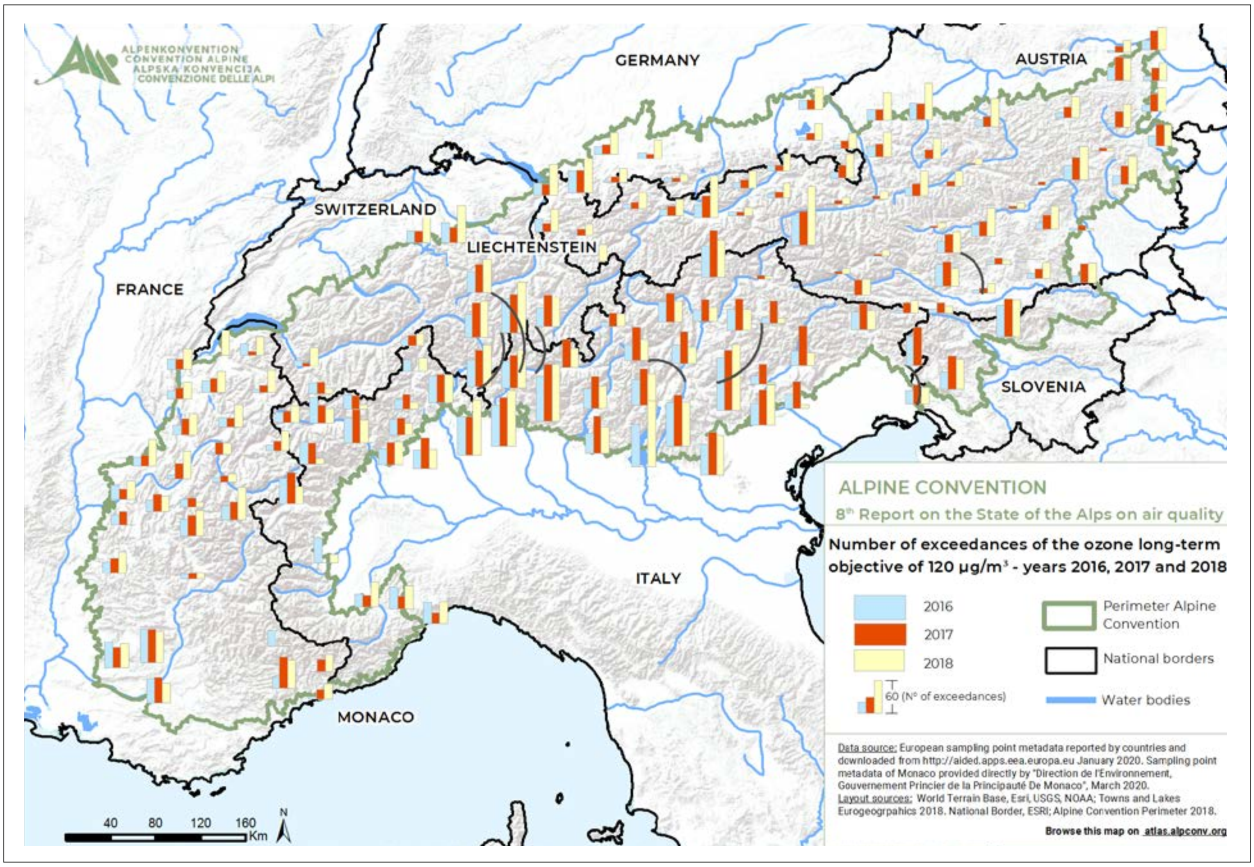

Figure 14: *Map of the evolution of the exceedances of the long-term O_3 objective for the protection of human health in the Alpine region.*

Nitrogen Dioxide

Figure 13 represents the distribution of the annual mean concentrations of NO_2 in 2016, 2017 and 2018. For all years, all exceedances of the EU annual limit value (40 µg/m³), which coincides with the annual WHO guideline, were recorded at traffic-related sites (12, 14 and 7 exceedances in 2016, 2017 and 2018 respectively). All the stations concerned by such exceedances are located in valleys where the combination of NO_x emissions and inversion situations may increase NO_2 concentration levels, as described in Chapter 3.1.1.

Exceedances of the 200 µg/m³ threshold (hourly WHO guideline) were recorded occasionally at a few stations (5, 4 and 3 stations in 2016, 2017 and 2018 respectively). The EU standard (200 µg/m³, no more than 18 times per year) was exceeded only once, at a French traffic site in 2016.

Ozone

Ozone pollution largely affects the Alpine region. Figure 14 represents the yearly number of exceedances of the long-term objective of 120 µg/m³ per station for the years 2016, 2017 and 2018.

The target value for the protection of human health is exceeded at most sites and throughout most of the territory, although Germany and Monaco are exceptions. Inter-annual variability can be noted in those areas, with a higher number of exceedances in 2018 compared to the previous years.

The long-term objective for the protection of human health (120 µg/m³) and the WHO guideline (100 µg/m³) are exceeded almost everywhere. As regards the target value and the long-term objective for the protection of vegetation, they are exceeded at many rural and suburban background sites across the region.

Particulate Matter - PM_{10}

Figure 15 represents the distribution of the annual mean concentrations of PM_{10} in 2016, 2017 and 2018. Despite spatial variability across the regions, all of them are significantly below the mean annual limit value of EU Directive 2008/50/EC (40 µg/m³). However, the WHO AQG (20 µg/m³) is exceeded each year in about a quarter of the stations.

Figure 16 represents the yearly number of exceedances of the 50 µg/m³ daily threshold per station and indicates in red the stations for which this number is strictly higher than 35 times per year, the European limit value. These stations are only a few (in 2018 just two of them exceeded the EU limit) and almost all of them located in Italy, in (sub) urban background or industrial locations. However, nearly half the stations (75 out of 162) exceeded the more demanding WHO guideline (50 µg/m³, no more than 3 days per year).

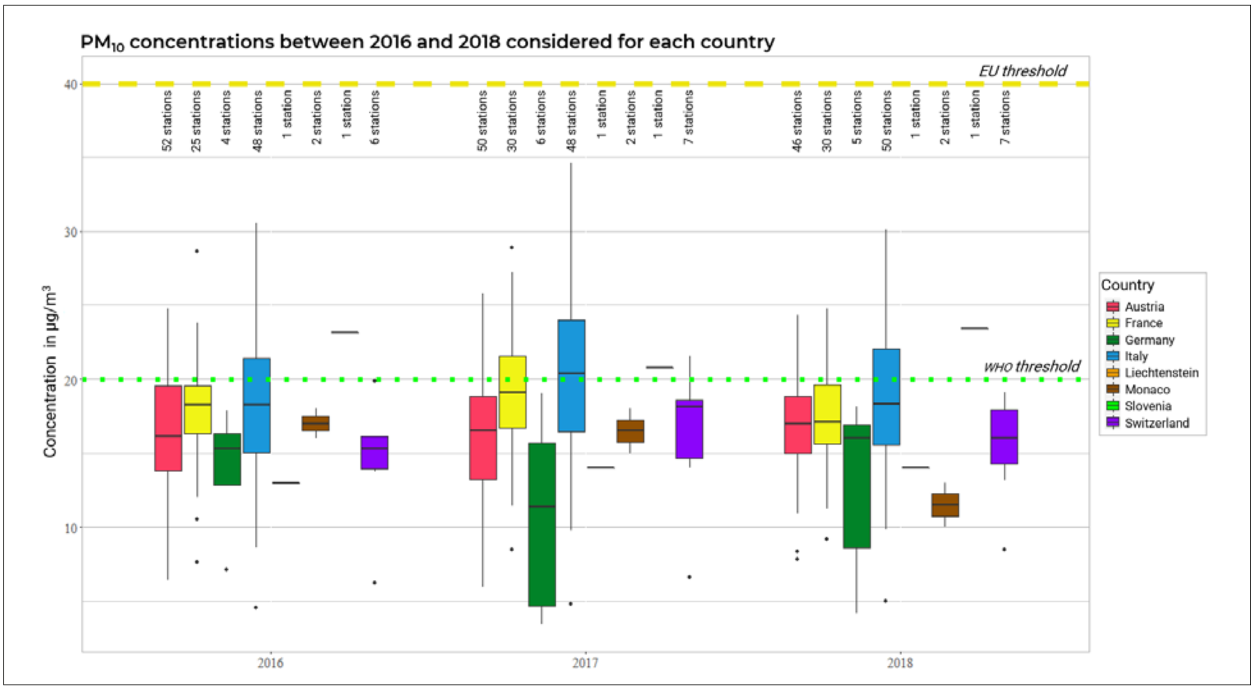

Figure 15: *Distribution of PM_{10} annual mean concentrations in 2016, 2017 and 2018 in the Alpine region.*

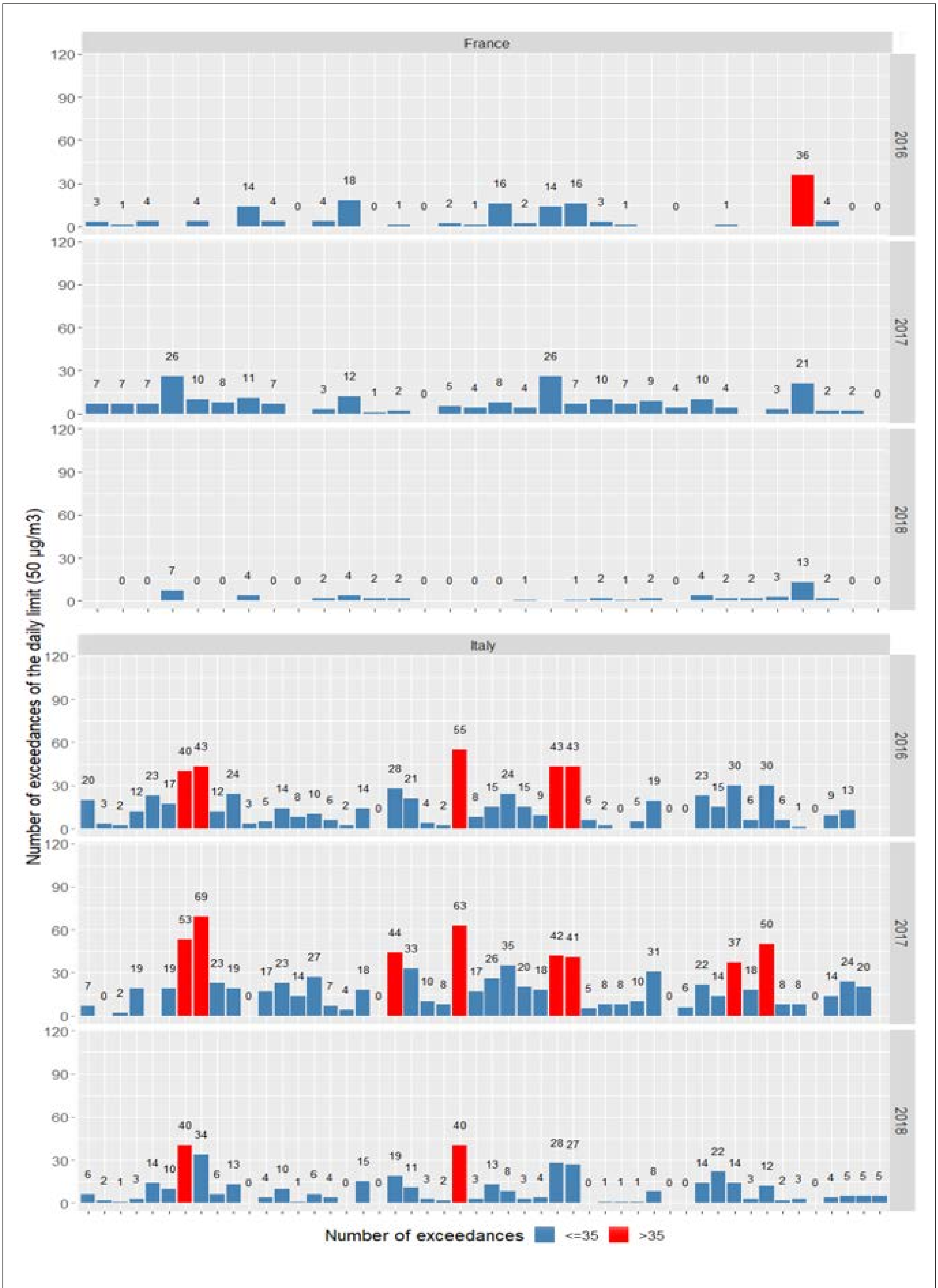

Figure 16: *Exceedance of PM_{10} daily limit value for the protection of human health in 2016, 2017 and 2018 in the French and Italian parts of the Alpine region. Apart from the French and Italian areas, all the other areas in the Alpine region have less than 35 days of exceedance.*

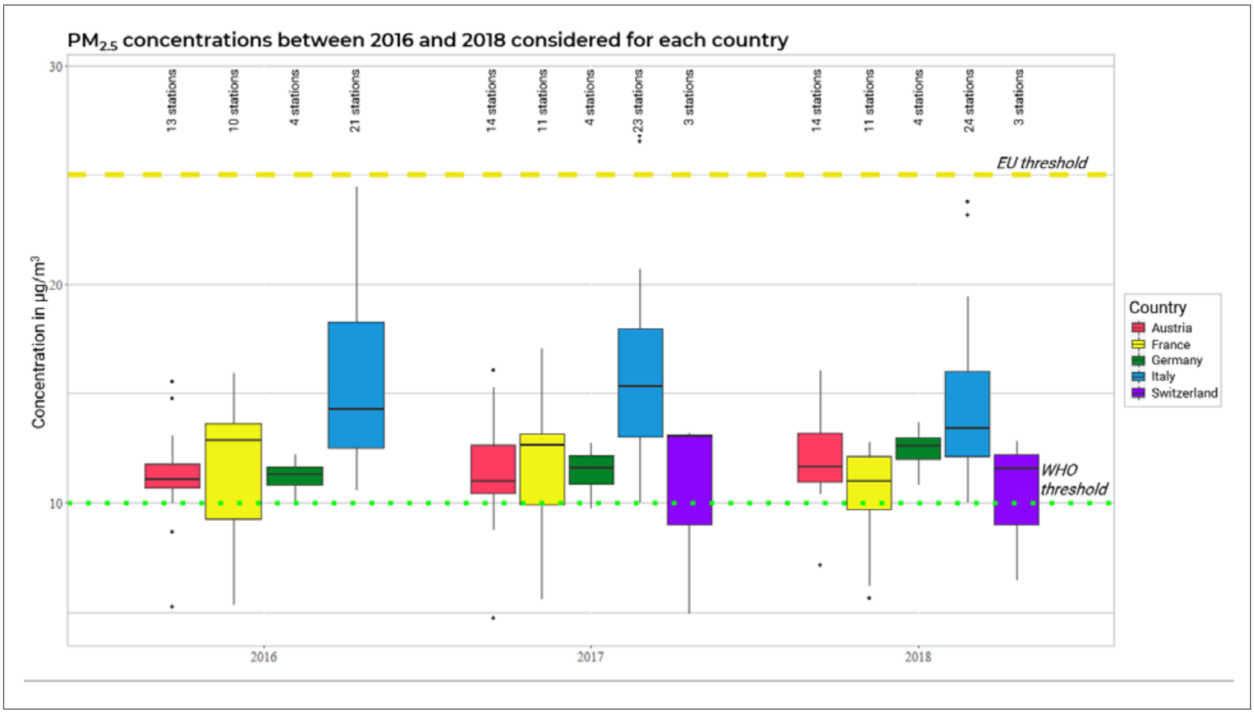

Figure 17: *Distribution of $PM_{2.5}$ annual mean concentrations in 2016, 2017 and 2018 in the Alpine region. The yellow dotted line represents the annual limit value of the EU Directive (2008/50/EC) and the green dotted line the WHO-Guideline for the protection of human health.*

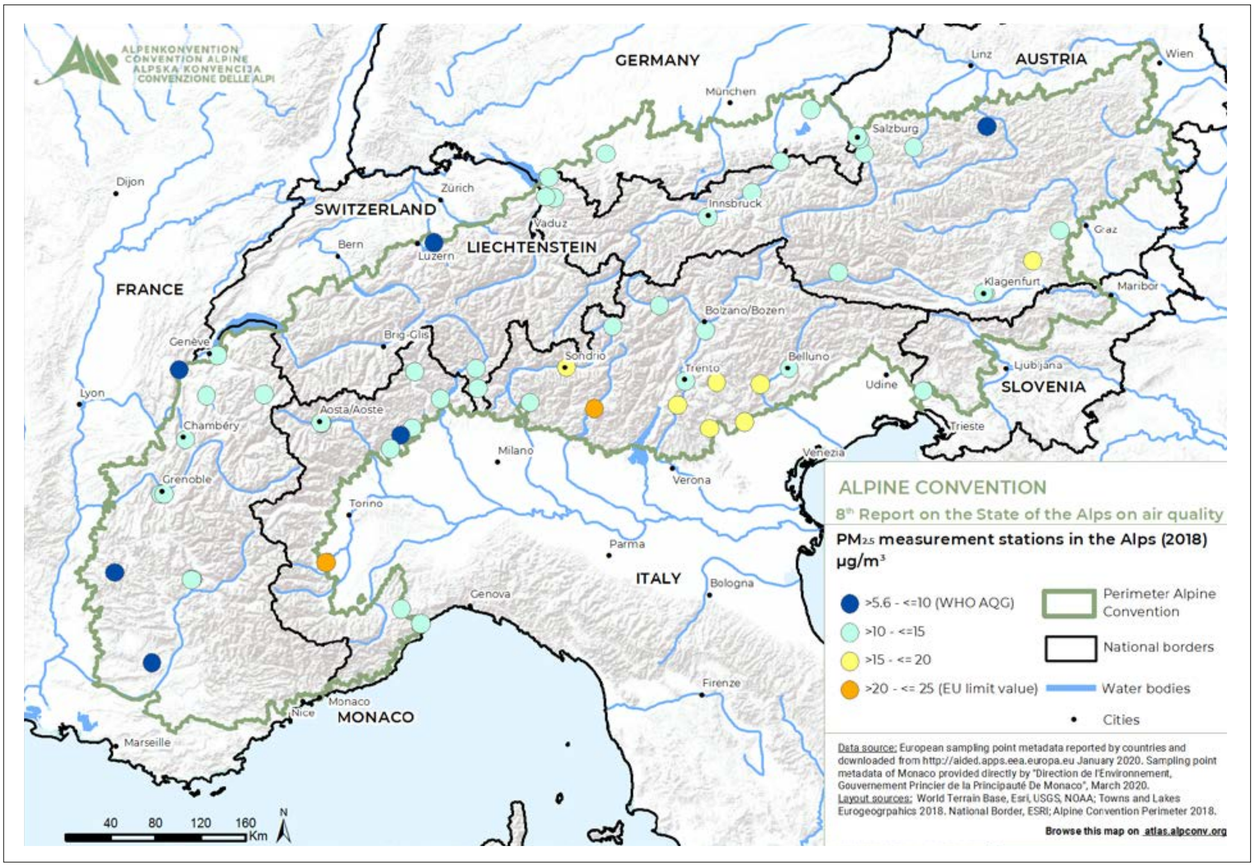

Figure 18: *Map of annual mean concentration of $PM_{2.5}$ in 2018 in the Alps.*

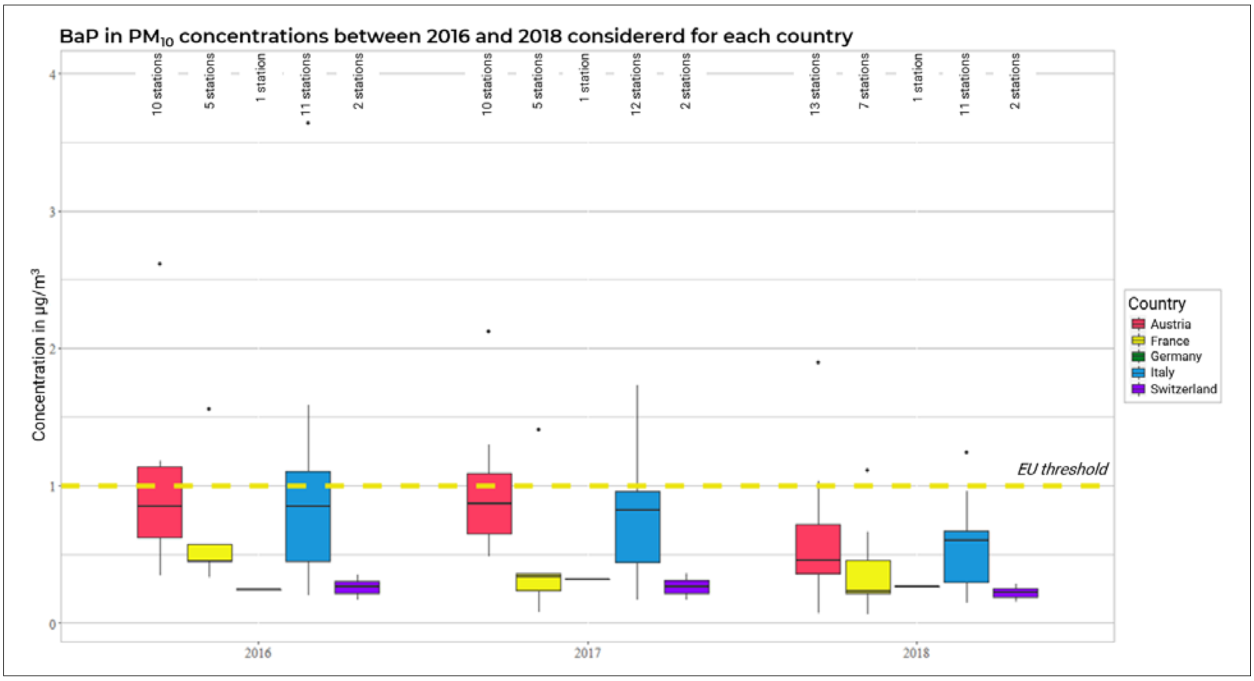

Figure 19: *Distribution of BaP annual mean concentrations in PM_{10} in 2016, 2017 and 2018 in the Alpine region. The yellow dotted line represents the annual limit value of the EU Directive (2008/50/EC).*

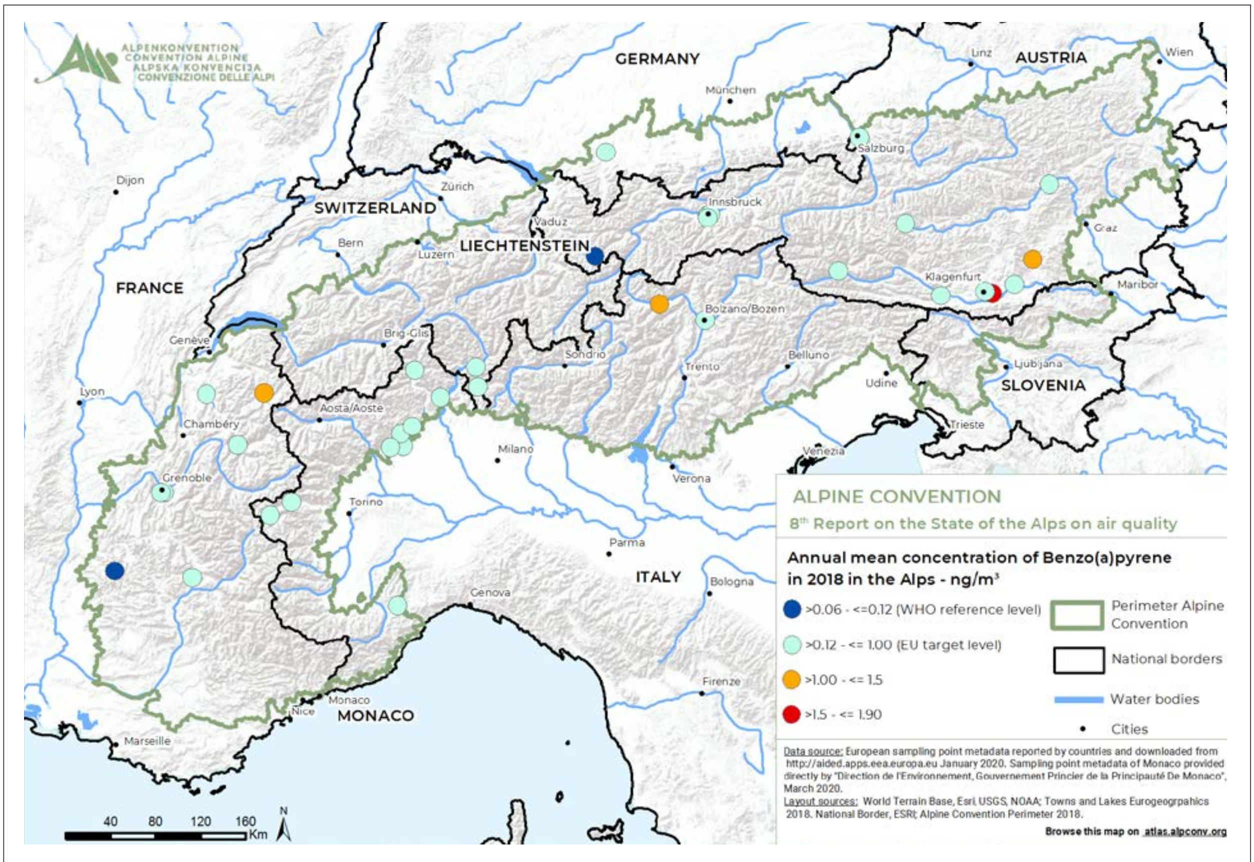

Figure 20: *Map of annual mean concentration of BaP in 2018 in the Alpine region. Exceedances of the EU target value are plotted in orange and red.*[32]

32. *According to Directive 2004/107/EC, for values >1 and < 1.5, the annual mean is rounded to 1 ng/m³ and is therefore not considered as an exceedance according to the EU reporting rules; for values >=1.5 the annual mean is rounded to 2 ng/m³.*

Particulate Matter - $PM_{2.5}$

Similarly to those of PM_{10}, $PM_{2.5}$ annual mean concentrations show spatial variability across the Alpine region. Figure 17 shows that all of them lie significantly below the annual limit value (25 µg/m^3). There are no exceedances of the legal limit values of the EU Directive 2008/50/EC in the Alps. However, in terms of human health, the WHO AQG (10 µg/m^3) is exceeded in most stations, and only a few background sites (between 7 and 10 depending on the year), mostly rural or suburban, comply with it.

The results of air quality monitoring in the Alps clearly demonstrate that $PM_{2.5}$ pollution is a major issue all over the Alpine Convention perimeter. Although the number of stations exceeding the EU limit value has decreased, the exceedance of the WHO AQG is widespread, as can be seen in the map in Figure 18.

Benzo(a)Pyrene

Concentration levels comply with the target value (1 ng/m^3) at most sites and an overall decrease of concentrations can be seen in 2018 (Figure 19). However, annual mean values higher than 1 ng/m^3 were observed at some urban or suburban background stations in Austria and Italy, with exceedances recorded at 5, 10 and 1 stations in 2016, 2017 and 2018 respectively, as shown in the map in Figure 20.

Other Pollutants

For SO_2, benzene, CO and heavy metals, observed concentration levels are low and do not exceed the European limit values. Only for SO_2 is the more protective daily WHO guideline (20 µg/m^3) occasionally exceeded.

5.2.2 COMPARISON WITH NATIONAL THRESHOLDS

Chapter 2.2 explained that Austria, Liechtenstein and Switzerland have established national air pollution limits lower than the EU limits for NO_2, PM_{10}, $PM_{2.5}$ (and BaP for Austria only) (see Table 2 for an overview). The comparison of these national limits with observed data reveals the following facts.

First, NO_2 concentrations in the Alps are fairly similar all across the Alpine countries and all parties of the Alpine Convention meet the most protective national legal limits, with the exception of the urban site of Monaco. There is no evidence of a difference between countries with stricter limits and the others.

At the same time, the figure for PM_{10} concentrations is more diverse. In France and, at least in 2017, in Italy, several stations recorded exceedances of the most protective WHO AQG. According to Figure 7 and owing to the conclusions of Section 3.2, the main reasons, at least in Grenoble and Chamonix, might be biomass burning, traffic and agriculture in conjunction with adverse dispersion conditions.

Finally, and as stated before, the situation for $PM_{2.5}$ is different. All the pollution levels measured in the area of the Alpine Convention are within the EU limit, but they are at the same time higher than the national limits of Austria, Liechtenstein and Switzerland. Switzerland seems to be slightly less polluted: this might be linked to a historically more drastic set of limits and thus an emission limitation strategy.

5.3 ANALYSIS OF TRENDS, CORRELATION WITH MITIGATION STRATEGIES

In this section, data from the years 2009 to 2018 were analysed to determine the trend of air pollution in the Alps. The slope of the trends and its significance were estimated using Mann–Kendall and Sen's slope estimator statistical tests. For NO_2, O_3, PM_{10} and $PM_{2.5}$, stations were selected according to data completeness criteria as set out in previous studies. Results per monitoring site were then aggregated according to station classification. For BaP, the analysis was performed by station as it was based on a reduced set of data.

Most of the trends are decreasing, which means an improvement of air quality over the last decade, except for ozone. A similar evolution can be observed on average across Europe.

5.3.1 NO_2

The graphs in Figure 21 show that the trend is towards a slow improvement of air quality regarding NO_2, decreasing especially when measured at traffic stations.

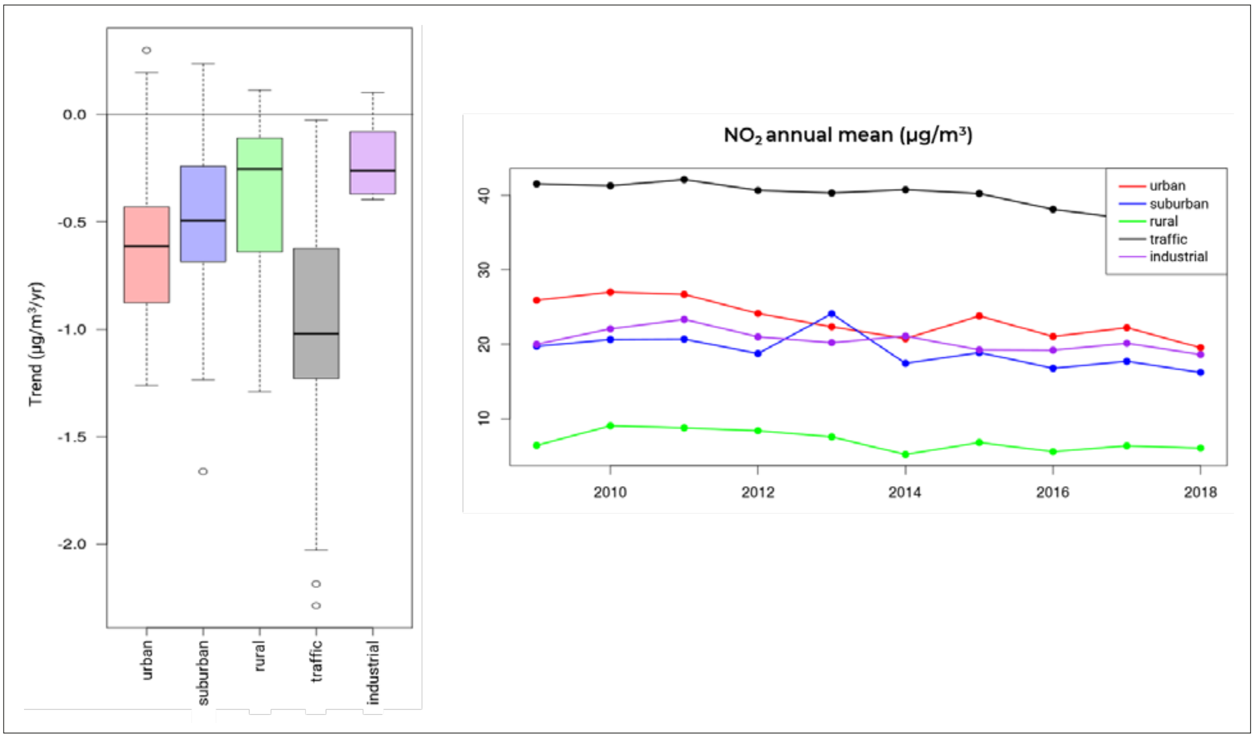

Figure 21: *Change in NO_2 annual mean concentrations in µg/m³ in the Alpine Convention perimeter from 2009 to 2018. Graph on the left: distribution of the slope of the trend by station classification. Graph on the right: Evolution of NO_2 annual mean in µg/m³ by station classification between 2009 and 2018. Stations qualified as rural, suburban and urban are background stations.*

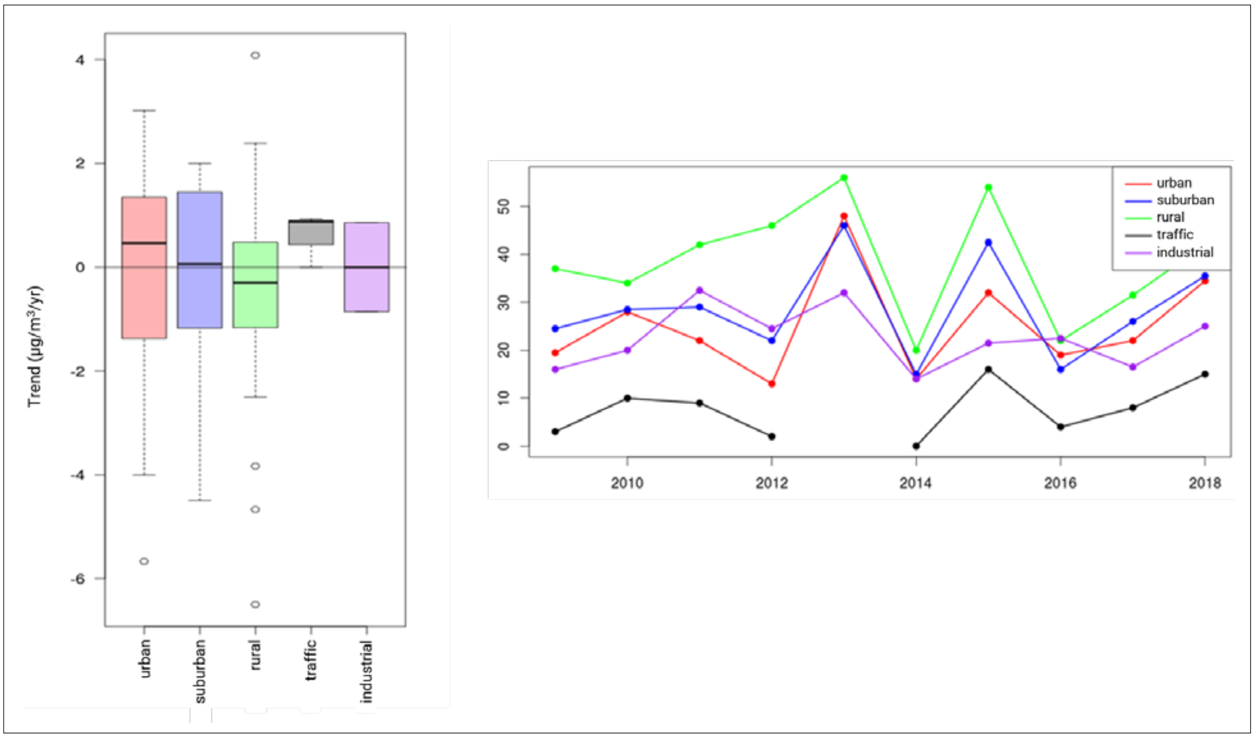

Figure 22: *Change in the number of days in which ozone concentration exceeded the 8-hour daily maximum average limit of 120 µg/m³ for more than 8 hours in the Alpine Convention perimeter from 2009 to 2018. Graph on the left: distribution of the slope of the trend by station classification. Graph on the right: evolution of the number of days of exceedances by station classification between 2009 and 2018. Stations qualified as rural, suburban and urban are background stations.*

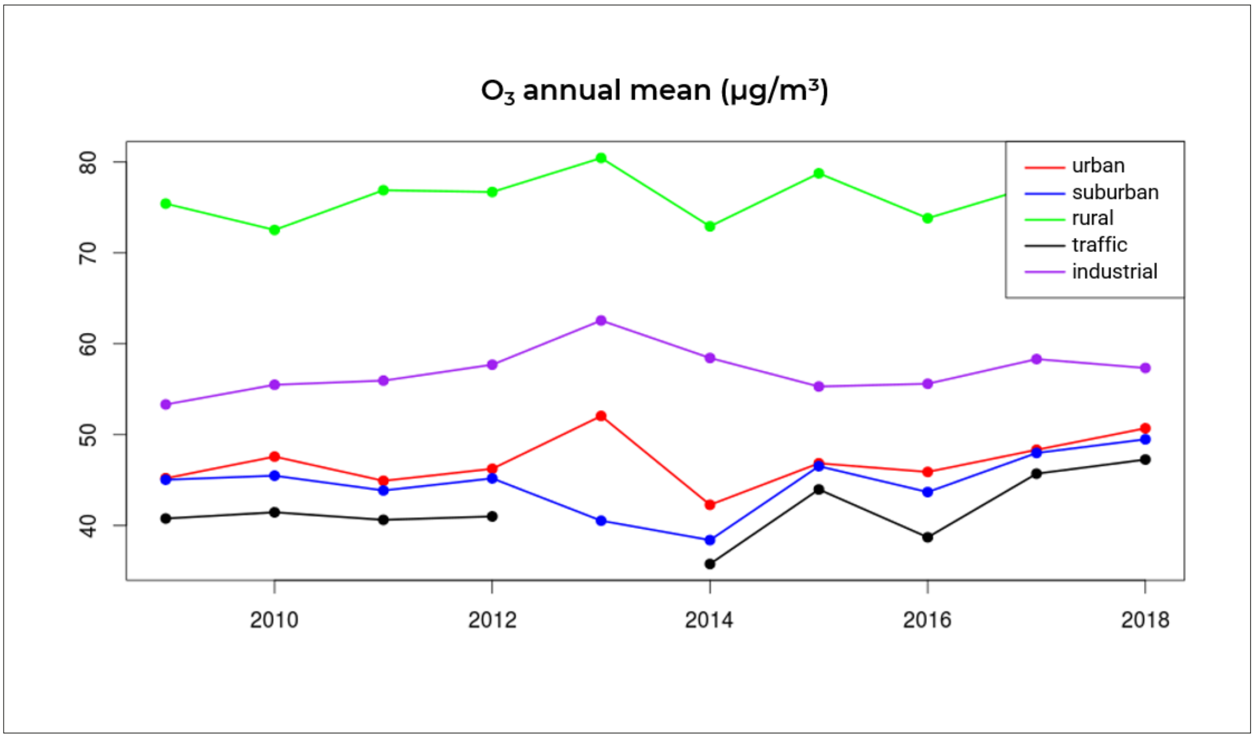

Figure 23: *Evolution of O_3 annual mean concentrations by station classification between 2009 and 2018. Stations qualified as rural, suburban and urban are background stations.*

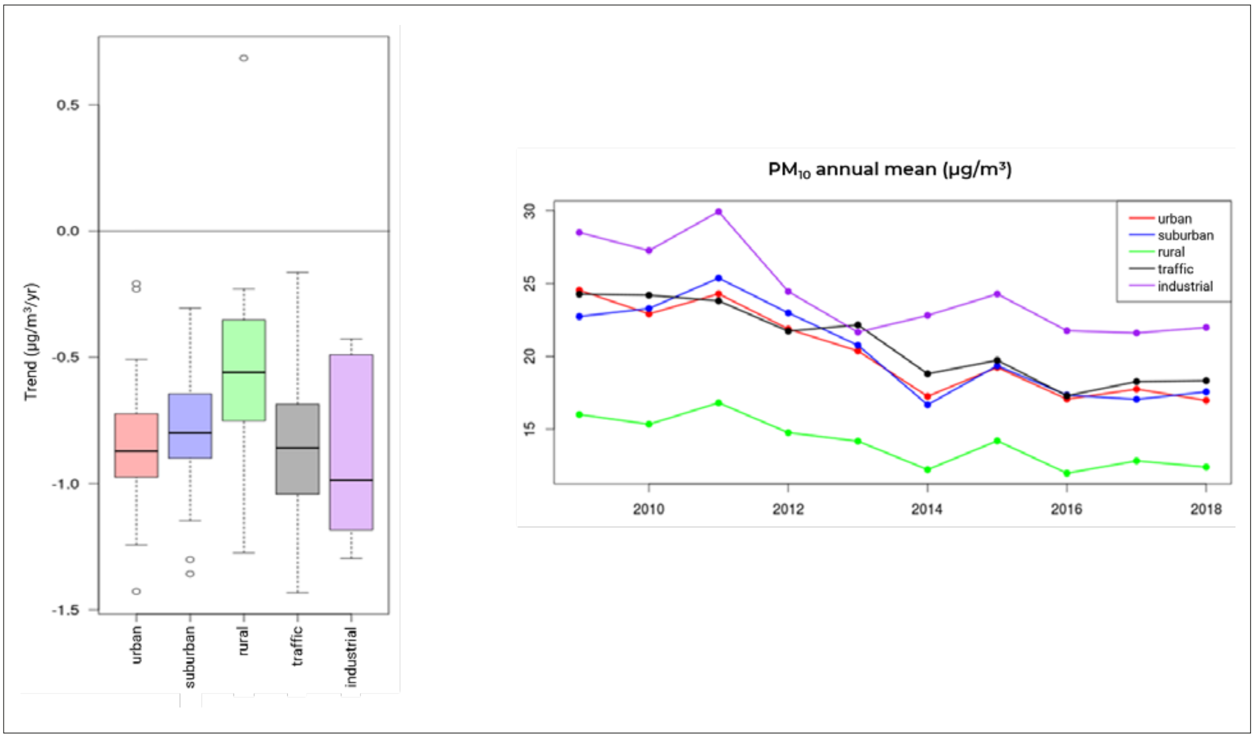

Figure 24: *Change in PM_{10} annual mean concentrations in µg/m³ in the Alpine Convention perimeter from 2009 to 2018. Graph on the left: distribution of the slope of the trend by station classification. Graph on the right: evolution of PM_{10} annual mean in µg/m³ by station classification between 2009 and 2018. Stations qualified as rural, suburban and urban are background stations.*

5.3.2 OZONE

Data available from the stations in the Alps do not reveal any clear trend for ozone concentrations. For most sites, the trend is not significant. Strong interannual variations are observed as shown in Figure 22. They are most probably linked to meteorology since O_3 formation from its precursors is catalysed by solar light.

5.3.3 PM_{10}

The trend for PM_{10} shows that its concentration sharply decreased from 2009 to 2014 but seems to have stabilised between 2014 and 2018. The trend of the annual mean over the 2009-2018 period is significant for the majority of sites. There is no difference between rural and urban situations or at stations representative of industry or traffic (Figure 24).

5.3.4 $PM_{2.5}$

Measuring stations for $PM_{2.5}$ are only located in urban and suburban areas. However, the clear trend seen in Figure 25 is a decrease of $PM_{2.5}$ concentration in the stations of the Alps.

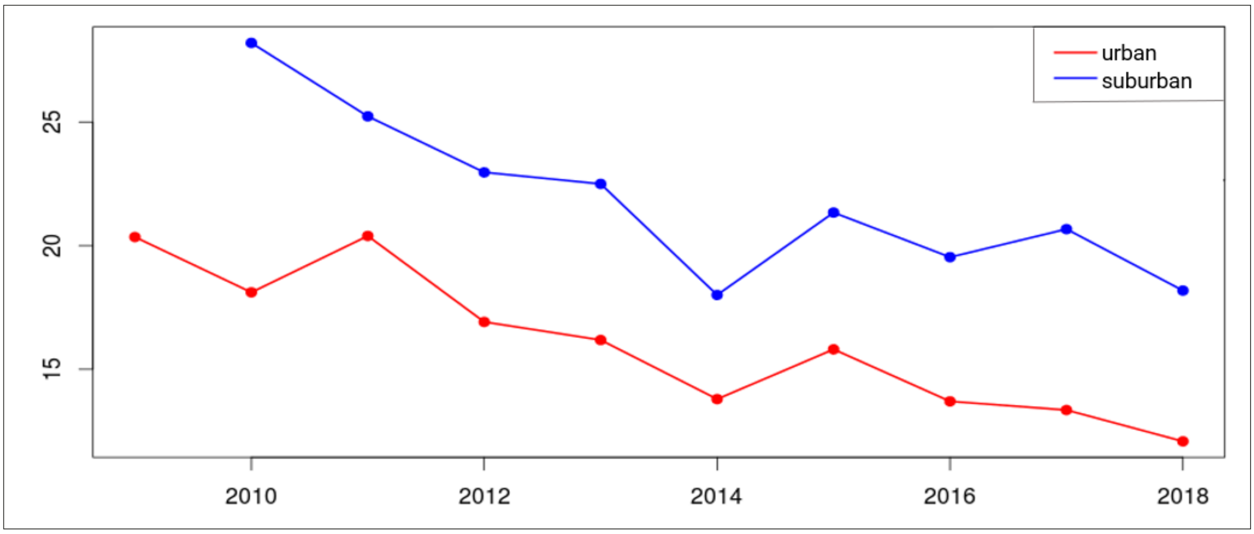

Figure 25: *Evolution of $PM_{2.5}$ annual mean in µg/m³ in urban and suburban background stations in the Alpine Convention perimeter from 2009 to 2018.*

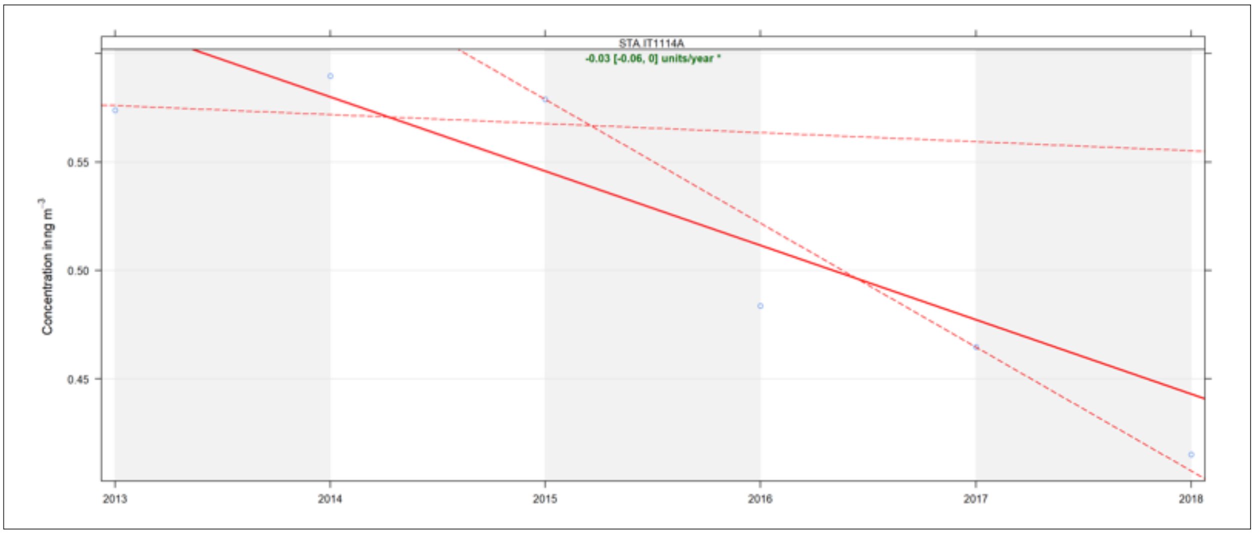

Figure 26: *Recent trend of BaP at an Italian monitoring station in the Alps. The solid red line shows the trend estimate and the dashed red lines show the 95% confidence intervals for the trend. The overall trend is shown at the top-left as - 0.03 µg/m³ per year and the 95% confidence interval is -0.06–0 µg/m³/year. The symbol * indicates that the trend is significant at the 0.05 level.*

5.3.5 BaP

Trends could only be assessed for 10 stations (1 in Germany, 3 in Austria and 6 in Italy) since other stations did not have enough historical data to evaluate a trend. The trend is generally downwards but not significant in most cases, except for one station in Italy where it is significantly negative (Figure 26).

The analysis of trends was focused on pollutants displaying exceedances of European limit or target values and WHO guidelines. In line with what was observed in Europe, the analysis performed on the 2009-2018 period shows an overall improvement of air quality for several pollutants. As illustrated by the graphs, interannual changes in concentration vary through time. However, over the considered decade, the average change rate of annual mean concentrations is negative both for NO_2 (-2.7%/year and -3.1%/year at traffic and urban background stations respectively) and PM_{10} (-3.1%/year and -4.0%/year at the same types of stations). $PM_{2.5}$ concentrations show the highest average rate of decrease: -5.6%/year at urban background stations. No trend could be identified for ozone. Concentrations of benzo(a)pyrene seem to be on a downward trend, but this needs to be confirmed by more data. This overall favourable development, combined with only a few persisting exceedances of EU thresholds or WHO guidelines, is an encouragement towards continued efforts and actions against air pollution.

6. RELEVANT RESEARCH PROJECTS AND OBSERVATORIES FOR AIR QUALITY IN THE ALPS

In addition to the regulated air pollutants shown in Table 1, other substances will become relevant for the future of the Alpine region. This chapter looks at relevant issues currently investigated in cooperative research programmes, with more details provided in Annex 2.

A major challenge in the Alpine region, reported in several national and transnational studies and reports summarised in the annexes, is the emissions and concentration levels of particulate matter ($PM_{2.5}$/PM_{10}/UFP) from wood combustion. Wood burning is a traditional anthropogenic behaviour, but the problems it creates in terms of POPs and VOCs are exacerbated by the special orographic situation of the Alps.

Climate particularly influences the ecosystem but also the atmosphere, which in turn will affect the distribution and deposition of air masses and pollutants as well as change the atmospheric layer heights and the chemical reactions. For the moment, information and evidence on how climate change will influence air quality, and thus human health, are still limited. The general assumption is that regional mean ozone concentrations will increase.

All these questions are observed and investigated by scientists. This chapter discusses the main past and ongoing research projects and observation facilities that contribute to a better knowledge of air quality in the Alps.

6.1 THE ENVIRONMENT RESEARCH PROJECT "PUREALPS"

The MONARPOP project, concluded in 2008 (see Annex 2) focused on POPs and other organic substances in the atmosphere of Alpine areas. Since 2016, these measurements have been continued by two projects of the same name, PureAlps (Freier K.P. *et al.*, 2019), in Austria and Bavaria. Pollutants such as polychlorinated dibenzodioxins and furans, polychlorobiphenyls (PCB), PAH, organochlorine pesticides (OCP), halogenated flame retardants, mercury and other novel organic fluorine and chlorine chemicals are being investigated. The results of more than 15 years of monitoring show that the high altitudes of the Alps are exposed to the input of persistent organic pollutants due to condensation effects (Figure 27). Although air concentrations of pollutants are many times lower than in urban regions, deposition of pollutants in the Alps often has a similar order of magnitude. This means that even remote Alpine areas are no longer free from environmental risks due to chemicals. Certain pollutants with significant regional sources, such as lindane from wood building materials or PAHs from the combustion of wood, are more prevalent in the central Alpine region.

Due to the EU regulation Reach (Registration, Evaluation, Authorisation and Restriction of Chemicals, Regulation EC/1907/2006) and to the Stockholm Convention, some pollutants have de-

Figure 27: *Result from air mass-related measurement: impact on the Alpine peaks from three dominating directions; as indicated, some directions show higher concentrations of PCB and OCP.*[33]

creased their ambient air concentrations in the Alps. These pollutants include the largely banned organochlorine pesticides. By contrast, the concentration of dioxins in the ambient air have so far only decreased slightly or, in the case of PCB, remained stable. The reasons are still unclear and are due to be investigated in more detail in the context of the PureAlps projects. There have been significant increases of octachlorostyrene in the air – a substance that is an unintended by-product in the production of chlorinated solvents and emits from the combustion of chlorinated hydrocarbons. The flame retardant decabromodiphenylethane (DBDPE), which is used in large tonnages, also exceeded the detection limits of measuring instruments for the first time in 2012 and currently has the highest concentration in ambient air of monitored halogenated flame retardants.

6.2 HIGH ALTITUDE ENVIRONMENT MEASURING STATIONS

In the Alpine region, high-altitude stations exist where monitoring and research activities on air pollution, weather and climate are performed: Zugspitze at Schneefernerhaus (DE, Umweltbundesamt Germany, see Figure 28), Hohenpeißenberg (DE, Deutscher Wetterdienst), Jungfraujoch (CH), Sonnblick (AT, see Figure 29) and Plateau Rosa (IT). The special locations in Europe and in the Alps make these stations of special interest for science research and monitoring tasks of e.g. long-range transport of pollutants, monitoring of airborne persistent organic substances for the aims of the Stockholm Convention on POPs[34], physical and chemical changes in the atmosphere, intrusion of air masses (and pollutants) from the stratosphere to the troposphere, and generation and transport of pollutants. Most of the above stations form part of the Global Atmospheric Watch Programme (GAW) of the World Meteorological Organization (WMO), the European Monitoring and Evaluation Programme (EMEP) network, and the ACTRIS programme (Aerosols, Clouds, and Trace gases Research Infrastructure Network). Italy also takes part in these programmes through another high-altitude station, Monte Cimone (northern Apennines). The Plateau Rosa (and Monte Cimone), Zugspitze/Hohenpeißenberg and Jungfraujoch stations are also part of the Integrated Carbon Observation System (ICOS) for the long-term monitoring of greenhouse gases, the EMEP and GAW Monitoring Network. These Alpine countries are also working intensively together in the GAW programme to collect data on worldwide atmospheric

Figure 28: *Umweltforschungsstation Schneefernerhaus at Zugspitze. © Markus Neumann (UFS).*

33. *PureAlps – Monitoring of Persistent Pollutants in the Alps; brochure published by Bavarian Environment Agency, Augsburg, and Environment Agency Austria, Wien; 2019, page 5 (available at https://www.bestellen.bayern.de/).*
34. *Stockholm Convention on persistent organic pollutions (http://chm.pops.int/TheConvention/Overview/TextoftheConvention/tabid/2232/Default.aspx).*

Figure 29: *Sonnblick Observatory. (© ZAMG/SBO Ludewig).*

processes in the fields of components affecting transnational and transboundary climate.

The altitude measuring stations Sonnblick (AT), Zugspitze and Hohenpeißenberg (DE) as well as the Swiss High-Altitude Research Stations Jungfraujoch (CH) and Climate Observatory "Ottavio Vittori" at Monte Cimone (IT) investigate airborne trace gases, which are used *inter alia* for the monitoring of the Stockholm Convention on POPs.

6.3 EXISTING MONITORING NETWORKS (OTHER THAN THOSE FOR 2008/50/EC AND 2004/107/EC) WITHIN THE ALPINE PERIMETER FOCUSED ON AIR POLLUTION ASSESSMENT

6.3.1 GERMAN ULTRAFINE NETWORK

There is a measuring station for ultrafine particles at the Umweltforschungsstation Schneefernerhaus (UFS) Zugspitze. It works as part of the GUAN - German Ultrafine Network - with the measuring station at the Hohenpeißenberg in the foothills of the Alps. UFP measurements in the high-altitude stations compare the UFP measurements in the Alpine region with the air in urban areas and provide information on natural particles formation compared to particles of anthropogenic origin.

Due to its measuring sensitivity, the UFS Zugspitze station is currently being used within the framework of the Virtual Alpine Observatory project, in cooperation with Italy, Austria, France and Switzerland, for altitude research, monitoring air quality and developing prediction models as well as for understanding processes of climate change.

6.3.2 NEXTDATA-PROJECT FOR OZONE-RESEARCH

In Italy, the NextData project (2011-2013) of the Italian National Research Council (Consiglio Nazionale delle Ricerche - CNR) was aimed at favouring the integration of a network in mountain and remote areas, based on atmospheric observatories for the monitoring of atmospheric composition and ancillary data (meteorological parameters and solar radiation). The main goal of this network was to investigate the processes which influence the variability of air pollutants and climate-altering compounds (stratospheric ozone-depleting halocarbons regulated by the Montreal Protocol, non-CO_2 greenhouse gases included in Kyoto Protocol, ozone and non-methane volatile organic compounds, mineral aerosol and black carbon), and to continuously monitor trace gases and aerosol properties (fine and coarse size distribution, absorption coefficient).

The network comprised five high-mountain atmospheric observatories: Monte Cimone (northern Apennines, 2165 m.a.s.l.), project Plateau Rosa (western Alps, 3480 m.a.s.l.), Col Margherita (eastern Alps; 2550 m.a.s.l.), Monte Portella – Campo Imperatore (central Apennines; 2401 m.a.s.l.), and Monte Curcio (southern Apennines, 1796 m.a.s.l.). Continuous O_3 measurements were implemented at Col Margherita to assess a possible transport to high altitudes of air masses influenced by anthropogenic emissions. According to other mountain sites, a diurnal O_3 variability was evident during the summer season, with the highest values during the evening/night and the lowest in daytime. During the central part of the day, it is possible that dry deposition occurs along mountain slopes, causing a decrease in O_3 concentration, while at night O_3 probably builds up either due to local anthropogenic emissions and favourable weather conditions or is transported long-range from and exchanged to the stratosphere. In addition, a significant weekly cycle of O_3 can be observed in the summer, with values increasing during the week. Conversely, in winter, a reverse day-night cycle can be observed.

6.4 OBSERVATION OF AIR QUALITY IN THE ALPINE REGION AS PART OF THE VIRTUAL ALPINE OBSERVATORY (VAO) - A CONTRIBUTION TO THE ALPINE CONVENTION

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The Virtual Alpine Observatory[35], is an association of Alpine and associated observatories from other mountain regions in Europe, whose aim is to jointly address scientific and social issues relevant to the Alps, especially in the context of climate change. The Alpine Convention has the status of an observer in the VAO.

Within the framework of VAO, air quality in the Alpine and pre-Alpine regions is monitored. For this purpose, measurements from ground-based stations, from satellite-based instruments (in particular the European Space Agency Sentinel Programme[36], Figure 30) as well as data from the European COPERNICUS Atmospheric Service[37] are used.

For the daily forecast of air quality near the ground (currently two days ahead), the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt - DLR) uses a numerical model system consisting of a meteorological model (WRF[38]) and a chemical transport model (POLYPHEMUS/DLR[39]), which takes into account the special conditions of the Alpine region. The distribution of air pollutants is predicted within administrative districts (counties) on an hourly basis and with a horizontal resolution of 6 km. Thanks to the so-called "nesting methods", the spatial resolution can be increased regionally to 2 km. In urban areas, a resolution of up to several metres can be achieved by coupling with another hydrodynamic model (EULAG[40]).

Air quality is one of what are called "environmental stressors". This means that air pollutants can affect human well-being. The potential impact of selected air pollutants - as well as meteorological stress - is therefore also calculated daily on the basis of the air quality situation and meteorological status and is reported in the form of an "Aggregated Risk Index, ARI" (Sicard P. *et al.*, 2012) or the "Universal Thermal Climate Index - UTCI[41]".

All results are available daily to the public via the Alpine Environmental Data Analysis Centre[42] (AlpEnDAC) of the VAO which offers it as a service without access restrictions.

The above system is also used for scientific studies (e.g. on the influence of climate change on air quality or on questions of the impact of the Covid-19 pandemic on air pollutant concen-

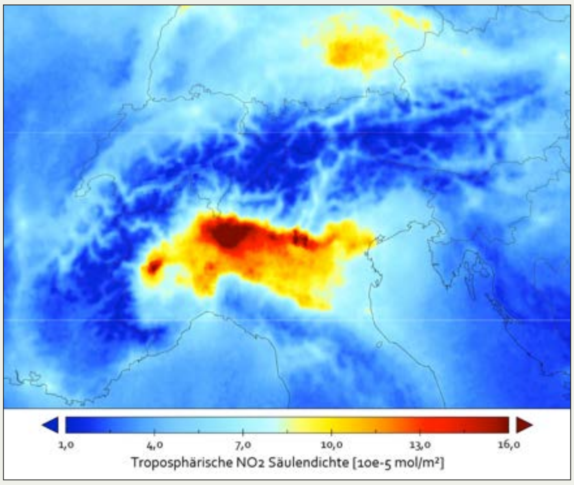

Figure 30: *Mean concentration of the tropospheric NO_2 column for the period from January to June 2019 over the Alpine region (satellite-based measurements from ESA's Sentinel 5P, German Aerospace Center).*

35. *https://www.vao.bayern.de.*
36. *https://sentinel.esa.int/web/sentinel/home.*
37. *https://atmosphere.copernicus.eu/.*
38. *https://www.mmm.ucar.edu/weather-research-and-forecasting-model.*
39. *https://www.spiedigitallibrary.org/conference-proceedings-of-spie/10793/1079303/Air-quality-monitoring-and-simulation-on-urban-scale-over-Munich/10.1117/12.2503969.short?webSyncID=a0ce46e9-e6ec-7a49-dab6-a0cbad059329&sessionGUID=ad883c9d-902b-c999-3ced-268bead49a28&SSO=1.*
40. *https://www2.mmm.ucar.edu/eulag/.*
41. *http://www.utci.org/isb/documents/windsor_vers04.pdf.*
42. *https://www.alpendac.eu/.*

trations) and it also enables the study of scenarios (e.g. questions on the impact on air quality of an increase in motor traffic, the expansion of transport routes or urban densification).

Some examples are presented below.

6.4.1 THE BIOCLIMATIC INFORMATION SYSTEM (BIOCLIS))

A service (with a project status) offered by AlpEnDAC is the Bioclimatic Information System. It provides average daily values as well as a time series of air pollutants, meteorological parameters and the influence on human well-being over a period of four days aggregated in districts. Figure 31 shows a screenshot of the BioCliS web page.

6.4.2 TWO EXAMPLES FOR SCENARIOS

As an example of a typical question, Figure 32 shows a simulation of NO_2 distribution and the distribution of PM_{10} as it would possibly result from a doubling of road traffic in the central Alpine transit routes. The figure shows the hypothetical situation for a period of 10 days in February 2018, indicating the increase of NO_2 load

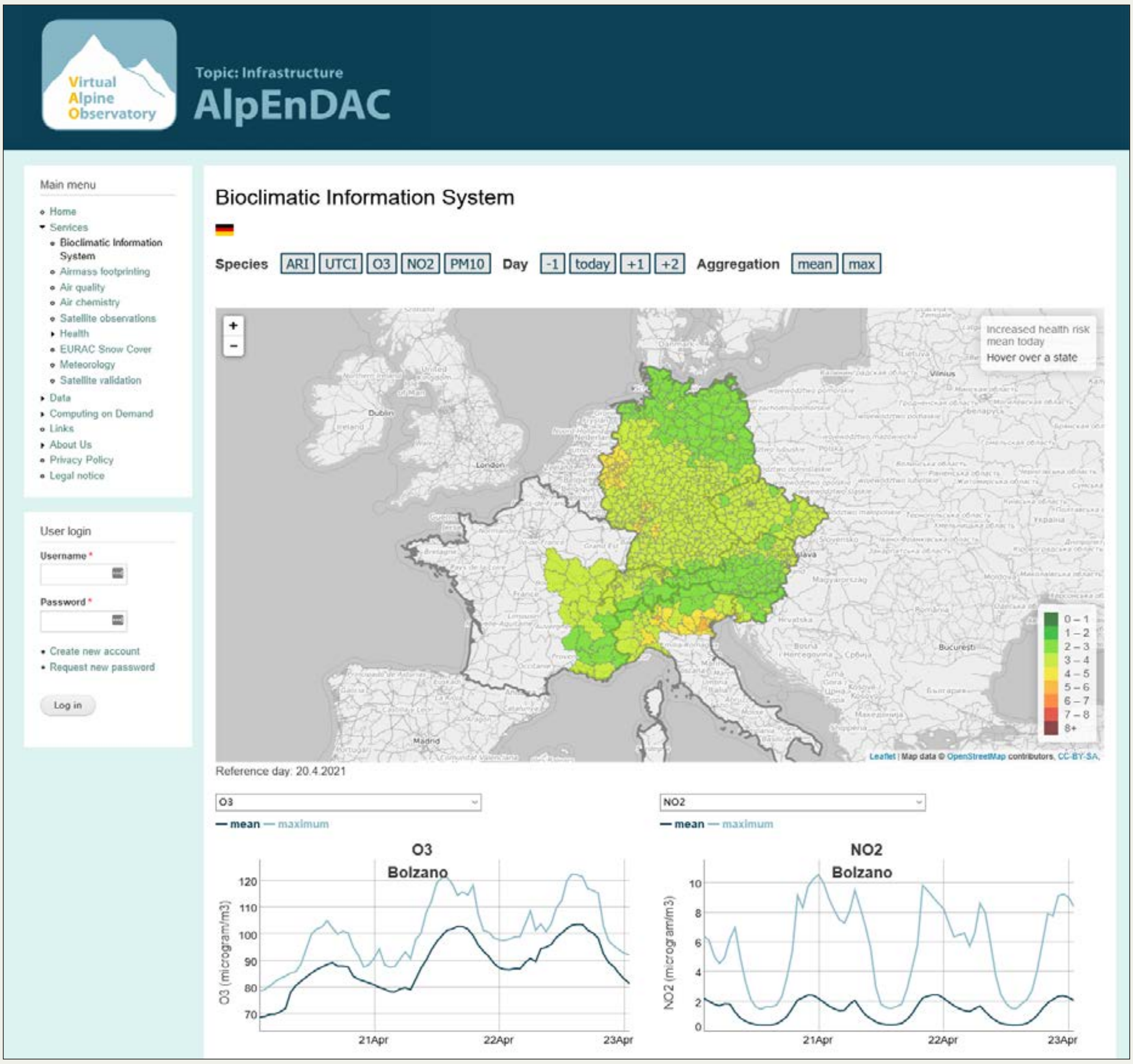

Figure 31: Bioclimatic information system by district (further information: https://www.alpendac.eu/landkreis-tool).

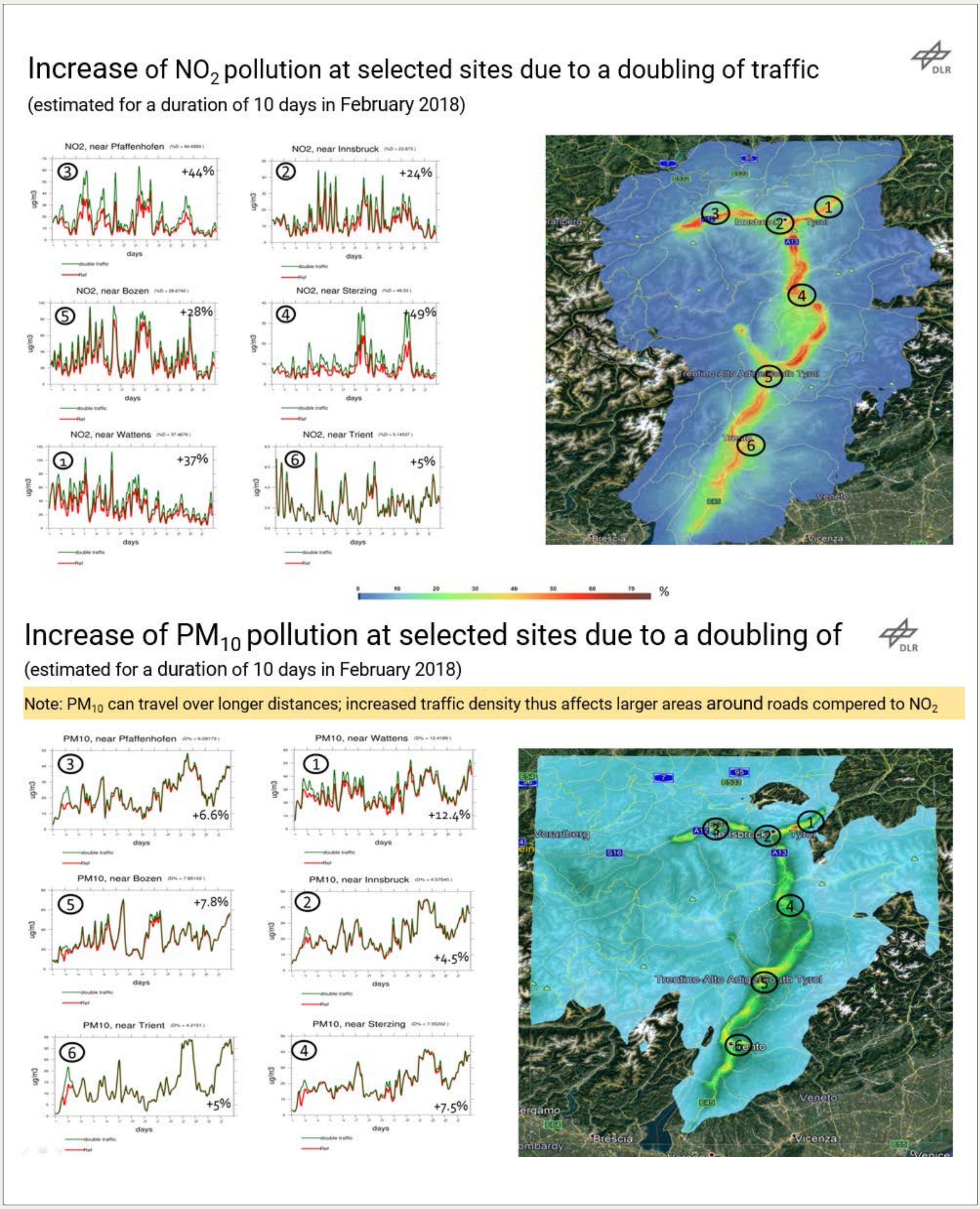

Figure 32: *Simulation of the influence of the doubling of road traffic for a period of 10 days in February 2018 on the NO_2 concentration (top) and on the fine dust concentration (PM_{10}) (bottom).*
Data are provided for normal traffic (red) and for doubled traffic (green). The map on the right side shows the mean deviation between normal and doubled traffic (on the motorway only) induced pollution for the first 10 days of February 2018.

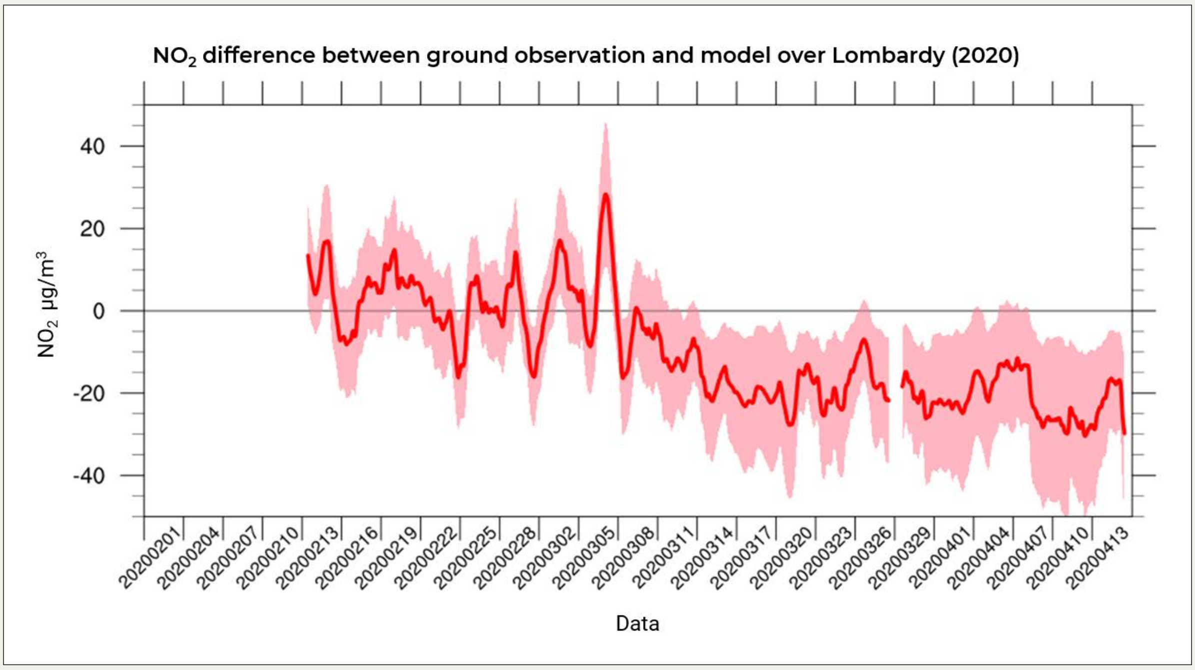

Figure 33: *Difference between the NO_2 concentrations measured at 25 ground stations in Lombardy and the WRF-POLYPHEMUS/DLR model for the period from 1 February 2020 to 13 April 2020.*

compared to the normal situation. For selected locations, the graphs on the left of the picture show the expected higher NO_2 load. It should be noted, however, that near larger cities, such as for instance Innsbruck, the impact of doubling motorway traffic might be comparably smaller due to the influence of high local emissions from numerous sources. The graph in Figure 32 shows the situation for PM_{10}.

Another example of a typical investigation is shown in Figure 33. The first lockdown due to the Covid-19 pandemic severely restricted road traffic and industry. Measurements of NO_2 from ground-based stations or even from satellites indicate a reduction of NO_2 pollution. However, natural variations in the NO_2 load due to weather masks this effect in the measurements. The reduction of NO_2 pollution caused by the lockdown becomes particularly clear when comparing measurements with the above-mentioned model because the model considers many natural influences on NO_2 variability. Figure 33 thus shows the difference between the model and over 25 measurements from ground stations in Lombardy. The decrease during the lockdown in NO_2 load by up to 30 µg/m³ can be clearly seen, corresponding to a decrease of up to 45% compared to the normal state.

6.5 WHICH FUTURE FOR THE MONITORING OF AMBIENT AIR POLLUTANTS?

The measurement and monitoring of trace pollutants such as POPs, F-gases, halogenated gases and of ultrafine particles at high altitude measuring stations are necessary and urgent. The Alpine region's special characteristic of being highly sensitive to pollutants, both showing a good dispersion of pollutants while also being a trap for them, requires additional attention. In this regard, the Alps can also be seen as a "sentinel" to detect emerging pollutants and alert on future impacts of anthropic activities.

In this context, measurements of UFP may also be of interest for densely populated valley locations with industry and traffic. However, scientific knowledge on the measurement methodology and the assessment of the health effects is still being acquired. Further research is therefore needed on UFP and their effects on human health and the environment.

In addition to collecting precise data about air pollutants, the measuring stations also need to be arranged representatively to be able to reliably describe the specific meteorological features of local areas.

The detection of air pollutants via data from satellites and its coupling with *in situ* measurements and modelling will become of greater importance, as exemplified by the VAO in Section 6.4. Such an observatory will give a better picture of air pollution in the Alps. A network of low-cost-sensors could also complement the existing measurements and involve the public to increase their awareness of air quality issues. However, it should not replace certified measurements since it lacks reliability and is currently not appropriate for health effect investigations.

7. EXAMPLES AND SMART SOLUTIONS TO REDUCE AIR POLLUTION

This chapter is based on examples of measures and solutions provided by the experts of the Working Group. These measures can be applicable at different levels, from national to local, for improving air quality with a focus on the Alpine region. Many actions to improve air quality have side effects that the current analysis tries to capture, especially when a positive effect on another environmental issue, for instance climate change, leads to adverse effects on air quality (the typical example is that of wood burning). At the same time, measures not intended to specifically reduce air pollution may also have positive impacts on air quality. When this information is available, this study stresses the efficient win-win situations. For instance, the decarbonisation of the Alpine economy might co-benefit air quality when cleaner transportation systems are implemented but could also have adverse effects if biomass combustion develops without appropriate technology.

7.1 BIOMASS COMBUSTION & GENERAL HEATING SYSTEMS

The legal framework, including limit values and measures that specifically target heating and wood-fired systems and industrial applications, was adapted in the regulations of some Alpine countries as shown in Chapters 2 and 3. Smart solutions for reducing emissions from heating activities, particularly wood-based, start by setting out guidelines and thresholds for heating buildings. In addition to ceilings and guidelines, financial incentives can be organised to help citizens meet the limits. Another pillar is setting up research or exchange networks and the dissemination of knowledge. Finally, several examples for district heating networks are presented. Under certain circumstances district heating provides a useful solution to ensure more efficient and cleaner heating.

7.1.1 FINANCIAL INCENTIVES

7.1.1.1 Reduction of particle emissions from wood heating systems in private households, France

In France, financial aid funds are available for private households located in communes particularly polluted by PM. These funds aim to help private households replace highly polluting heating systems by improved versions whose emissions and energy efficiency are labelled. All eligible households have access to these funds, irrespective of their income: this gives the population an incentive to replace their old heating systems. These funds are backed by communication campaigns to the public to improve their knowledge about good practices in this respect.

A simple but effective measure was needed for areas polluted by particulate matter. Therefore, an economic incentive was tested for over four years in one Alpine region. The evolution of the concentration of PM_{10} originating from wood burning was measured throughout this pilot project. The following efficiency gains were observed:

- a steady reduction of PM over time;
- a reduction of PM_{10} between 4% and 12% when replacing less than 30% of inefficient heating systems was observed after 4 years in the pilot project.

Thus, this measure was considered a success and was expanded on a national scale.

7.1.2 KNOWLEDGE ENHANCEMENT

7.1.2.1 Measures for wood use in heating, Slovenia

Complementing the heating measures outlined in the Plan for Maintaining Air Quality, the *Strategy for Wise Use of Wood for Energy Purposes* focusses on improving resource input of wood heating. It is based on a precise analysis of the use of wood to heat buildings in Slovenia where 205,000 combustion units use solid fuels. More than half of them are over 20 years old.

The objectives of the Strategy are:

- to use wood wisely and efficiently as a domestic and renewable resource for raw material and energy;
- to efficiently process and use round timber from Slovenian forests in the country, primarily in the wood industry and secondarily for energy purposes;
- to ensure high efficiency when using wood for energy purposes;
- to support the construction of modern and efficient shared boilers using wood biomass, where the spatial distribution of buildings allows it;
- to support the replacement of individual combustion units and reduce particulate matter emissions from outdated combustion units;
- to establish a competence centre for heating with wood, together with a mobile demonstration centre for small combustion units;
- to improve the cooperation and coordination of decision-makers, experts and other stakeholders involved in the use of renewable energy sources.

7.1.2.2 Knowledge Transfer on different administration levels: Cercl'Air Swiss society on air quality, Switzerland

Cercl'Air is an association of Swiss authorities and academics in the field of air quality and non-ionising radiations. It fosters and promotes, in the complex federal system, inter-cantonal coordination of the implementation of air quality protection laws and facilitates knowledge transfer between science and administrations. One of its fields of activity also covers domestic heating (wood burning and fuel quality).

7.1.2.3 Agreement on small wood-burning small systems, Italy

In Italy, financial incentives for replacing old appliances with low-emission versions are in place, but it is also necessary to promote a cultural change on this issue. To this end, an agreement[43] has been signed between the Ministry of Environment, Land and Sea and the Associazione Italiana Energie Agroforestali, a trade association representing more than 500 companies in the wood energy sector including producers and distributors of firewood, wood chips and certified pellets, manufacturers of heat generators and biomass systems as well as installers and maintainers of biomass systems. The association promotes the energy exploitation of biomass from agriculture and forestry.

This agreement promotes investments in research and development by the associated manufacturers to support and accelerate the process of technological innovation of biomass plants, aimed at increasing the efficiency of generators and reducing emissions, with particular reference to PM and BaP. It activates appropriate training processes for updating and providing professional qualifications to installers and maintainers of wood-based biomass plants. The agreement also foresees information campaigns for producers and users and encourages the addition of a short guide on the correct use of domestic appliances using wood and pellets to the use and maintenance manuals for heating systems in the high-quality classes. Lastly, it sets out some actions aimed at finding resources to promote replacing old systems with new, low-emission types.

It also enables access by all the Regions and Autonomous Provinces concerned, which commit to both the intensification and strengthening of operations for controlling civil thermal biomass plants as well as to providing more constant information to the public.

43. *https://www.minambiente.it/sites/default/files/archivio/allegati/inquinamento_atmosferico/Protocollo_Intesa_MATTM_AIEL.pdf.*

7.1.3 DISTRICT HEATING

7.1.3.1 Measures for buildings' heating according to the Plan for Maintaining Air Quality, Slovenia

The Plan for Maintaining Air Quality[44] shall cover all areas outside of urban agglomerations, which have individual plans for improving air quality. The measures are differentiated according to the spatial characteristics and among others include:

1. setting up new microsystems for wood biomass district heating in separate, densely settled areas and connecting them to all buildings in the area;
2. setting up shared small wood biomass combustion units where conditions permit and connecting them to all buildings in the area;
3. substituting outdated small wood biomass combustion units with modern ones and, in dispersed settlement areas, with heat pumps;
4. providing information, communication and education about good practices, demonstrating and promoting the positive effects on air quality in areas where outdated small combustion units are still in use.

7.1.3.2 District wood heating system in Disentis-Mustér, Switzerland

By establishing a district heating network in the municipality of Disentis-Mustér in the Canton of Grisons, fine dust emissions could be significantly reduced as compared to those of decentralised heating systems tanks to the proper functioning of the system and to filter systems. The chosen fuel is wood, which is also low in CO_2 emissions and locally available.

Disentis-Mustér is a mountain village in the canton of Grisons. In November 2009, many oil and gas heating systems in the centre of the village had become outdated and had to be replaced. In early 2010, instead of returning to fossil fuels, the local population, supported by communal and cantonal administrations, took the initiative and aimed at creating a district heating plant fired by locally available wood resources, whose heat would then be distributed throughout the village. A welcome side effect of this measure is that particulate emissions can be reduced. By now, 117 recipients are connected to the district heating network, including the monastery of Disentis, the town hall and the local supermarket. The first heating boiler has a capacity of 1,977 kW, the second has 1,955 kW. The pipeline network has a total length of 4.7 km. The plant saves an estimated 1.2 million litres of fuel oil annually and has a total output of 3.5 MW[45]. Due to the lack of comparative figures, no statement can be made about the particulate matter emissions saved. However, the savings must be considerable as the plant is equipped with state-of-the-art electrostatic precipitators and emissions fell considerably below the fine dust limit values of 20 mg/Nm³ [46].

Heating networks offer the advantage that instead of several decentralised heating systems, there is only one central control unit, which is equipped with the necessary filter systems and has very low emission values and a high degree of efficiency.

7.1.3.3 Enlargement of district heating system, Bavaria, Germany

The target of this measure is to reduce contributions to air pollution by substituting individual house heating by connecting households to a centralised combined heat and power plant.

Example:
Bioenergie Berchtesgadener Land (Bavaria)
In 2011, the company Bioenergie Berchtesgadener Land GmbH put a biomass power plant in the municipality of Schönau am Königssee into operation. It uses biomass to generate electricity and heat: for energy production, only regional forest woodchips coming from within a radius of 80 km are used. Most of the wood comes directly from the Berchtesgaden basin. The district heating network extends over a distance of more than 33 km, covering parts of the communities Schönau am Königssee, Berchtesgaden and Bischofswiesen. Coupled with the technical performance to overcome 150 m of elevation difference, the inter-communal district heating supply of Bioenergie Berchtesgadener Land is a showcase project for the use of renewable energies in a rural area[47]. By

44. *After public consultation in the beginning of 2020 the Government will adopt the Plan by the end of 2020.*
45. *https://www.gr.ch/DE/institutionen/verwaltung/bvfd/aev/dokumentation/EnergieeffizienzEnergieaperoDokumente/EA81_Sac.pdf.*
46. *The term "N" stays for "normal", i.e. under normal conditions of temperature and pressure (usually 25 °C, and 1 atm respectively).*
47. *https://www.bebgl.de/.*

operating a centralised combined heat and power plant, the emissions of air pollutants like NO_x and PM have been significantly reduced compared to individual heating systems operating in each household.

7.1.3.4 Environmental support scheme for biomass district heating, Austria

In order to promote district heating with biomass, the Austrian Environmental Support Scheme for district heating was established, which applies to:

- biomass plants for district heating;
- construction and expansion of heat distribution networks based on biomass, geothermal energy or industrial waste heat;
- optimisation of local heating systems - primary and secondary;
- renewal of boiler systems in existing biomass local heating systems;
- biomass cogeneration (biomass CHP).

A precondition for obtaining funds is to take part in the "Quality Management Heating Plant" programme, which addresses energy efficiency and optimisation of technologies and plants. Another precondition is to construct and operate the plant to maintain the emission limit values shown in Table 10.

7.2 REDUCTION OF VOC/ZONE PRECURSORS EMISSIONS

This section considers two countries where reductions of VOC and NMVOC emissions have been organised: the legal framework of Germany for VOC emitting installations and the corresponding Swiss legislation, as well as a success story of Switzerland's NMVOC incentive fee.

7.2.1.1 NMVOC Regulation, Switzerland

In order to reduce NMVOC emissions, Switzerland has three policies and measures in place: (i) the international exhaust gas regulations for motor vehicles, which are fully implemented in Swiss regulations, (ii) the Ordinance on Air Pollution Control for stationary sources, and (iii) the NMVOC incentive fee to reduce emissions of NMVOCs.

The NMVOC incentive fee is defined in the Ordinance on the Incentive Tax on Volatile Organic Compounds, which came into force in 1997. As a market-based instrument in the field of environmental protection, it creates a financial incentive to further reduce NMVOC emissions. The tax (CHF 3/kg VOC) currently raises around CHF 110 million annually and is largely redistributed to Swiss residents by lump-sum payments.

The Swiss Federal Office for the Environment regularly reviews the effect of the levy, analysing the mass balances reported and paid by 600 of the most affected companies. In addition, a company survey was carried out in 2017 in cooperation with the industry associations concerned. The results show that the levy continues to contribute to emission reductions. From 2007 to 2016 the emissions regulated by the ordinance fell by 15% overall, while the intake of VOC rose by 20% among the companies filing mass balances.

The submission of Switzerland's Informative Inventory Report 2020 (IIR) shows that the Ordinance on Air Pollution Control, the NMVOC incentive fee and the development of Euro emissions standards have helped considerably reduce VOC emissions by almost 30% compared to the emissions of 2005[48].

7.2.1.2 Stricter Regulations for VOC emitting installations, Germany

In order to reduce ozone concentrations, there are

Thermal input	≤ 500 kW	0.5 – 1 MW	1 – 2 MW	2 – 5 MW	5 – 10 MW	> 10 MW
NO_x (mg/Nm^3; 10% O_2)	200	275	275	220	220	110
Dust (mg/Nm^3; 10% O_2)	40	83	36	22	11	11

Table 10: *Emission limit values for biomass district heating plants (Austrian environmental support scheme).*

48. *Switzerland's Fourth Biennial Report under the UNFCCC 2020: https://unfccc.int/sites/default/files/resource/CHE_BR4_2020.pdf.*

several EU Directives for lowering the emissions of volatile organic compounds from installations. For example, Chapter V of the Industrial Emission Directive (IED) (2010/75/EU) and the Petrol Stage I/II Directives (1994/63/EC, 2009/126/EC). By setting stricter requirements in the implementation of the VOC Directives and application of best available techniques, the VOC emissions can be reduced to a larger extent.

Examples:
Implementation of Chapter V EU Industrial Emission Directive in the German ordinance regarding the reduction of VOC emissions resulting from the use of organic solvents in specific installations – 31st BImSchV (Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes)[49]:

- Many thresholds for VOC activities have been lowered.
- For coating/printing installations: captured waste gases without purification are considered as fugitive emissions. This generally requires the application of a reduction scheme or of waste gas abatement.
- For installations requiring an environmental permit, the best available techniques must be applied.
- The federal TA Luft (Technische Anleitung zur Reinhaltung der Luft) emission values for organic compounds of class I No 5.2.5 have to be applied for stack emissions: 20 mg/Nm3 (compared with Chapter V IED: only for halogenated VOC which are assigned or need to carry the hazard statements H341 "Suspected of causing genetic defects" or H351 "Suspected of causing cancer"). Chemical Dry Cleaners: only Perchloroethylene (PERC) is allowed as a halogenated cleaning agent. Machines must have electronic interlock and a PERC measurement device. The machine door may only be opened if the measured emission mass concentration in the air from the drum after drying is below of 2 g/m³.

Implementation of Petrol Stage I/II Directives in 20th and 21st BImSchV[50]:

- The scope of 20th and 21st BImSchV is much broader than Petrol Stage I/II Directives and includes Naphtha and mixtures of fuel with 10%-90% bio-ethanol.
- Vapour recovery units at terminals: the emission limit value is 50 mg C/Nm^3 (without methane) instead of 35 g/Nm^3 (including methane).
- Automatic interlock system at service stations that only allows fuel to be unloaded from a road tanker if the vapour balance line is connected to the storage tank.
- Automatic monitoring of the vapour recovery system of petrol service stations during refuelling of vehicles is mandatory.

7.3 TRANSPORT SECTOR FOCUSING ON REDUCTION OF NO_2 AND PM

The examples from the transport sector provided here as inputs from countries and regions represent the largest field of action with the broadest variety of measures targeting the reduction of air pollution. Most of these measures for reducing air pollutants include a mix of features applicable to infrastructures, vehicles, regulations, operations, technological and managerial innovations, and financing. Moreover, in most cases, regulatory provisions are established nationwide, not specifically at regional or Alpine level. Action plans for clean air at regional level or sustainable urban mobility plans reflect the integral character of this combination of measures based on national or European rules.

Nevertheless, in case of necessity, the regional authorities within the perimeter of the Alpine Convention may introduce strong specific measures which counterbalance and remedy exceedances of the limit values.

7.3.1 REGULATORY MEASURES AND MODAL SHIFT POLICY FROM ROAD TO RAIL: FREIGHT AND PASSENGER TRANSPORT

7.3.1.1 Modal shift in Freight Transport, Alpine-wide

Transalpine freight transport is a major challenge regarding air quality (and noise pollution) for the inner Alpine Arch. Four main road axes crossing the Alps have significant impacts in terms of air

49. Examples: https://www.gesetze-im-internet.de/bimschv_31/.
50. Examples: https://www.gesetze-im-internet.de/bimschv_20_1998/, https://www.gesetze-im-internet.de/bimschv_21/.

pollutant emissions (Fréjus, Mont Blanc, Gotthard, Brenner) (Figure 34).

In all countries and regions, efforts are being undertaken to reduce air pollution by substituting road transport with rail, both in the freight and passenger sectors, at national level and partly in the Alps. Specifically in the Alpine region with its narrow valleys and limited natural resources, reducing the negative impacts on air quality by substituting road transport with rail could have significant positive effects. In most of the countries and regions, specific measures are taken to promote intermodality with the aim of increasing the share of goods transported by rail. In many cases, although measures promoting intermodality are taken and implemented outside the Alpine area, they have a strong impact in terms of lowering emissions within it.

A comparison of emissions between rail and road freight transport is given by the updated Handbook of Emission Factors, summarised in Table 11, which has also been taken up by the German Federal Agency for the Environment (Umweltbundesamt Deutschland, UBA)[51]. The last line provides an average surface land use factor (high-speed train vs. motorway):

Air pollutant in g/t.km / land use (dimensionless)	HGV (>3.5t)[a]	Freight train[b]
NO_x	0.269	0.037
PM[c]	0.004	0.000
VOC[d]	0.037	0.003
CO_{2equiv}	112	18
Land use factor[e]	3	1

Table 11: *Comparison of emissions between rail and road freight transport. Reference year: 2018; g/t.km: grams for moving one tonne for one km, incl. transformation processes.(a) Mix of different types of Heavy goods vehicle: > 3.5t up to 40t, mono-truck, lorry with trailer, semitrailer; (b) Basis: average mix of electricity in Germany; (c) Without abrasion of tyres, brakes, road surface, overhead contact; (d) Without methane; (e) https://www.allianz-pro-schiene.de/themen/umwelt/flaechenverbrauch/.*

Figure 34: *Transport pathways through the Alps (Alpine Traffic Observatory, 2020).*

51. https://www.hbefa.netl and https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#emissionen-im-guterverkehr-tabelle.

Moreover, the Grace study of 2006 and the more recent EUSALP study (2017) on external cost in mountain areas were able to calculate a so-called Alpine “mountain factor” which takes into account the specificity of mountain regions as far as the external cost of environment degradation is concerned. These mountain cost factors represent the ratio between external costs in mountainous and non-mountainous areas and are summarised in Figure 35. The additional external cost factor for road transport air pollution in Alpine areas averages 4.2 compared to 2.6 for rail transport. Modal shift policy from road to rail may in this respect have a particularly positive impact in Alpine areas.

7.3.1.2 Modal shift policy in transalpine freight transport, Switzerland

In Switzerland, the modal shift policy in the freight transport sector has been a key issue for 25 years. A Constitutional Act on the protection of the Alps was established in 1994 by a popular initiative, followed by federal laws regarding the introduction of the performance-related HGV fee. The modal shift law specifies the maximum number of heavy vehicles allowed in transalpine transport (650,000 per year), the construction of the new railway link through the Alps and various complementary measures. The Land Transport Agreement between Switzerland and the EU embraces this overall package for implementation.

The modal shift policy includes both aspects: transport reduction in terms of number of vehicles and, implicitly, reduction of transport related emissions. The push and pull measures are:

- infrastructure construction as an alternative to road transport = new railway base tunnels through the Alps;
- introduction of performance related HGV fee (weight, distance and emission related);
- increased maximum total weight limit for HGV from 28 to 40t (transport efficiency);
- regulatory railway reform measures;
- financing measures to promote rail freight subsidies for combined transport/slot prices in freight, terminal links.

Since 2004, the relevant air pollutants NO_2 and PM decreased significantly, due to improved vehicle technology and the reduction in the number of vehicles, as shown in Figure 36. Nevertheless, the specific topography of Alpine valleys is still contributing to stronger negative impacts of air pollutants than in flat regions, which results in some exceeding of the limit values for NO_x and PM. The long-term experience over almost 20 years shows that the combined measures of regulatory, technical and financial provisions, including incentives, in the framework of an overall sustainable freight transport policy (road and rail) had a positive impact on air quality and transport efficiency[52].

	Present EUSALP study		GRACE study (2006)	
Cost category	**Road transport**	**Rail transport**	**Road transport**	**Rail transport**
Air pollution	**4.2** (1.3 – 14.2)	**2.6** (0.9 – 6.6)	5.25 (2.4 – 19.8)	3.5 (2.1 – 5.2)
Noise	**4.1** (1.3 – 14.7)	**3.0** (1.0 – 11.25)	5.0 (2.3 – 19.8)	4.15 (2.1 – 10.4)
Nature & landscape	**1.3** (1.0 – 1.6)	**1.4** (0.8 – 2.0)	n.a.*	n.a.*
Accidents	**3.9**	n.a.	n.a.	n.a.

Figure 35: *Comparison of additional external cost factor for road and rail transport in Alpine areas (EUSALP, 2017, Facsimile).*

52. *See chapter 3 (Umweltkapitel) in the modal shift report: Bericht über die Verkehrsverlagerung vom November 2019.*

7.3.1.3 Modal shift and polluting vehicle ban policy in transalpine transport for freight and passengers, Austria

Austria offers important examples from the transport sector, specifically in Tyrol, which is very much affected by the main transit route of the Inn valley and the Brenner Motorway (A171 and A13 from Kiefersfelden/Kufstein/border with Germany to the Brenner Pass/border to Italy). NO_x emissions from HGV were substantially reduced despite the growth in traffic thanks to a quicker renewal of the vehicle fleet on this axis as shown by the red and yellow values in Figure 37.

The main measures are the following

- a permanent speed limit of 100 km/h for passenger cars was introduced in 2006, modified to become a variable limit depending on NO_2 concentrations, and then reintroduced at a fixed limit in 2014;
- a series of sector bans for specific goods was introduced for HGVs in 2007, revoked in 2011 and reintroduced in 2016, giving an incentive to shift to rail;
- since 2006, a ban on night driving for HGV has also been introduced, exempting only the latest Euro emission class (currently the Euro 6 class);
- an incremental ban on older HGVs was imposed for the A12/13 and currently, HGV up to Euro 3 emission class are no longer allowed to use the transit routes.

The building of the new Brenner Railway Base Tunnel represents a part of the modal shift policy for rebalancing the transalpine freight flows on the Scandinavian-Mediterranean corridor.

7.3.1.4 Low Emission Zones and vehicle conversion bonus, France

The introduction of Low Emission Zones (LEZ) affects municipalities and private individuals. A LEZ is an area restricting certain types of polluting vehicles and there are currently 220 LEZ in

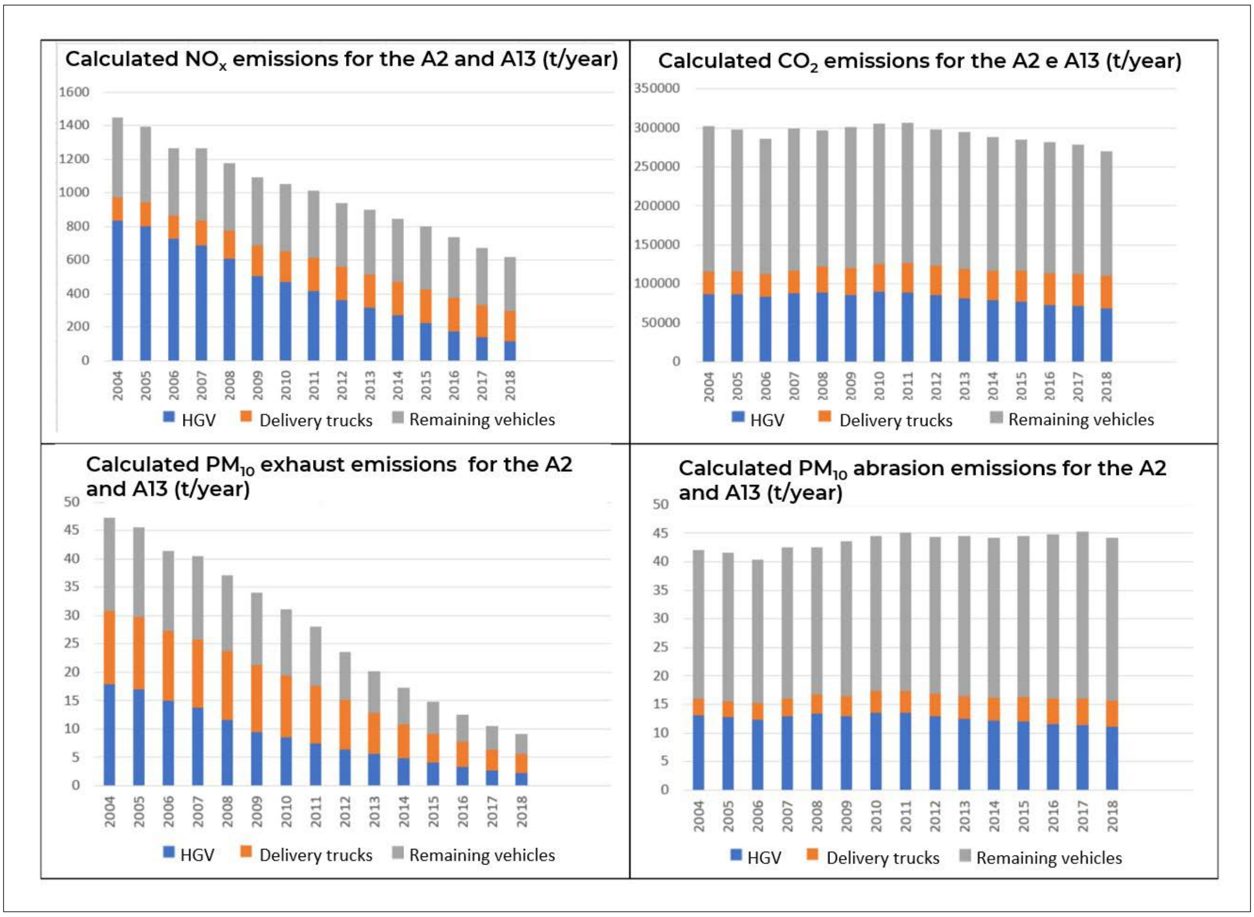

Figure 36: *Evolution of air pollutants and CO_2 emissions between 2004 and 2018 on the Swiss A2 and A13 motorways in the Alpine region.*

Europe[53]. Vehicles are classified by a visible label which is required for entering these zones. The French vehicle classification is based on the European classification (Euro1-6). Having a distinctive label on the vehicle in these zones will later allow automated controls.

There is also a vehicle conversion bonus, a subsidy given to citizens to change their old vehicles to new, less polluting models (106g of CO_2/km on average, converted to vehicles Euro 4 minimum). This is a financial incentive that meets the objectives of the LEZ, which is to reduce the exposition of the population to harmful pollutants.

Since 2018, the vehicle conversion bonus has helped in the renewal of 550,000 vehicles. It is a measure that has been a great success (on condition that these vehicles are not operated outside the European Union/EFTA Member States) in that it has exceeded the provisional budget and could meet the target of 1 million vehicles converted before 2022. Incentives like these also raise awareness of the impact of traffic on air quality, and therefore the general acceptance of LEZ being imposed in urban areas (all over France, not just within the perimeter of the Alpine Convention).

For instance, the LEZ in Grenoble started on 2 May 2019 with other 9 cities and as of February 2020 is in place in 27 cities[54]. The most heavily polluting vehicles cannot enter these cities, with the excep-

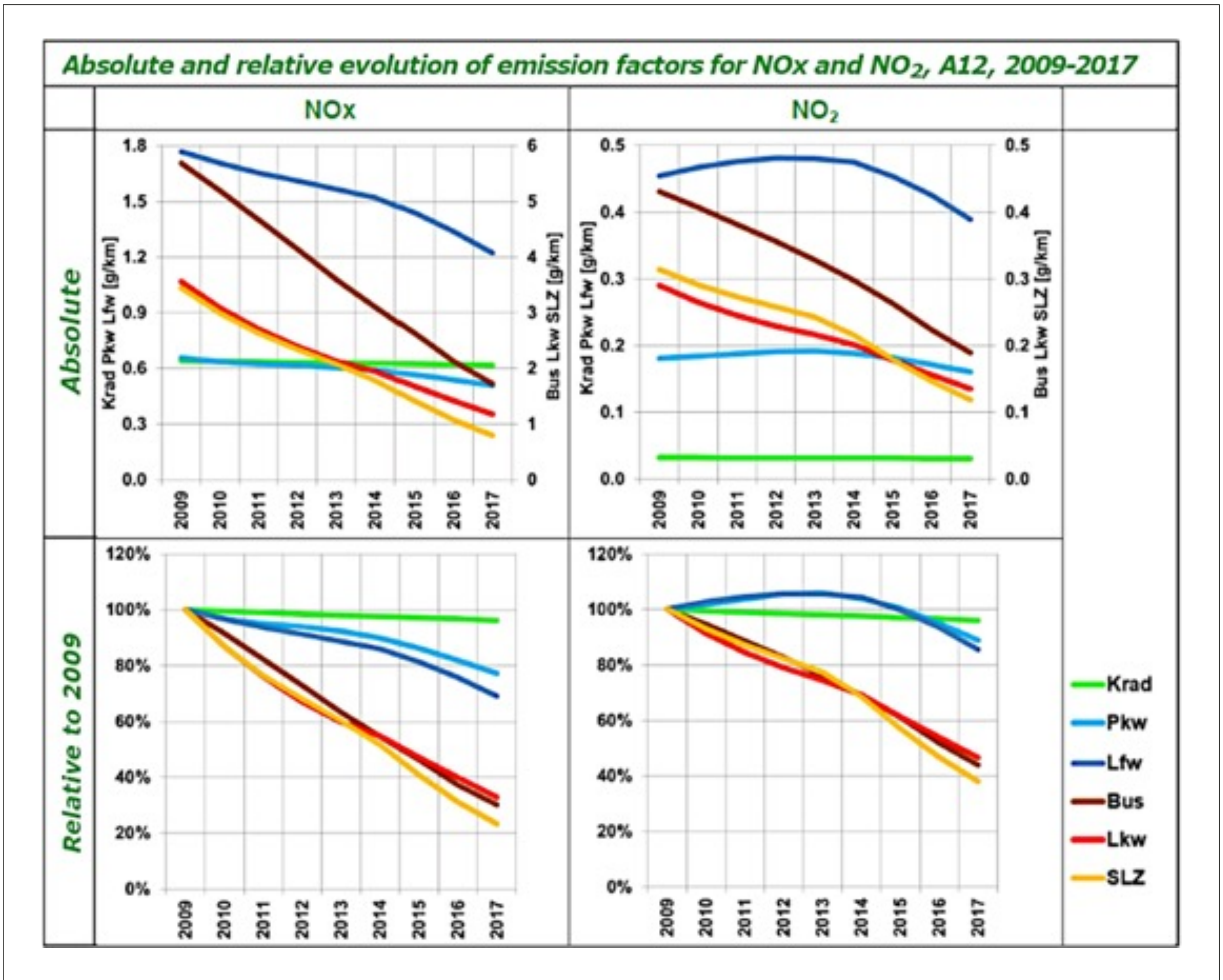

Figure 37: *Evolution of the emission factors for NO_x and NO_2 on the motorway A12 in Austria[55].*
Krad: motorcycles, PKW: passenger cars, Lfw: delivery vans; Bus: buses; LKw: trucks; SLZ: truck-trailer combination.

53. https://urbanaccessregulations.eu/userhome/map.
54. https://www.grenoblealpesmetropole.fr/761-la-zone-a-faibles-emissions.htm.
55. https://www.tirol.gv.at/fileadmin/themen/umwelt/umweltrecht/Luftseiten/Luft/Evaluation_der_LKW-Massnahmen_auf_der_A12_Euroklassenfahrverbot__Nachtfahrverbot__Sektorales_Fahrverbot.pdf.

tion of motorways. The aim is to avoid exceeding the exposure limits by 2026 for the 4,300 people currently affected.

An LEZ is a highly efficient and low-cost way for improving air quality as it places direct limitations on traffic pollution, the main source of pollution in urban areas.

7.3.1.5 Example of best maritime practices: Monaco Sea Shipping Controlled Emission Area, Principality of Monaco

Setting a controlled emission area in the Mediterranean Sea provides a further push to the strategy adopted by the International Maritime Organization with the MARPOL Convention (International Convention for the Prevention of Pollution from Ships). This measure has already been applied successfully in the Baltic Sea and the North Sea. The general public and local politicians alike are aware of the impact of maritime transport on air quality and are in favour of such a project. Therefore, ensuring this project's success is essential for improving air quality in this region. The measure would set out a combined zone to reduce SO_2 and NO_x emissions in the Mediterranean Sea. The goal specifically for SO_2 emissions is to limit the sulphur content in fuel to 0.1%.

Since July 2018, the Principality of Monaco has decided to drastically limit the use of heavy marine fuel in its territorial waters and harbours to minimise airborne emissions from ships. The Government of Monaco chose to act in advance of the creation of a controlled emission area in the Mediterranean Sea and the worldwide reduction in the level of sulphur in heavy fuel oil. Thus, since July 2018, all ships equipped with diesel engines must use marine fuel in the ISO-F-DMA category and meet the ISO 8217 standard, commonly known as Diesel Marine Léger (DML) or Marine Gas Oil (MGO), which has a maximum sulphur content of 0.1%. Alternatively, they must be fitted with an exhaust gas cleaning system operating in a closed-loop scrubber. Open gas cleaning systems are forbidden in order to limit the impact on marine biodiversity.

France and Italy are in favour of setting up a controlled emission area in the Mediterranean Sea. It is anticipated that this will ensure a 95% reduction in SO_x, 80% for PM, 51% for black carbon and 5% for NO_x compared to 2015-2016.

7.3.1.6 Dynamic regulatory measures – BrennerLEC, Italy

The Life BrennerLEC project aims to create a "Lower Emissions Corridor" (LEC) along the Brenner motorway axis to sharply improve the environment in terms of air and climate protection, as well as to reduce noise pollution[56].

The project started in September 2016 and two phases of experimental tests were carried out to check the effects of a dynamic speed limit reduction on some sections of the motorway. Reduced speed limits were displayed on variable message panels positioned along the motorway implementing a semi-automatic traffic management system to evaluate the possible effects on noise, air pollution and traffic flows. The application of speed limits was mandatory in the first phase of the tests, while only recommended for environmental purposes in the second phase: this latter phase showed still significant albeit reduced effects.

In any case, the results confirm the positive impacts of the application of the dynamic speed limits, in terms of improving both traffic flow on days with a high number of vehicles and of air quality. The reduction of nitrogen oxide concentrations along the motorway is consistent with the speed reduction recorded during the experimental sessions. In particular, the experimental data collected with recommended limits showed decreases of about 7% for NO and about 2-3% for NO_2 with an average speed reduction for light vehicles of about 5 km/h, compared with reductions of 10% for both pollutants with mandatory limits, leading to an average speed reduction for light vehicles of about 14 km/h.

7.3.2 MOBILITY MANAGEMENT

Mobility management is the promotion of sustainable transport and the management of the demand for car use by influencing travellers' attitudes and behaviours with a view to shifting from individual motorised transport to more sustainable mobility systems. Since the 1990s, this approach has been increasingly gaining attention

56. https://brennerlec.life/it/home.

as part of the efforts to balance mobility demand against the negative impacts and environmental quality as a whole. In many cases, mobility management is also linked to integrated land-use planning, in which mobility issues are considered the most important basic elements for any spatial and land-use planning at local, regional and national level.

The appeal of mobility management lies in its numerous potential benefits, which include:

- less congestion resulting in a reduction of air pollution and noise, and of time wasted in traffic jams, as well as less stress;
- a greater variety of transport solutions, resulting in better accessibility for all;
- more efficient use of existing transport infrastructure, resulting in less public spending on unnecessary infrastructure and external cost factors;
- more efficient land-use management;
- cost savings for local authorities, institutions, private companies and individuals;
- healthier lifestyles and less stress, thanks to more active modes of transport like cycling and walking.

Examples are given in the fields of home to work mobility, home to school mobility, collective transport for major events, sustainable urban mobility plans including sustainable urban logistics, parking management, active mobility/cycling and demand for responsive transport. A specific subchapter about interlinkage between spatial planning and mobility planning can provide an overview about the positive impacts of integrated planning procedures and implementation.

7.3.2.1 Institutional framework for sustainable mobility by a Coordination Office, Switzerland

A specific intersectoral coordination body for sustainable mobility projects has been set up in Switzerland with a view to promoting and facilitating innovative projects to help reduce transport-related emissions. The Coordination Office for Sustainable Mobility (COMO) is the central contact and coordination point and the first contact point at federal level in matters of sustainable mobility. It supports innovative projects with a financial contribution and, as a knowledge platform, provides information on completed and ongoing projects. Six federal offices are responsible for COMO.

A wide variety of project sectors for sustainable mobility are covered[57]:

- IT Solutions;
- sharing mobility;
- leisure time mobility;
- pedestrian and cycling traffic;
- public transport;
- more efficient private motorised road transport;
- freight traffic and logistics;
- children and young people;
- mobility management.

In this context, many examples exist in the mobility sector, such as the creation of the “Quality Alliance Eco-Drive” (QAED), initiated back in 1999 by the Swiss Federal Office of Energy (SFOE) and Energy Switzerland as a partner association to implement good practices in Ecodriving and as a multiplicator for Ecodriving in instructing driving teachers and specifically fleet operators for heavy vehicles (buses and HGVs).

However, the quantity of emission savings is still not clear due to different emission factors and the variety of types of vehicles.

7.3.2.2 SwitzerlandMobility for car-free travelling throughout the country linking tourism, leisure, hotel accommodation and points of interest, Switzerland

SwitzerlandMobility/SchweizMobil is the national network, initiated in 1998, for non-motorised individual transport especially for leisure and for tourists. A route planner on the web and a smartphone application[58] (since 2012), linked to summer and winter leisure/cultural events, museums, sports areas and hotel accommodation make it possible to travel car-free by public transport (rail, road, cable car, boats, etc.) and human-powered active mobility (biking, hiking).

57. *https://www.energieschweiz.ch/page/de-ch/komo-projekte (in German, French, Italian).*
58. *https://www.schweizmobil.ch/en/summer.html.*

The route planner was created and supported as a foundation by numerous organisations like Switzerland Tourism, Veloland Schweiz, Swiss Hiking Trails, Alpine Club, Inventory of the historical transport routes and others. Financial support is granted by the Swiss Confederation (different Federal Offices), all Cantons and the Principality of Liechtenstein.

The target is car-free tourism and leisure mobility, based on the highly developed public transport system and active mobility, as well as on the promotion of mountainous and outlying regions of Switzerland by adding value in the form of tourist attractions, cultural events and sports.

While its contribution to reducing emissions is difficult to evaluate, the number of bookings and reservations exceeds one million per year.

7.3.2.3 Mobility Management Concept in Carinthia, Austria

Companies with about 3,000 employees are the largest employers in the region around St. Michael ob Bleiburg in Eastern Carinthia. When it became necessary to expand businesses, it was decided to motivate employees to switch from private cars to public transport and bicycles through mobility management.

The measures in the mobility concept were coordinated by the Verkehrsverbund Kärnten (cooperation of public transport companies in Carinthia) on behalf of the province (Land) of Carinthia. By December 2017, the S-Bahn service had already been improved, providing employees with more train connections. Since August 2018, an electric bus travels between the St. Michael railway station and the operating sites, taking the staff to the company premises. The e-bus replaces the diesel-operated company vehicles and the service forms part of the public transport network so that it is also available for all passengers. Employees get discounted fares.

All those living within cycling distance from their workplace have been provided with improvements in the bike connections and the number of bicycle parking spaces has been significantly increased. In addition, lockable bicycle boxes were built at the St. Michael railway station.

7.3.2.4 Increase the attractiveness of public transport system by free transportation of pupils, subsidies for public transport, free public transport on weekends, Bavaria, Germany

Bavaria hosts specific examples targeted towards reducing people's reliance on personal motorised vehicles and increasing the attractiveness of the public transport system, both for the local population and for tourists. The target is a reduction of the individual motorised traffic, increasing the attractiveness of the public transportation system in several ways:

- **by offering free transportation of pupils (to reduce the so-called "parent taxi")**

  Young people will be offered a better utilisation of existing lines and, to further reduce the use of individual vehicles by parents taxiing their children around, the public transport system will be boosted. Complexity and costs are frequently cited reasons for the low use of existing public transport services (bus transport) by children and adolescents in their free time. In order to tackle this problem, this ticket offer was developed together with the transport company RVO[59], which operates the majority of all bus routes in "Oberland".

  The district of Miesbach has decided to allow pupils with a valid RVO student card or a valid pupil card to travel on public transport free of charge, beginning from 1 November 2019. This offer is valid for all pupils resident in the district, without age restrictions, on all lines in the "Oberland". Holders of an RVO pupil card and pupils without an RVO student card but with a valid pupil's card must purchase a "€ 0 monthly ticket" from the driver. For each of these tickets the RVO will receive €11 net from the district. As a hedge for the district of Miesbach, an annual amount of € 23,000 has been introduced as a ceiling. The assignment of the costs of the used "€ 0 monthly ticket" refers to the exact bus lines where it was used. The RVO provides quarterly statistics on the number of users. These tickets are valid all day on holidays, weekends and public holidays. On school days, these tickets are valid from 14:00.

- **by an ambitious financial subsidisation of public transportation**

  As an example of reduction of motorised indi-

59. RVO: Regional Traffic for Upper Bavaria; regional public bus transportation for Bavarian uplands.

vidual traffic and of environmental pollution as well as an increase in the attractivity of public transportation, the city of Sonthofen has set itself the longer-term goal to increase the attractiveness of the city bus (line 1 and line 2). The city bus lines have regularly recorded passenger numbers of over 20,000 in the past few years. The city of Sonthofen promotes the city bus in Sonthofen by offering favourable tariff options with a financial subsidy of approximately € 3.50 per resident per year.

- **by offering free transportation at weekends and public holidays**

  To reduce the use of individual cars by tourists through the free use of the public transport within the municipality and surrounding local communities, the "Stadtwerke Bad Reichenhall" is offering public transport services for free at weekends and public holidays for the whole service area "Bad Reichenhall, Bayerisch Gmain and Piding". Numerous smaller cities in Upper Bavaria (Bad Heilbronn, Benediktbeuren, Bad Tölz, Wolfratshausen, Lenggries, Jachenau, Kochel am See, Garmisch-Partenkirchen, and many others) introduced free public transport at local and regional level for tourists with (electronic) guest cards, thus avoiding many individual car trips and reducing emissions of air pollutants and CO_2. Tourism and sightseeing in this attractive region of beautiful mountains, lakes and castles is facilitated by free travel by bus and train ("Allgäumobil im Schlosspark").

Generally speaking, tourists staying overnight receive a guest card that allows the free use of public transport. The area covered by free public transport depends on the individual regulations of the municipalities. For example, in winter in Lenggries, holiday guests as well as day trippers arriving by train can use the free ski bus for local transfers to the ski areas. The holiday destinations "Garmisch-Partenkirchen, Grainau and Tyrolian Zugspitz Arena" are offering their guests the Zugspitz Arena Bayern-Tirol Card allowing free use of various buses and other forms of transport. The Zugspitz Arena Bayern-Tirol Card is sponsored by the European Union as an Interreg project.

With the guest card from the tourism region Berchtesgaden-Königssee, overnight guests travel free of charge on almost all lines of the Regionalverkehr Oberbayern (RVO) and the Berchtesgadener Land Bahn (BLB) in the area of the tourist region Berchtesgaden-Königssee. Trips to Salzburg (bus line 840) and Bad Reichenhall (bus line 841) are also significantly cheaper with the guest card. This offer applies to almost all lines in the southern district of Berchtesgadener Land – with a few exceptions: for the line "Kehlstein" (bus 849), call-bus "Berchtesgaden" and Alpine Experience Bus (bus 847) special rates apply, for the Rossfeld line (bus 848) the toll is charged separately. For trips to Salzburg and Bad Reichenhall, only a small additional payment has to be made.

The reduction of traffic and of environmental pollution increases the appeal of these areas as tourist destinations as well as a climatic health resorts. It provides accessibility by train and mobility on-site and in an extensive, networked area by public transport. Therefore, more and more guests travel by train and use the (free) mobility services, freeing these holiday destinations from the individual motorised traffic and reducing the lack of parking spaces.

7.3.2.5 Mobility concept including S-Bahn project: Transport sector, Liechtenstein

The Mobility Concept 2030, updated since the 2015 strategy for integrated spatial and mobility planning, is focusing on more stringent spatial planning, setting development poles and densification to avoid increasing mobility demand. It also focuses on better use of public transport (road and rail), specifically the new project of the S-Bahn FL-A-CH linking Feldkirch (AT), Schaan (FL), Vaduz (FL) and Buchs (CH), which has large potential for shifting commuters from road to rail[60].

7.3.2.6 Promotion of cycling in Salzburg, Austria

Cycling is one of the most energy and space-efficient modes of transport. A substantial percentage of daily car trips might be replaced by cycling, since over 50% of all trips are shorter than five kilometres. With proper infrastructure, cycling is the fastest and most efficient way to travel short distances, as cyclists can usually follow the most direct route at a higher average speed compared to motorised individual transport.

60. https://www.mobilitaet2030.li/.

Salzburg, the capital of the province (Land) with 156,159 inhabitants, has recently focused on the improvement of the conditions for cycling. The network of bike lanes has been progressively extended over the last 30 years. There are now 187 km of paths for cyclists and over 6,000 bicycle-parking facilities. More than two-thirds of all the one-way streets can also be used in the opposite direction by cyclists. Cycling is allowed in almost all pedestrian areas and bus lanes. The main target of the cycling strategy 2025+ is for cycling to account for 24% of the total number of trips by 2025. This means 20,000 fewer car journeys each day in Salzburg.

Important measures in the cycling strategy are:

- development of a safe and comfortable main bike lane network with optimisation of the winter service;
- introduction of the bike rental system "S-Bike", in its first stage with 50 stations and 500 bicycles;
- implementation of a first "Premium Cycle Path" in the region from Salzburg to Freilassing (Bavaria) with a new bridge over the river Saalach as a "model" for the importance of cycling for connections between communities in the hinterland and the city;
- campaigns and public relations for more cycling;
- using all federal- and EU-funding programmes to increase the budget for measures to promote cycling.

Due to the already good cycling infrastructure, around 100,000 trips a day occur on bicycles in the city of Salzburg, accounting for 20% of all trips. But with a 45% share, the number of car trips is still rather high, while public transport, amounting to 15% of all trips, has good potential for growth. 20% of journeys in the city of Salzburg are done on foot.

7.3.2.7 General Promotion of use of bicycles instead of motorized vehicles in Bavaria, Germany

The reduction of motorised individual traffic and of environmental pollution increases the appeal of areas for tourists as well as their role as climatic health resort. It also reduces the lack of parking spaces. Municipalities have different approaches for encouraging the use of bicycles instead of cars, such as:

- preparing and implementing a concept for cycling that ensures a safe and well-signalled connection between and within municipalities;
- setting up stations for bike rental;
- expansion of bicycle infrastructure.

Examples:

- Garmisch-Partenkirchen (Bavaria): fast cycle path "Loisachtal", covering 33 km between Murnau and Garmisch-Partenkirchen. Created under the funding project "Climate Protection in Cycling" (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety);
- Jachenau (Bavaria): cycling path to connect Jachenau with Lenggries;
- Jachenau (Bavaria): bike rental stations partially offering discounts to people with guest cards;
- Sonthofen (Bavaria): between 2017 and 2019, the cycling infrastructure in Sonthofen was expanded. Important structural measures were implemented: renovation of protection and wheel strips, addition and creation of protective strips at intersections with parking areas, addition of missing cycle sections, construction of a mini-roundabout, construction of parking facilities in the city centre. In addition, the city of Sonthofen has been promoting low-emission commercial traffic since 2018-2020 by offering cargo bikes at 30% of the purchase price. The commitment of the city of Sonthofen as a bicycle-friendly community in Bavaria was rewarded by the Bavarian State Ministry of Housing, Building and Transport on 22 November 2019.

7.3.2.8 Promotion of Smart Mobility within Swiss PostAuto for Increasing Modal Share of Public Transport, Switzerland

The largest Swiss public transport provider by road is promoting smart mobility solutions by improving the existing mobility chain with a view to filling existing gaps and responding to specific needs which, up to now, could not be satisfied due to the cost factor[61]. The areas with the most potential for a possible increase of public transport use

61. *Smart Mobility von PostAuto (https://www.postauto.ch/de/file/134959/download?token=mE1KUtH0).*

are located in rural and mountain/tourist regions since the use of public transport is generally already very high in urban and suburban areas. A focus is placed on the:

- dynamic response of public transport availability in tourist regions depending on seasons and weather, giving the possibility to multiply bus services very quickly to satisfy demand;
- increase in the quality of mobility in smaller cities by combining it with the smart village approach (example Spiez in the Bernese Oberland), where mobility, local activities, shopping, administration services and co-working spaces are combined;
- development of multimodal mobility for seamless transport between conventional public transport and private and taxi transport (door-to-door).

The approach is based on the cooperation of a large number of stakeholders, including the integration in the programme "Mobility management for undertakings" set up by Energy Switzerland for Communities (Energie Schweiz für Gemeinden) with a view to changing mobility patterns and behaviour in the long-term.

7.3.2.9 Enhance soft mobility, Principality of Monaco

Mobility is one of the main challenges of the Government of Monaco since it concerns both sustainable development and public health. It also plays an important role economically. The main actions are focused on:

- The development of "clean" urban public transport: currently, all the buses from the *Compagnie des Autobus de Monaco* are using Diester, a cleaner fossil fuel. Experiments are ongoing aimed at having an electrical bus fleet by 2025;
- The development of multimodal clean transport: free-floating electric car sharing, electric bike-rental all over the Principality;
- Incentive rates to encourage the use of car parks (about 15,500 parking places) at the entry to the Principality, combined with the use of public transport;
- Development of a huge network of public escalators and lifts throughout the territory to facilitate walking;
- Financial support, started in 1994, to purchase electric or hybrid-gasoline-electric vehicles. These now account for about 5% of the road vehicle fleet in Monaco;
- Development of a smart nation, using various sensors (among them, air quality sensors) combining direct information on transport, local activities and environmental indicators.

7.3.3 TECHNICAL MEASURES: ALTERNATIVE FUELS / PROPULSION SYSTEMS

Among the technical measures, innovative alternative fuels and propulsion systems are becoming more and more important in mobility systems, supported by the European Directive on the deployment of the Alternative Fuels Infrastructure (2014/94/EU, AFID). In short, Member States had developed national policy frameworks for the market development of alternative fuels and their infrastructure by November 2016.

The Directive "establishes a common framework of measures for the deployment of alternative fuels infrastructure in the EU in order to minimise dependence on oil and to mitigate the environmental impact of transports. This Directive shall foster low-emission fuels such as electricity, hydrogen, compressed natural gas (CNG/Bio-CNG) or liquefied natural gas (LNG/Bio-LNG)" (Alpine Convention, 2018b). Examples for the promotion of alternative fuelled vehicles including e-mobility at local or regional level are provided by many stakeholders.

7.3.3.1 2050 energy strategy/energy savings, Switzerland

In order to prepare Switzerland for the current challenges of energy supply and the economic, environmental and technological demands and needs of the near future, the Federal Council has developed the 2050 Energy Strategy. This should enable Switzerland to take advantage of the new starting position and maintain its high supply standard. At the same time, the Strategy contributes to reducing Switzerland's energy-related environmental impact.

The energy strategy was accepted in a popular vote in May 2017, and a first step for its implementation started in 2018.

The 2050 energy strategy aims to gradually phase out nuclear power from Switzerland, increase the use of renewable energy and, at the same time, reduce the dependency on imported energy sources. It mainly consists of three pillars:

- increase energy efficiency (buildings, mobility, industry, machinery/devices);
- increase the share of renewable energy (traditional renewable [hydropower] and new renewable [solar, wind]) by promotion measures and improvement of the legal framework;
- progressive phasing out of nuclear power.

Concerning the mobility sector, which is responsible for a third of the CO_2 emissions and air pollutants, the aim is to reduce energy consumption by 44% for personal mobility and 25% for goods transport by 2050.

The instruments to achieve this objective will be: increasing energy efficiency, substitution by alternative fuels and propulsion systems, integrating decentralised renewable electricity generation, lightweight construction and experimental aspects of new urban models as well as reduction of transport demand by developing new societal and economic skills[62].

On the basis of the declared objective of 44% energy consumption savings, the car retailing sector in Switzerland as a federative association (Auto Schweiz) has also declared the firm objective of 10/20: i.e., by 2020, one every 10 new passenger cars registered in Switzerland and Liechtenstein should be a battery electric vehicle (BEV) or plug-in hybrid electric vehicle (PHEV). This is a very ambitious objective as the share of such vehicles in the total market of newly registered vehicles was only 5.6% in 2019.[63]

7.3.3.2 In-depth analysis of promoting non-fossil modes of transport on public roads, Switzerland

In March 2019, the National Council (the parliamentary chamber) of Switzerland accepted proposal 19.3000 "*Helping non-fossil modes of transport to break through on public roads*". The Federal Council (the government) advocated accepting it, especially in order to conduct a comprehensive cost-value ratio analysis of encouraging buses using alternative propulsion (focus on e-buses) and to point out already existing supporting measures[64].

The goals of the proposal report are as follows: the report shall give a comprehensive account of the current and future potential and gains of alternative propulsions as replacements for existing diesel buses, as well as demonstrate current and future costs/extra-costs transparently. Additionally, existing and possible new supporting measures on a national level shall be demonstrated. In order to achieve a widely supported and accepted result, a support group has been established in which all stakeholders are represented. The aim is to finalise the baseline study by June 2020 and to present the proposal report in autumn 2020.

Rural and Alpine regions are particularly under focus, since they are places where the potential applications are more limited and there are major challenges (weather conditions, differences in altitude, long distances, limited financial power etc.). In the support group there are consequently also representatives of rural transport companies (RBS and Postauto) and Alpine transport companies (Engadin Bus). The technical application potential, as well as the extra costs, are being analysed for different existing exemplary routes in clusters, including challenging rural and mountain routes. From the examinations of the pilot projects, it has already been learned that a lack of charging stations for electric propulsion (and related infrastructure, i.e. strong enough electricity supply) is a serious issue in rural and Alpine regions that also needs to be addressed.

7.3.3.3 Promotion of e-mobility, Bavaria, Germany

Conversion of municipal vehicle fleet to electric cars or hybrid cars

The target of this policy is to substitute municipal vehicles with combustion engines by electric or hybrid cars. As an example, since 2016 the city of Sonthofen (Bavaria) has been continuously equipping its fleet with electric and hybrid vehicles. Vehicles with electric drive replace disused vehicles with combustion engines. Both passenger cars and commercial vehicles will be replaced.

62. *http://www.sccer-soe.ch/en/home/.*
63. *https://www.auto.swiss/themen/alternative-antriebe/.*
64. *https://www.parlament.ch/de/suche#k=Postulat%2019.3000.*

Three old vehicles have already been replaced by electric vehicles. The e-vehicles are charged by electricity from 100% certified renewable sources (hydropower from the Alpine region).

The charging takes place at a charging station for municipal vehicles (wall boxes). The vast majority of work travel takes place in the urban area. The ranges of electric vehicles suffice for this purpose. E-vehicles are virtually emission-free on the road and reduce noise pollution in the city centre. E-vehicles are also significantly cheaper to operate than comparable conventional vehicles.

The conversion is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) within the framework of the National Climate Initiative on the basis of a resolution of the German Federal Parliament.

Municipal e-car sharing offer and installation of new e-charging stations

By offering an attractive and CO_2-neutral municipal electric car sharing system, citizens as well as the local industry/commerce will be motivated to no longer use second cars. The result is a considerable cost advantage due to savings of around €2,000 per car per year, reducing the stock of second cars in the municipality and lowering the number of vehicles with combustion engines.

The city of Fischbachau (Bavaria) promotes e-mobility by installing new e-charging stations for vehicles.

Another approach is to improve the use of e-cars instead of cars with combustion engines by the design and operation of an "intelligent charging infrastructure". Garmisch-Partenkirchen (Bavaria) participated as a model municipality in the project "Intelligent charging infrastructure" funded by the State of Bavaria between 2011 and 2016. The aim was to develop a barrier-free charging infrastructure (including the possibility of implementing different charging options; networking of different charging infrastructure or stand-alone solutions etc.) with interfaces for integration into a municipal smart grid system with cross-system processes and data flows.

In the city of Sonthofen reloading e-cars at public charging stations located centrally in the city has been possible since 2011. Sonthofen is constantly expanding and modernising the charg-

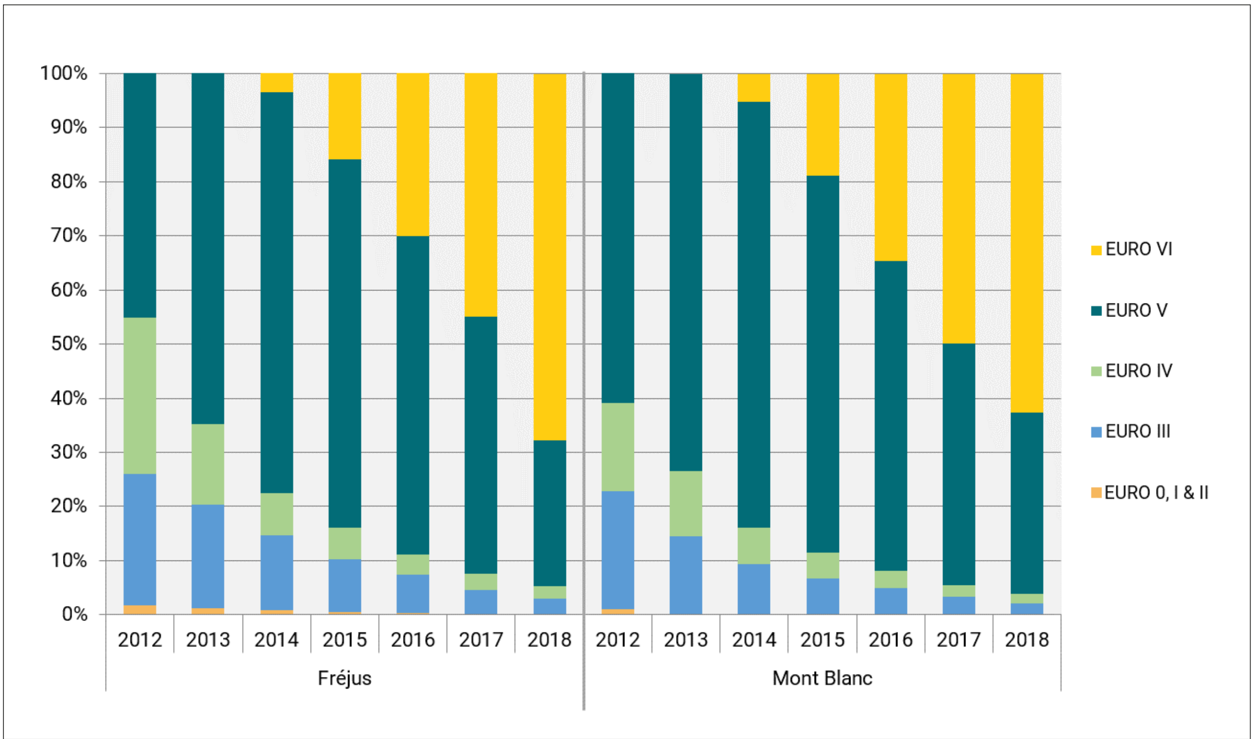

Figure 38: *Observation and analysis of transalpine freight transport flows in two transalpine tunnels. Euro 0 to 6 are the EU emission limits of trucks: the NO_x level, for instance, decreased from 14.4 g/kWh to 0.4 g/kWh between Euro 0 and Euro 6 (Alpine Traffic Observatory).*

ing infrastructure. Designated parking spaces in the city centre are reserved for e-vehicles. Nine modern public charging points are available in Sonthofen, exceeding the recommendation of the Alternative Fuels Infrastructure Directive. For this, the city of Sonthofen works closely together with the company "Allgäuer Kraftwerke". The construction was supported by the Federal Ministry of Transport and Digital Infrastructure (BMVI) on the basis of a resolution of the German Federal Parliament.

For the rural districts of Berchtesgadener Land and Traunstein, an electromobility concept supported by the Ministry of Transport and Digital Infrastructure has been developed to strengthen electromobility in the region. The focus is on the design of a high-performance and needs-based charging infrastructure for electric vehicles in central locations and tourist destinations for employers, hotels and residential areas with apartment buildings. As a result, the number and locations of charging stations were designated for all 50 municipalities.

7.3.4 EVOLUTION OF FREIGHT ROAD TRANSPORT

The chairman of the Transport Working Group of the Alpine Convention has analysed the trends concerning road freight transportation in the Alps.

In terms of air pollution, Euro standards have led to an indisputable improvement in road traffic. The statistics for the two Franco-Italian tunnels are shown in Figure 38.

At the rate at which the heavy goods vehicles fleet has been renewed, it can reasonably be assumed that, within 5 years, all the HGV in circulation on the transalpine routes will meet the Euro 6 standard, and that HGV operating cabotage will do so shortly after. This would represent an improvement of around 25% in NO_x and PM emissions. The share of Euro 6 vehicles is even higher in Switzerland and Austria, which therefore reduces the room for improvement.

In the medium term, the outlook is obviously more open. Some "weak signals" can be perceived. Electrification of HGVs is no longer an unachievable goal. According to recent analyses by the French Ministry of ecological and inclusive transition, the cost (in tonne/km) for the transporter of a 40-tonne electric truck is currently close to that of a diesel truck, whereas electric trucks were considerably more expensive to run back in 2017. It seems reasonable to consider the possibility of producing 300 Wh/kg batteries in 2025 - 2030 and 400-500 Wh/kg in 2040. By this time, a 4-tonne battery pack would provide a range of 800 km to a semi-trailer and thus open up the transalpine market.

At that point, the main residual local pollution from truck traffic would be that produced by tyre on road contact and by brake residues. In France, these are estimated to account for at least 40% of particulate pollution emitted by road traffic. Even if the truck fleet were to be fully electrified, this nuisance, as it stands, would remain. A drop in this contribution can, however, be expected for at least two reasons: the fact that the braking of an electric vehicle is partly purely electric, without contact, and that there is also promising technological research (biodegradable coating of tyres, vacuum cleaner for particles in front of the brakes etc).

It is certain that the regulatory constraints in terms of air pollution and global pollution will tighten. After Euro 6, a Euro 7 standard is being prepared for application by 2025. We can therefore expect, in the medium term, with the - presumed economically profitable - wider spread of electric traction for HGVs, a reduction of two-thirds of the particulate pollution compared to the Euro 6 standard, which would be a quarter of the road freight pollution currently produced.

7.4 INTEGRATED PLANNING: MOBILITY PLANNING AND SPATIAL PLANNING

The link between mobility planning and spatial or land-use planning is fundamental for future transport demand, both private and public, passenger and freight. Regardless of the geographic region, integrated planning processes at every administrative level (local, regional, national, supranational) contribute to an effective mobility system, saving as many natural resources as possible and limiting negative impacts on environment and health.

The EU Air Quality Directive requires air quality action plans in areas where air quality limits are exceeded. In Switzerland, the Federal Ordinance on Air Pollution Control (Luftreinhalteverordnung) and the Environmental Protection Act requires every canton to provide an action plan for air quality. In the perimeter of the Alpine Convention, all cantons have adopted such an action plan. An air quality action plan usually consists of the description of the emission sources responsible for generating the excessive concentrations and contains measures for their reduction or elimination. Furthermore, it quantifies the effect of the individual measures and sets deadlines for their order and implementation.

7.4.1.1 Spatial Concept Switzerland (Raumkonzept Schweiz), Switzerland

The Swiss concept (published in 2012) has the following main goals in relation to transport and mobility:

- Switzerland operates a sustainable, safe, and reliable transport system for passenger and freight traffic;
- The costs of operation, maintenance, and renewal are affordable;
- The population and economy of Switzerland benefit from good international and regional accessibility. This strengthens regional competitiveness and the cohesion of the country;
- The transport system promotes settlement development internally and reduces the negative impact of mobility on quality of life, energy consumption and landscape;
- The Swiss population benefits from short distances between work, living, and leisure activities;
- Strong rural centres with businesses and industry help reduce commuter movements;
- In the planning procedures, the so-called development poles (Entwicklungsschwerpunkte) should concentrate additional working places, businesses, schools and leisure and sport activities in appropriate locations with a view to reducing and concentrating mobility to existing (and extended) transport infrastructure and to avoiding urban sprawl and additional mobility demand for both private individual and public transport.

At the different levels of planning (local, regional, and national), new areas for housing/settlements, business, working places, shopping centres, leisure and sport activities with transport intensive installations (>2000 car movements/daily) need a specific *ex ante* mobility plan, which considers most of the expected mobility demand by sustainable modes of transport, e.g. public transport or soft mobility, before approval of the project. Most of these projects with higher transport intensity present so-called "traffic contingency models" (Fahrleistungsmodell) in which the project leader establishes how the transport demand generated by the project will be covered in modal share between public and private modes, mostly by public transport extension (infrastructure and operation), soft mobility, and additional private car movements. The sum of modelled additional emissions generated by the transport sector and the existing ambient air pollution needs to be within the ceilings defined by the Federal Ordinance on Air Pollution Control (OAPC)[65].

In a convention between the project leader/investor and the relevant local or regional authority, the modal share calculated is monitored and provided with a bonus/malus system depending on whether the figures are achieved or not. Since its implementation in 2001, the Bernese Traffic contingency model has served as a planning instrument for many municipalities. As a follow-up step, the basic rules from the model were integrated in the cantonal plans of spatial planning and mobility planning (*kantonale Richtplanung*).

65. *https://www.admin.ch/opc/en/classified-compilation/19850321/index.html.*

The federal government, cantons, cities, and municipalities coordinate planning of the transport infrastructure with their spatial development ideas.

The Swiss Raumkonzept[66] is especially recommended for the spatial development in the Alps:

- To promote sustainable development of side valleys with their typical landscape;
- The resident population should remain in the still functional areas of the side valleys;
- This requires that a sufficient basic availability of goods, services, and jobs in the Alpine tourist areas and rural centres is guaranteed;
- Regional strategies for spatial development should be based on these priorities;
- The aim is to achieve an optimal combination of natural and cultural tourism, agriculture, and trade;
- Traditional cultural landscapes with their typical forms of settlement and their traffic history should be carefully cultivated and developed further.

7.4.1.2 An integrated atmosphere protection plan, France

In France, certain regions are considered sensitive to air pollution and additional action plans are implemented in those areas to improve air quality. In the Alps, the Arve valley is the best example for such plans. Due to the topography of the region, air pollution is a problem to its inhabitants. Thus, an atmosphere protection plan[67] has been in place since 2012. Every 5 years, evaluations are carried out and then a revised plan is implemented. The plan approved in 2019 includes local actions such as:

Energy:

- "Air Gas Fund": funding private individuals to change wood heating systems to natural gas systems, which emit far less particulate matter.
- Prohibition on the use of open fireplaces (high PM emitters): decree prohibiting the use of open fireplaces.
- Development of biogas production: develop exploitation of different types of waste to produce green energy.

Agriculture:

- Education of farmers in good practices to reduce pollutant emissions: inform and educate farmers about their impact on air quality and new methods with minimum impact.

Urbanism:

- Taking air quality into account during urban planning to encourage the creation of compact urban hubs and the development of heating networks.

Transport:

- Promotion of eco-driving and carpooling: promote a network of carpooling car parks, possibly on scales more suited to more sparsely populated areas; develop a platform to connect car-poolers.
- Improvement of public transport capacity and efficiency and promotion of active mobility.
- Increase of the transfer of freight from road to rail to reduce the traffic load on roads in the region.

7.4.1.3 Common regional programme for clean air, different sectors, including transport sector, Italy

Northern and central Italian regions and cities, densely populated and highly polluted, are cooperating in a common programme for clean air known as Life PrepAir[68]. Co-financed by the European Union, the programme is operational between 2017-2024 and is directed by the Regione Emilia Romagna with 17 partners. Actions envisaged are in the following sectors: agriculture, biomass burning, transport, energy, emissions evaluation, communication and capacity-building.

66. *https://www.are.admin.ch/are/de/home/raumentwicklung-und-raumplanung/strategie-und-planung/raumkonzept-schweiz.html.*
67. *https://www.haute-savoie.gouv.fr/content/download/15754/92617/file/ppa_20120305.pdf.*
68. *https://www.lifeprepair.eu/?lang=en.*

The main actions for the transport sector are:

- **Promotion of active mobility/cycling**

  Partners involved in the project promote active and cycling mobility through different actions according to the different territorial and planning specificities. Actions include training courses to public officers and to citizens and students in order to change and improve cyclo-mobility planning and use; surveys on availability of bike infrastructures in railway stations; improvement of bike infrastructures; geo-tracking of bike lanes and bike navigator; modal split analysis.

- **Demonstration action for conversion from diesel to electric propulsion**

  After selecting the longest bus route in the project territory there will be a feasibility study on the revamping of a diesel bus and the production of a prototype of a modular electric propulsion system suitable for city buses for testing on a real/operative public transport route.

- **Rationalisation of short distance freight logistics in urban and peri-urban areas**

  Rationalisation of short-range freight logistics in urban areas, mainly in the city centres, and of extra-urban and peri-urban short-range freight logistics by defining the most widespread logistic model and conducting a pilot study for loading/unloading of goods.

- **Development of ICT instruments in public transport**

  The proposed action aims at designing and developing a new multi-modal "open" and integrated journey planning tool for public transport services at regional level via web and app.

- **General promotion of electric mobility**

  Collaboration with and information to public and private stakeholders to enhance the diffusion of electric mobility, also at policy level. Courses will be started for local administrators, professionals and mobility managers, together with consultations and studies.

- **Eco-Driving Instruction**

  The driving style denoted as "eco-driving" can help reduce fuel consumption and vehicle emissions that are largely affected by drivers' behaviours. This action, aimed at bus drivers, taxi drivers and driving schools, involves a programme of eco-driving lessons, development and adoption of technological solutions, integration of eco-driving in driving school curricula and driving tests.

7.5 REDUCTION OF AMMONIA EMISSIONS FROM AGRICULTURE IN MOUNTAIN AREAS

7.5.1.1 Reduction of agricultural ammonia emissions, Switzerland

As part of its Agricultural Policy 2014-2017, Switzerland set a target of reducing ammonia emissions from agriculture to a maximum of 41,000 tonnes of nitrogen per year by 2017. In the dispatch to a decision of the Federal Council on the financial resources for agriculture for the period 2018-2021, it was stated that the goals proposed in the Agricultural Policy 2014-2017 should be pursued as milestones until 2021. The non-scheduled environmental target is the emission of a maximum of 25,000 tonnes per year.

Agriculture accounts for 93% of all ammonia emissions in Switzerland. By far the largest share (93%) comes from animal husbandry, in which the main share comes from cattle farming (78%). In a European comparison, Switzerland has the highest ammonia emissions per hectare of agricultural land after the Netherlands. The reasons for such high emissions are the widespread practice in Switzerland of open-air stables and in particular the high animal stocking rate. Between 1990 and 2015, agricultural ammonia emissions in Switzerland were reduced by 18%, mainly as a result of the reduction in the number of animals between 1990 and 2000. In this period, the number of livestock units in Switzerland fell by almost 115,000 to around 1,337,000 units. Since then, emissions have stagnated at a high level. Between 2007 and 2017, the number of livestock units decreased by only 1.8%. In order to get nearer to the goal of 41,000 tonnes per year by 2017, livestock units would have had to fall by more than 130,000 units (around 10% of the 2007 stock) in the corresponding period.

In order to reduce the environmental impacts and the impact on air quality of ammonia emissions, the federal government supported cantonal resource projects on ammonia with contributions from 2008 to 2018 as part of the Resource Programme. Since 2014, specific measures have been supported throughout Switzerland through resource efficiency contributions. The measures promoted relate in particular to manure storage and spreading, the structural adaptation of stables, for example to allow urine to drain quickly, and balanced or protein-reduced feeding.

However, during the period in which the Confederation supported ammonia-reducing measures, emissions only fell by about 2%. Despite these efforts, the high animal population in Swiss agriculture and the socially demanded consideration of animal welfare led to only slightly decreased ammonia emissions (see also section 4.4). In addition, feeding measures and the use of drag hoses are only of limited use or feasibility, especially in mountainous areas. A balanced feed ration with low crude protein surpluses is dependent on the supply of energy-rich feed such as maize from the valley. However, this is only of limited use due to the transport routes. Furthermore, the spreading of liquid manure via drag hoses, which allows a near-ground and thus emission-reduced application, is no longer possible above a certain slope inclination. Although mountain areas produce less emissions compared to lowlands, the question arises as to which type of livestock farming least pollutes the sensitive ecosystems in the mountains.

The exclusive focus on technical and construction measures does not do the situation of mountain regions justice. What is needed is a holistic approach that takes into account not only technical measures but also questions of available feed resources and the carrying capacity of ecosystems. Air quality is protected by adapting the number of animals to the sensitivity of the natural environment. The widespread practice of grazing, particularly in mountainous areas, is another important measure for ammonia reduction: urine seeps quickly into the soil and there is less ammonia loss than in stables. If, in addition, drag hoses can be used to spread manure, the manure storage area is covered and if it is also ensured that the walking and resting areas in the barn are clean, ammonia emissions and their effect on sensitive ecosystems can be considerably reduced.

The most significant factor of ammonia emissions in agriculture is the number of farm animals. If this number stagnates or even increases, a reduction in nitrogen and ammonia emissions will be difficult to achieve. In addition, the reduction of ammonia emissions in agriculture is partly in conflict with animal welfare aspects. Open-air stables contribute to animal welfare, but also lead to higher ammonia losses. Reconciling societal demands regarding the number of animals, animal welfare and environmental protection remains a challenge that politicians must face.

8. SUM-UP AND POLICY RECOMMENDATIONS

8.1 REDUCTION OF WOOD BURNING EMISSION OF PARTICLES INCLUDING BAP

Chapter 5.2 showed that PM concentrations, especially $PM_{2.5}$ including in particular BaP are still a concern for many Alpine regions, although the trend shown in chapter 5.3 is of a decrease in PM_{10} and $PM_{2.5}$ concentrations over the last decade. Wood burning is a major source of particulate matter concentrations contributing massively to critical values of ambient air quality in the Alpine atmosphere, as demonstrated by specific research programmes and discussed in Chapter 3.2.1.

To mitigate this problem, it is proposed to develop measurement campaigns to measure emissions of small-scale domestic sources as well as to monitor $PM_{2.5}$ and BaP in order to inform the Alpine inhabitants about technical and operational options to lower emissions and to further reduce particulate and BaP emissions through support actions. In certain areas with high levels of particulate pollution, stricter regulations should be introduced for the Alpine region on a voluntary basis, such as more stringent emission limit values for new appliances, stricter controls of existing appliances and fuels used, information campaigns, training on proper handling, etc.

8.1.1 MEASUREMENT AND INFORMATION

Information campaigns on the health impacts of particulate matter and BaP and on proper heating with wood should be based on the ability to measure PM emissions and its sources, and this information should be made available to the public. Emission measurement should be complemented by monitoring campaigns for $PM_{2.5}$, BaP and black carbon at least over one heating season. Information for citizens needs to be supported by measurements adapted to the physical and geographical characteristics of the Alpine space: diverse relief and meteorological specificities, diverse settlement types, longer heating season and various sources of air pollution (individual furnaces, traffic, industry etc.). With respect to the topographic and climatic situation, to the heterogeneous distribution of population and the emission sources in Alpine areas, the selection of monitoring points should consider different types of areas and should include black carbon monitoring points.

RECOMMENDATION 1

Support relevant organisations to:

- measure *in situ* fine particles and in particular benzo(a)pyrene coming from wood-burning heaters and boilers;
- inform the population about the health significance of wood-burning for heating.

8.1.2 SUPPORT UPGRADING THE SMALL-SCALE HEATING SYSTEMS

According to specific diagnoses, all operators and individuals should be offered the possibility to technically retrofit or replace old wood or oil-fired heating systems with technically new and modern low-emission heating systems. In larger settlements, towns or cities, the feasibility of a central community heating system should be examined because centralised modern heating systems usually guarantee a clean energy supply, are more energy efficient and cause lower emissions.

RECOMMENDATION 2

Reduce domestic heating emissions by improving overall energy performance of buildings and renewing heating systems towards low emitters through support and guidance to all operators by:

- improving the energy performance of buildings;
- replacing old heavily polluting heating systems and boilers;
- substituting traditional fuels with a cleaner type.

8.2 PROMOTING CLEAN MOBILITY

As shown by the previous chapters of this report, especially Chapter 3.2, the concentration of traffic within the Alpine valleys and cities remains a major source of air pollution for people living close to the main roads. The examples presented in Chapter 7.3 show that the Alpine Convention Contracting Parties are already involved in reducing air pollution using active mobility, restricted circulation areas, promoting public transportation, introducing speed limits and using new technologies. This sharing of experiences is an incentive for all countries to learn from their partners, customising the proposed solutions, spreading information and awareness campaigns, and finally implementing them. Solutions are available at several levels, from the EU and national to the local communities. Last, but not least, most of these actions also have positive effects on mitigating climate change.

8.2.1 ADOPT AMBITIOUS MOBILITY POLICIES

Cities, districts and regions are encouraged to use the available tools (air quality mapping and modelling, evaluation of the effects on air quality of shifting to active modes etc.) to demonstrate the link between mobility choices, air pollution and human health. Discussions and debates with the citizens concerned about the use of these tools might help in proposing and implementing ambitious solutions and monitoring their benefits for everyone. Mobility initiatives using a coherent set of measures, coupling regulatory and financial or fiscal incentives with restrictions, both in passenger and freight transport policies, and adopted after concerted consultation and environmental evaluation, could help transform wishes and needs into public policies.

RECOMMENDATION 3

After consultation and environmental evaluation, adopt regional and local mobility initiatives for passenger and freight transport favouring public transportation and active modes, coupling incentives with restrictions where a relevant impact on air quality is expected.

8.2.2 INVEST IN CLEAN TRANSPORTATION

Smart public transportation systems, numerical tools to help use them smoothly, smartphone apps integrating public transportation in multimodal mobility systems as well as new technologies tending towards zero-emission vehicles are already available and will improve further. Their development depends on market signals that can be accelerated using, for example, a coherent set of public funding, regulations or real cost-based taxation systems designed to promote clean mobility. Such tools, within national or regional policies and including the promotion of combined transport solutions outside the scope of the Alpine Convention but having an impact inside the Alpine region, are recommended to foster quick adoption of smart solutions and to provide the conditions for innovative solutions to reach the market.

RECOMMENDATION 4

Promote clean mobility and zero-emission vehicles strategy, e.g. by using a balanced taxation and incentives system to internalise external pollution costs within real transport costs, and enhance the market signals in favour of clean mobility and zero-emission vehicles.

RECOMMENDATION 5

Promote the use of smart traffic management, e.g. speed limits, road pricing, favouring clean vehicles on Alpine motorways and tunnels to lower emissions, as well as:

- encourage the implementation of alternative transport technologies and combined transport;
- integrate public transport in multimodal mobility systems;
- incentivise modal shift of passenger and freight transport.

8.3 REDUCING EMISSIONS FROM AGRICULTURE

As shown in the previous chapters, agriculture is generally not the major source of air pollution in the Alps. However, chapter 3.2 shows that the contribution of agriculture in some intensive agricultural areas is not negligible. Chapter 4.4 illustrates the fact that critical loads of nitrogen deposited from the atmosphere can be exceeded in some areas of the Alps.

RECOMMENDATION 6

Support the development of good agricultural practices limiting the emissions of nitrogen compounds like ammonia, and the open burning of green waste and slash in the Alpine region.

8.4 AIR QUALITY POLICIES

The Alpine Convention Contracting parties encourage all initiatives that contribute to the improvement of air quality in the Alps. The coherence of the initiatives needs to be addressed at several levels. Within the various countries it is important that all the different communities benefit from good air quality since social inequalities are often linked with environmental inequalities[69].

8.4.1 SETTING UP AIR QUALITY INITIATIVES IN THE ALPS

The aim is to encourage initiatives from local and regional policymakers. This might also contribute to a better understanding of differences and to eliminate inequalities regarding mobility, air pollution and housing. Setting up air quality plans is an obligation from EU legislation for areas where the EU concentration limits are exceeded (Directive 2008/50/EC). The Alpine Convention would like to encourage additional initiatives, inspired by the WHO air quality guidelines.

RECOMMENDATION 7

The Contracting parties of the Alpine Convention are encouraged to set up air quality initiatives incorporating measures addressing their most relevant sources of air pollution like domestic heating, mobility, energy, industry and agriculture

8.4.2 EXTEND THE USE OF THE ESPOO AND CLRTAP CONVENTIONS REQUIREMENTS

The Convention on Environmental Impact Assessment in a Transboundary Context, adopted in Espoo in Finland in 1991 (UNECE 1991), requires its parties to take appropriate measures to prevent, reduce and control adverse transboundary effects of their activities. This aspect is already included in European law in Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (s. Art. 7) and in Directive 2001/42/EC (s. Art. 7) of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the envi-

69. *For instance, cycling and walking are easier for people who can afford to live close to urban facilities than for people living in suburbs where housing costs are lower.*

ronment. Pollution of the Alps can, however, also originate from outside the Alpine Convention area as exemplified by the Convention on long-range transboundary air pollution.

RECOMMENDATION 8

The Contracting parties of the Alpine convention should liaise with neighbouring countries and regions to stimulate the reduction of transboundary pollutant transport in the geographic area of the Alpine Convention.

8.4.3 SUPPORT THE EU GREEN DEAL INITIATIVE IN THE FIELD OF AIR POLLUTION

Ambient air quality concentration targets in the Alpine Convention perimeter to protect human health are based on the EU Air Quality Directive 2008/50/EC, but some Member States have set stricter regulations. Considering objective "c" of the Alpine Convention[70], an alignment of air quality limits to the WHO Air Quality Guidelines would clearly change policies towards improved preservation of human health. It does not solve the problem per se since it does not cover emissions, but it might help Member States and communities to identify priorities and trigger solutions where it is necessary.

RECOMMENDATION 9

The Alpine Convention Contracting parties should:

- support the air quality chapter of the EU Green Deal;
- strive to achieve WHO air quality guidelines.

8.5 INCREASE KNOWLEDGE ON THE ANTHROPOGENIC CAUSES OF AIR POLLUTION

This report has been sourced from official reports from mandated agencies, like the EEA, the WHO and the U.S. EPA, from former reports of the Alpine Convention as well as from scientific publications, many of them being the result of collaborative European research programmes (listed in the Annex 2). Most of them were launched during the last two decades. It would not have been possible to write many chapters of this report without this information. However, uncertainties remain on the precise causal relationships between human activities, biogenic sources and air quality. The effects of climate change on air quality also remain to be addressed and modelled as a function of different scenarios. The exposure of people to ultrafine particles, their generation, transport and effects, is still an active research subject.

Moreover, the expectance of citizens living in the Alps, their knowledge of the actual situation and of their role in air pollution, their requirements from policy makers and their willingness to adapt their behaviour in order to improve the quality of the air could be better understood by social and political scientists involved in consultation processes. Therefore, this report calls for an enhancement of multidisciplinary research programmes dealing with air quality in the Alps, for a fast communication of the results to stakeholders and for the involvement of the public in discussions and mutual understanding with research communities studying the Alps.

RECOMMENDATION 10

Develop in-depth and specific studies on air quality in the Alps, especially where problems referring to ambient air quality are identified or expected from the monitoring of the situation, for studying the influence of the sources of air pollution, as well as on the related social and political issues.

70. *c. "prevention of air pollution: the objective is to drastically reduce the emission of pollutants and pollution problems in the Alpine region, together with inputs of harmful substances from outside the region, to a level which is not harmful to man, animals or plants".*

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ANNEX 1

OVERVIEW OF THE MOST COMMON POLLUTANTS

Ammonia (NH_3)
Ammonia is a colourless alkaline gas and is one of the most abundant nitrogen-containing compounds in the atmosphere. It is an irritant with a characteristic pungent odour. Upon inhalation, ammonia is deposited in the upper airways: occupational exposures to it have commonly been associated with sinusitis. Small amounts of NH_3 are naturally formed in nearly all tissues and organs of the vertebrate organisms.[71]

Arsenic (As)
Arsenic and its compounds are ubiquitous in nature. Arsenic is released to the atmosphere from both natural and anthropogenic sources. The principal natural source is volcanic activity, whereas man-made emissions to air arise from the smelting of metals, the combustion of fuels, especially of low-grade brown coal, and the use of pesticides. It is mainly transported in the environment by water.[72] Arsenic in air is present mainly in particulate forms as inorganic arsenic. It is highly toxic and a confirmed carcinogen in its inorganic form.[73]

Benzene C_6H_6
Benzene is a colourless liquid, that evaporates quickly when exposed to air. Benzene is formed from natural processes, such as volcanoes and forest fires, but most exposure to benzene results from human activities. Benzene is a natural component of crude oil and is emitted during its production and from coke ovens. Besides these industrial sources, emission also occurs from different combustion sources, such as motor engines, wood combustion and stationary fossil fuel combustion. The major source is exhaust emissions and evaporation losses from motor vehicles, and evaporation losses during the handling, distribution (e.g., car refuelling) and storage of petrol. IARC classifies benzene as carcinogenic to humans.[74]

Benzo(a)pyrene (BaP)
It is a PAH formed during the incomplete combustion of organic matter. It is primarily found in gasoline and diesel exhaust, cigarette smoke, coal tar, charcoal-broiled foods and certain other foods. It has a role as a carcinogenic agent and it presents a threat to the environment since it easily penetrates the soil and contaminates groundwater.[75]

Black carbon (BC) and elemental carbon (EC)
They are primary constituents of atmospheric aerosols. They are produced from incomplete combustion of fossil fuel or biomass burning emission.[76]

Cadmium (Cd)
Cadmium is a heavy metal found in tiny amounts in air, water, soil, and food. In the past cadmium was mainly used in the electroplating of metals and in pigments or stabilisers for plastics. Nowadays, cadmium has in many respects become a vital component of modern technology: cadmium nickel battery manufacture, for example, consumes 55% of the cadmium output and it is expected that this application will expand (e.g. with the use of electric vehicles). In the European Union and worldwide, approximately 85–90% of total airborne cadmium emissions arise from anthro-

71. *https://pubchem.ncbi.nlm.nih.gov/compound/222.*
72. *https://www.euro.who.int/__data/assets/pdf_file/0014/123071/AQG2ndEd_6_1_Arsenic.PDF.*
73. *https://www.who.int/news-room/fact-sheets/detail/arsenic.*
74. *https://www.cancer.org/cancer/cancer-causes/benzene.html*
https://pubchem.ncbi.nlm.nih.gov/compound/benzene.
75. *https://pubchem.ncbi.nlm.nih.gov/compound/Benzo_a_pyrene.*
76. *https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014JD022144*
https://www.hindawi.com/journals/amete/2014/179301/.

pogenic sources, mainly from smelting and refining of nonferrous metals, fossil fuel combustion and municipal waste incineration. Cadmium has an exceptionally long biological half-life resulting in a virtually irreversible accumulation of the metal in the body throughout life. It is classified as a human carcinogen.[77]

Carbon monoxide (CO)

CO is an odourless, tasteless, poisonous gas, that results from the incomplete combustion of carbon. Inhalation in high concentrations causes central nervous system damage and asphyxiation.[78]

Lead (Pb)

Lead is a heavy metal that is denser than most common materials. It is considered highly poisonous and can get into human body by contaminated water or food, or from breathing fumes or dust that contain lead. On a global scale the combustion of alkyl lead additives in motor fuels accounts for the major part of all lead emissions into the atmosphere, followed by coal combustion. Most people receive the largest portion of their daily lead intake via food: most lead enters food during storage and manufacture, or through direct foliar contamination of plants by atmospheric lead. Lead water pipes or lead-containing paint in old houses can be important sources of lead exposure for humans.

The toxicity of lead may largely be explained by its interference with different enzyme systems and for this reason, many organs or organ systems are potential targets: most importantly, it can have effects on haem formation, on the nervous system, on blood pressure and cardiovascular system as well as on the kidneys. According to IARC, evidence of the carcinogenicity of lead compounds in humans is inadequate.[79]

Mercury (Hg)

Mercury and its compounds are ubiquitous in nature. It is released into the environment either naturally, from volcanic activity and weathering of rocks, or as a result of human activity, which is the main cause of mercury releases, particularly coal-fired power stations, residential coal burning for heating and cooking, industrial processes.[80] Exposure to mercury – even small amounts – may cause serious health problems and is a threat to the development of the child in utero and early in life. Human exposure occurs mainly through inhalation of elemental mercury vapours released by dental amalgam filling, and through consumption of fish and shellfish contaminated by methylmercury compounds.[81] The IARC classifies the latter as possibly carcinogenic to humans.

Nickel (Ni)

Nickel is a heavy metal widely distributed and normally occurs at very low levels in nature. The burning of residual and fuel oils, nickel mining and refining, and municipal waste incineration are the main anthropogenic sources of nickel emissions to the atmosphere, accounting for about 90% of the total global emission. Nickel fumes are respiratory irritants.[82] Nickel compounds are classified by IARC as carcinogenic to humans.

Nitrogen oxides (NO_x)

NO_x is a generic term to refer to nitric oxide (NO) and nitrogen dioxide (NO_2). These gases are poisonous and react with other chemicals in the air to form particulate matter, ozone and acid rain. NO_x gases are usually produced during combustion of fuels, such as hydrocarbons, especially at high temperatures, such as in car engines, heating and power generation. In areas of high motor vehicle traffic, such as in large cities, the nitrogen oxides emitted can be a significant source of air pollution. NO_x are very toxic and cause significant inflammation of the airways.[83]

Ozone (O_3)

Ozone is a gas composed of three atoms of oxygen. Ozone occurs both in the Earth's upper atmosphere and at ground level. The first kind of ozone, called stratospheric ozone, occurs naturally and forms a protective layer that filters the sun's UV rays. At the same time, ground level (or tropospheric) ozone is an air pollutant harmful for health. It is not emitted directly into the air but is

77. *https://www.cancer.gov/about-cancer/causes-prevention/risk/substances/cadmium*
https://www.who.int/ipcs/assessment/public_health/cadmium/en/.
https://www.euro.who.int/__data/assets/pdf_file/0016/123073/AQG2ndEd_6_3Cadmium.PDF
78. *https://pubchem.ncbi.nlm.nih.gov/compound/281.*
79. *https://www.euro.who.int/__data/assets/pdf_file/0020/123077/AQG2ndEd_6_7Lead.pdf.*
80. *https://www.who.int/news-room/fact-sheets/detail/mercury-and-health.*
81. *https://www.who.int/ipcs/assessment/public_health/mercury/en/.*
82. *https://www.euro.who.int/__data/assets/pdf_file/0014/123080/AQG2ndEd_6_10Nickel.pdf.*
83. *https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health*
https://www.epa.gov/no2-pollution/basic-information-about-no2#What%20is%20NO2.

created by the reaction between NO_x and VOCs in the presence of sunlight. Hence, ozone is most likely to reach unhealthy levels on hot sunny days in urban environments, although it can still reach high levels during colder months. It can also be transported long distances by wind, so even rural areas can experience high ozone levels. Breathing ozone can trigger a variety of breathing problems. Ozone also affects sensitive vegetation and ecosystems.[84]

Particulate matter (PM)

PM indicates a mixture of solid particles and liquid droplets suspended in the air. These particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some particles are emitted directly from a source (such as construction sites, fields or fires), but most of them form in the atmosphere as a result of complex reactions of chemicals such as SO_2 and NO_x. PM includes: PM_{10} (diameter of 10 micrometres (µm) and smaller), $PM_{2.5}$ (2.5 µm and smaller) and UFP (or $PM_{0.1}$, smaller than 0.1 µm). The smaller the particles, the easier they can gain access to the lungs' alveoli and reach cells and organs.[85]

Perchlorethylene (PERC)

PERC is a colourless liquid that may emit toxic fumes when exposed to sunlight or flames. Exposure to it irritates the upper respiratory tract and eyes and causes neurological effects as well as kidney and liver damage. It is reasonably anticipated to be a human carcinogen. PERC is a common soil contaminant. Because of its mobility in groundwater, its toxicity at low levels, and its density (which causes it to sink below the water table), clean-up activities are more difficult than for oil spills.[86]

Persistent organic pollutant (POP)

POPs are primarily synthetic chemicals of anthropogenic origin. They can be created as industrial products or unintended by-products resulting from industrial processes or combustions, but they can also result from waste and waste burning, traffic and agriculture (some POPs are pesticides, like DDT). They are of global concern due to their potential for long-range transport (they are globally distributed and can enter into atmospheric processes), persistence in the environment (up to decades or centuries), ability to bio-accumulate and in particular to bio-magnify in ecosystems and organisms (the highest concentrations are thus found in organisms at the top of the food chain: background levels of POPs can be found in the human body), as well as their significant negative effects on human health and the environment. Human exposure - for some compounds and scenarios even to low levels of POPs - can lead, among others, to increased cancer risk, reproductive disorders, alteration of the immune system, neuro-behavioural impairment and increased birth defects.[87]

Polycyclic aromatic hydrocarbon (PAH)

They are a class of chemicals that occur in coal, crude oil and gasoline. They also are produced when coal, oil, gas, wood, waste and tobacco are burned. High-temperature cooking will also form PAHs in foods. In 2010, the IARC Monographs Programme has reviewed experimental data for 60 individual PAHs. Of these 60 PAHs, BaP is classified as carcinogenic to humans (Group 1). Other PAHs are classified as probably carcinogenic to humans (Group 2A) or possibly carcinogenic to humans (Group 2B), while another group is not classifiable as to their carcinogenicity to humans (Group 3), because of limited or inadequate experimental evidence. PAHs share a similar mecha-nism of carcinogenic action in both humans and experimental animals. A number of PAHs have caused cancer, reproductive problems, damage to the skin, body fluids, and the immune system in laboratory animals that were exposed to PAHs. PAHs are a concern because they are persistent and can stay in the environment for long periods of time.[88]

Primary and secondary organic aerosol (POA and SOA)

An aerosol is a particulate matter, a suspension of fine solid particles or liquid droplets in the air. POA is directly emitted from various sources,

84. https://www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics
https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.
85. https://www.epa.gov/pm-pollution/particulate-matter-pm-basics.
https://www.nature.com/articles/s12276-020-0403-3.
86. https://pubchem.ncbi.nlm.nih.gov/compound/31373.
87. https://www.who.int/foodsafety/areas_work/chemical-risks/pops/en/.
88. https://archive.epa.gov/epawaste/hazard/wastemin/web/pdf/pahs.pdf.
https://www.epa.gov/sites/production/files/2014-03/documents/pahs_factsheet_cdc_2013.pdf.
https://publications.iarc.fr/Book-And-Report-Series/Iarc-Scientific-Publications/Tumour-Site-Concordance-And-Mechanisms-Of-Carcinogenesis-2019.

both natural (vegetation and micro-organisms) and anthropogenic (such as combustion of fossil fuels as well as biomass burning). SOA is formed from the atmospheric transformation of organic species.

Sulphur dioxide (SO_2)

It is a colourless gas with a sharp odour. It is produced from the burning of fossil fuels and the smelting of mineral ores that contain sulphur. The main anthropogenic source of SO_2 is the burning of sulphur-containing fossil fuels. SO_2 can affect the respiratory system and the functions of the lungs and causes irritation of the eyes. Hospital admissions for cardiac disease and mortality increase on days with higher SO_2 levels. When SO_2 combines with water, it forms sulfuric acid: this is the main component of acid rain.[89]

Volatile organic compounds (VOC) and Non-methane volatile organic compounds (NMVOC)

VOCs and NMVOCs are a set of organic compounds (such as benzene, ethanol, formaldehyde, cyclohexane, trichloroethane or acetone) that differ widely in their chemical composition but display similar behaviour in the atmosphere: they are emitted by a wide array of product and processes, both natural and human-made, numbering in the thousands. Most scents or odours are of VOCs. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. Certain NMVOC species such as benzene are hazardous to human health and they contribute to the formation of ground level ozone.[90]

89. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.
90. https://www.eea.europa.eu/data-and-maps/indicators/eea-32-non-methane-volatile-1
https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality.

ANNEX 2

RELEVANT PROJECTS IN THE ALPINE REGION

ALPNAP: INTERREG IIIB PROGRAMME ALPINE SPACE

ALPNAP (Monitoring and Minimisation of Traffic-Induced Noise and Air Pollution Along Major Alpine Transport Routes) was concluded in 2007. This three-year project (2005–2007) was co-funded by the European Regional Development Fund (ERDF) within the European Interreg IIIB Alpine Space programme. The objectives of ALPNAP were to collect and describe up-to-date science-based methods to observe and predict air and noise pollution along trans-Alpine transport corridors and to assess the related effects on health and well-being. The added value of ALPNAP was increased by a coordinated cooperation with the contemporaneous project MONITRAF ("Monitoring of Road Traffic Related Effects in Alpine Space and Common Measures"), a network of regional transport and environment administrations in the Alps. The objectives of MONITRAF were to develop comprehensive measures that aim at reducing the negative effects of road traffic, while simultaneously enhancing the quality of life within the Alpine region.

http://alpnap.i-med.ac.at/

http://alpnap.i-med.ac.at/results-en.html

LIFE BRENNER LECBRENNER LOW EMISSION CORRIDOR (ITALY)

"BrennerLEC is the contraction of Brenner Lower Emissions Corridor. BrennerLEC aims at making traffic along the Brenner axis more respectful of the local population's health and more compatible with the geographical features of the land, in order to protect the particular Alpine environment crossed".

With speed regulations and traffic management, the maximum for an environmental and traffic benefit should be reached. The project is intended to demonstrate the effectiveness of such measures in order to use them on a larger scale.

http://brennerlec.life/en/home

ESPACE MONT BLANC (FRANCE, ITALY, SWITZERLAND)

Espace Mont-Blanc project is a cross-border cooperation initiative bringing together Savoie (FR), Haute-Savoie (FR), Aosta Valley (IT) and Valais (CH), engaging in the protection of the exceptional natural and environmental heritage and joint economic and tourist activities. Espace Mont-Blanc launched a cross-border air measurement campaign in 1998. This action was perpetuated by the implementation of continuous monitoring of air quality. The effectiveness of actions would have an ancillary benefit for the whole Alpine region due to the reduction of local sources and pollution transport from the Po valley.

http://www.espace-mont-blanc.com/

MONARPOP (AUSTRIA, GERMANY, ITALY, SWITZERLAND, SLOVENIA)

Monarpop (Monitoring Network in the Alpine Region for Persistent and other Organic Pollutants) was concluded in 2008; it was a joint project of the EU, Austria, Germany, Italy, Slovenia, and Switzerland. As a pilot project, Monarpop assessed for the first time the load of the Alps with POPs (phase 1) and established - based on the results - conclusions (e.g., a common declaration) and implemen-

tation steps to reduce this load (phase 2). The Alps represent a significant sink and a barrier for long-range transported POPs. This is the most prominent finding of the Monarpop project.
The project investigated Alpine air pollution with POPs and other organic components. Twelve partners in the network cooperated via an Alpine Space Programme of the European Union. Plants, soil, and air were analysed in profiles of different altitudes. The deposition and the air flow reveal the air transport path and the allocation of the area of origin. Monarpop contributed to the effective monitoring of the Stockholm Convention by continuously measuring air and precipitation on selected mountain peaks to monitor time series. The extension of the project is necessary in order to establish conclusions for the geographical origin and the seasonal change of the origin of POPs in the Alpine atmosphere.

http://www.monarpop.at/

https://keep.eu/project/122/monitoring-network-in-the-alpine-region-for-persistent-and-other-organic-pollutants

LIFE PREPAIR (PO REGIONS ENGAGED TO POLICIES OF AIR) (ITALY)

"PrepAir (Po regions engaged to policies of air) aims at implementing the measures set out in the regional plans and in the Po Valley agreement on a larger scale so as to strengthen the sustainability and durability of results: the geographical coverage of the IP is the Po Valley with the regions and cities that mainly influence air quality in the basin. The IP actions are also extended to Slovenia in order to assess and reduce transportation of pollutants also across the Adriatic sea".
The project aims to initiate measures in the regional plans of the Po Valley on a larger scale for sustainability and permanence. The Po Valley in northern Italy is an important source zone for PM, NO_x (NO_2), NH_3 and O_3. This zone covers the territory of the northern Italian regions and includes several urban agglomerations such as Milan, Turin, and Bologna. The transport and distribution of pollutants are determined by the morphological influences on the Po Valley. In order to further reduce air pollution in the background, all regions of the Po Valley have come together and planned measures to reduce emissions by the burning of biomass, transporting of goods and passengers, heating, industry, energy and agriculture in the coming years. Therefore, they have signed an agreement to develop and coordinate short- and long-term measures to improve air quality in the Po Valley. The project measures will also be extended to Slovenia in order to assess and reduce the transport of pollutants across the Adriatic.

http://www.lifeprepair.eu/

PUREALPS (GERMANY, AUSTRIA, ITALY)

The goal of the Bavarian-Austrian programme PureAlps is to protect the Alps from critical influences by POPs and to monitor the air concentrations, the deposition of POPs by precipitation, snow and dust. 106 substances and substance classes in connection with POPs have been analysed in the ambient air at the environmental research station Schneefernerhaus (UFS) on the Zugspitze.

GUAN GERMAN ULTRAFINE AEROSOL NETWORK (GERMANY, ITALY, AUSTRIA, SWITZERLAND)

Ultrafine particles could have some risks for humans. GUAN is a cooperative measuring network in Germany that creates new scientific bases for the evaluation of ultrafine particles. The main measurement variables are the particle number, the size distribution and the soot mass concentrations. In the meantime, the cooperative network has grown to 17 measuring stations. The data compiled can be used for revising the EU Air Quality Directive. The GUAN measuring stations in the Alpine area are located in the UFS on Zugspitze and at Hohen Peißenberg in the northern foothills of the Alps.

INVESTIGATION OF REGIONAL CO_2 BUDGET ON ATMOSPHERIC MEASUREMENT SERIES (GERMANY, ITALY, AUSTRIA AND SWITZERLAND)

The characterisation of the CO_2 and CH_4 budget of the Alpine Space based on atmospheric measurements of local observatories is possible and reliable. Furthermore, the methodology of the project can be used to reliably measure climate-specific source and sink areas as well as seasonal variations.

VOTALP I AND VOTALP II VERTICAL OZONE TRANSPORT IN THE ALPS (SWITZERLAND, AUSTRIA, GERMANY, EU)

Votalp (Vertical Ozone Transport in the Alps) was concluded at the end of 1999; it was a joint project

between the University of Agricultural Sciences in Vienna, Austria, the University of Cologne and the Fraunhofer Institute for Atmospheric Environmental Research in Garmisch-Partenkirchen, Germany, the Paul Scherrer Institute, the University of Bern and the Metair AG, Switzerland, the National Research Council, Italy, and the University of Ljubljana, Slovenia. Its main focus was: investigation of the enhanced vertical exchange above the Alps as well as other processes which might be relevant to increased ozone concentrations. It developed through two consecutive projects: Votalp I and Votalp II. It was funded by the European Commission under Framework Programme IV, Environment and Climate, and by the Government of Switzerland.
The main objectives of Votalp were to investigate the vertical pollutant exchange over Alpine foothills by aircraft measurements including ozone explorations. The urban plumes of Milan and Munich in the Alpine region were also investigated by aircraft measurements and compared with earlier campaigns. A significant increase in concentration could be observed above the Alpine foothills. With these studies, the vertical exchange of pollutants over the foothills was characterised for the first time. Milan is a major source of pollutants. During the summer months, the pollutants of this area often hit the Alps.

https://imp.boku.ac.at/votalp/

VAO – VIRTUAL ALPINE OBSERVATORY (GERMANY, ITALY, FRANCE, AUSTRIA, AND SWITZERLAND)

The Virtual Alpine Observatory (VAO) project serves to network research activities of the European Alpine high mountain research observatories for improved climate and environmental monitoring. This supports research activities of the high mountain research stations by combining their measurements and carrying out joint research projects. Together with access to other e.g. satellite data and powerful computing facilities, this creates unique research opportunities.

GAW – GLOBAL ATMOSPHERE WATCH (GERMANY, ITALY, FRANCE, AUSTRIA, SWITZERLAND)

The Global Atmosphere Watch (GAW) programme of the WMO is a partnership in which WMO members are involved, bringing together networks and cooperating organisations and institutions that provide reliable scientific data and information on the chemical composition of the atmosphere, its natural and anthropogenic alteration and contribute to improving the understanding of interactions between atmosphere, CLRTAPs and biosphere.
GAW focuses on aerosols, greenhouse gases, selected reactive gases, ozone, UV radiation and precipitation chemistry (or atmospheric deposition). GAW creates a network for research, a data platform, a modelling, and a monitoring network.

BB CLEAN – STRATEGIC TOOLS TOWARDS A SUSTAINABLE USE OF BIOMASS FOR LOW CARBON DOMESTIC HEATING (ITALY, FRANCE, SLOVENIA, AUSTRIA): STRATEGIC INSTRUMENTS FOR THE SUSTAINABLE USE OF BIOMASS FOR LOW-CARBON DOMESTIC HEATING SYSTEMS

In the Alpine region it is necessary to initiate a better use of local resources such as wood and at the same time to reduce the impact on the environment and climate. Biomass is an economic resource that is available locally and therefore very important for the population. The combustion of wood avoids fossil CO_2 emissions in the atmosphere. Nevertheless, using the wrong technique for biomass combustion (BB) leads to unacceptable particle emissions (PM) into the ambient air, which the population is not even aware of. The main objective of the project is therefore to develop transnational strategies for the sustainable use of biomass for domestic heating in order to minimise these impacts and to improve the intelligent use of this resource in the Alpine region. The development of common policy-relevant documents will promote the application of harmonised rules for the sustainable use of biomass in the Alpine Space.

ACTRIS/ACTRIS II AEROSOL, CLOUDS AND TRACE GASES RESEARCH INFRASTRUCTURE (AUSTRIA, FRANCE, GERMANY, ITALY, SWITZERLAND)

Actris (Aerosol, Clouds and Trace Gases Research Infrastructure) is a pan-European initiative consolidating actions amongst European partners producing high-quality observations of aerosols, clouds and trace gases. Different atmospheric processes are increasingly in the focus of many societal and environmental challenges, such as air quality, health, sustainability and climate change. ACTRIS aims to help deal with such challenges by providing a platform for researchers to combine their efforts more effectively, and by providing observational data on aerosols, clouds and trace gases openly to anyone who might want to use them.

CLIMGAS-CH (HALCLIM)/AGAGE MEASUREMENT OF HALOGENATED GREENHOUSE GASES AT JUNGFRAUJOCH

Between 2000 -2018 more than 50 ozone-depletion and greenhouse gases have been continuously measured at Jungfraujoch within the Swiss national HALCLIM project under the management of Empa and BAFU (Swiss Federal Office for the Environment). Since 2018 in the CLIMGAS-CH project, commonly managed by Empa and BAFU, all non-CO_2 greenhouse gases (halocarbons, methane and nitrous oxide) are analysed and their regional emissions are estimated. This activity is also contributing to the common measurement technique of GCMS (gas chromatograph – mass spectrometer) to the AGAGE network. This makes possible, (1) the assessing Swiss and regional European emissions of non-CO_2 greenhouse gases and (2) the contributing to the control of the national emission inventory, (3) the locating of sources and dominant source regions of non-CO_2 greenhouse gases using atmospheric transport models, (4) long-term continuous measurements of different halocarbons can be used to identify global and regional emissions. For example, HFC-134a is used in great quantities as a cooling agent (e.g. in mobile air conditioners). HFC-125 is used in stationary cooling blends. Concentrations of both gases are currently rising (early identification).

BLACK CARBON AIR POLLUTION - CASE STUDY OF LOSKI POTOK

Research is focused on a study of air pollution caused by black carbon and fine particulate matter carried out in the rural area of the municipality of Loški Potok in the winter season of 2017/2018. The measurement results revealed the main sources of black carbon air pollution in this area: domestic heating using biomass (almost 80% of all black carbon emissions) and unfavourable meteorological conditions for diluting pollutants during temperature inversions. In the winter of 2017/18, the average concentrations in the Retje hollow were even higher than those of Ljubljana, which calls attention to the problem of polluted air in rural (hilly mountain) areas, too.

OVERVIEW OF THE IMPACT OF WOOD BURNING EMISSIONS ON CARBONACEOUS AEROSOLS AND PM IN LARGE PARTS OF THE ALPINE REGION: IN JOURNAL ATMOSPHERIC ENVIRONMENT 89 (2014) 64-75

In past years, actions implemented for the reduction of particulate matter emissions have in many European countries focused on road traffic emissions. Much less attention was paid to emissions from domestic wood combustion, although the importance of residential wood burning as a source of atmospheric particulate matter (PM) in the Alpine region has been demonstrated in many studies. Here we review the current knowledge about the contribution of wood burning emissions to ambient concentrations of elemental carbon (EC), organic carbon (OC) and PM in the Alpine region. The published results obtained by different approaches (e.g. macro-tracer method, multivariate receptor modelling, chemical mass balance modelling, and so-called Aethalometer modelling) are used in an ambient monotracer approach to estimate representative relationships between wood burning tracers (levoglucosan and mannosan) and EC, OC and PM from wood burning. The relationships found are applied to available ambient measurements of levoglucosan and mannosan at Alpine sites to estimate the contributions of wood burning emissions to average levels of carbonaceous aerosols and PM at these sites. The results imply that PM from wood burning alone often adds up to 50% and more of the EU daily limit value for PM_{10} in several Alpine valleys during winter days. Concentrations of carbonaceous aerosols in these valleys are often up to six times higher than in urban or rural sites at the foothills of the Alps.

IMPACT ON PARTICLE EMISSIONS OF REPLACING OLD WOOD HEATING APPLIANCES BY EFFICIENT WOOD BURNING STOVES

This impact is evaluated by taking measurements on site before and after renewal of the appliance (measurements carried out in the Arve Valley, Haute-Savoie). The tests are conducted directly at home, taking into account the real operating conditions of appliances in terms of performance, wood species and moisture, load of wood, stack draft, etc. 35 sites including 19 renewals with log devices and 16 with pellet devices were investigated. The results obtained provide information on the impact of device replacement on pollutant emissions and energy efficiency. When changing an old appliance with a recent log appliance: energy efficiency gains of 16 points; 57% reduction in particulate matter. When renewing an old appliance with a pellet appliance: energy efficiency gains of 34 points; 44% reduction in particulate matter.

LONG-TERM MONITORING OF PARTICLES FROM BIOMASS COMBUSTION IN GRENOBLE

This study is based on measurements taken as part of the national "CARA Program", a programme for the characterisation of PM chemical composition, in close collaboration with Atmo Auvergne Rhône-Alpes and the Institute of Environmental Geosciences (IGE). Measurement data collected between 2008 and 2017 are analysed. The objective of this monitoring is to determine the influence of biomass combustion on PM levels, a source considered as one of the most polluting anthropogenic activities, particularly in the Alpine valleys. Another objective is to study the link between the evolutions of PM from biomass (with levoglucosan as biomass combustion tracer) and PAH concentrations. Results show a significant decrease of PM_{10} concentration levels but also of EC and PAH concentrations. Meanwhile, concentrations of PM from biomass combustion do not show any significant trend. Their relative contribution to PM_{10} has therefore increased: in winter, this contribution rose from 20% in 2009-2010 to 30-35% in 2016-2017. These results suggest a reduction of PM emissions from sources other than biomass combustion whereas wood burning remains one of the main PM sources in Grenoble.

SPATIOTEMPORAL VARIATIONS OF MAJOR CHEMICAL SPECIES AND TRACE COMPOUNDS OF PM_{10} IN METROPOLITAN FRANCE

This study is based on measurements taken as part of the national "CARA Program" (a programme for the characterisation of PM chemical composition) and by the Institute of Environmental Geosciences (IGE). It analyses the seasonal and spatial variability of mean concentrations of specific particle compounds measured at 19 sites of various types (rural background, urban background, traffic, Alpine valleys). It was conducted along with a wide study on PM sources performed by Positive Matrix Factorisation. This study provides an overall view of the main sources of PM and their impact depending on the type of site. Regarding the Alpine valleys (see pages 11 & 13 of LCSQA report), results show higher levels of organic matter and levoglucosan in winter (Passy, Marnaz & Chamonix sites), indicating the influence of biomass combustion.

SOURCES (FRANCE)

Research programme funded by the Ademe, conducted by the IGE and coordinated by Ineris. Set up to gather and investigate in harmonised way 15 datasets of chemical compounds from PM_{10} collected for PMF studies during a 5-year period (2012-2016) in France. Includes the sites of Chamonix and Revin (Weber S. *et al.*, 2019).

http://pmsources.u-ga.fr/.

NETDESA: EMISSIONS, TRANSPORT AND DEPOSITION OF AEROSOLS UNDER EXTREME STAGNANT CONDITIONS IN AREAS INFLUENCED BY HUMAN ACTIVITIES IN MOUNTAINOUS REGIONS.

The life cycle of aerosols is of interest for understanding and predicting atmospheric pollution, whether they are emitted anthropically (from automobile traffic to accidental releases) or naturally. This project aims to better simulate the emissions, transport and deposition of aerosols in environments with steep reliefs and in conditions of atmospheric stagnation, when the concentrations exceed the regulatory thresholds for air quality.

ALPENKONVENTION
CONVENTION ALPINE
ALPSKA KONVENCIJA
CONVENZIONE DELLE ALPI

The **Alpine Convention** is a pioneer of its kind as the first international treaty dedicated to the protection and sustainable development of an entire mountain range – the Alps. The Convention was signed by the eight Alpine countries (Austria, France, Germany, Italy, Liechtenstein, Monaco, Slovenia and Switzerland) and the European Union, and came into effect in 1995.

The foundations of the Alpine Convention are the Framework Convention and the implementing Protocols and Declarations, which establish guiding principles and a framework for transnational cooperation in key areas of Alpine environments, societies, and economies. Based on these foundations, the Convention works to build partnerships and establish cross-sectoral approaches to address the most pressing challenges in the Alps.

Work is carried out in different formats by the Alpine Convention's various bodies: the biennial Alpine Conference, the work of the Contracting Parties, the Permanent Committee, the Compliance Committee, numerous Thematic Working Bodies, and the Permanent Secretariat. Several Observer organisations also contribute to the implementation of the Convention.

The Alpine Convention is leading the way for sustainable life in the Alps, working to safeguard their unique natural and cultural heritages – now and for the future.

What do we know about Alpine air quality, a vital element of this region on the roof of Europe? And what can be done to improve it?

These and other questions are explored in this report, which carries out a thorough investigation of Alpine air quality, as well as of the phenomena and trends that influence it.

The Report also provides a list of smart solutions implemented throughout the Alpine region, as well as a set of policy recommendations to preserve this essential public good.