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1 Eighth Report on the State of the Alps (RSA 8) on the subject of air quality

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AIR QUALITY IN THE ALPS

REPORT ON THE STATE OF THE ALPS

ALPINE CONVENTION

The preparation of the eighth Report on the state of the Alps was coordinated by the French Presidency of the ad hoc expert group and the Permanent Secretariat of the Alpine Convention.

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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

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ABBREVIATIONS

AEI:	Average exposure indicator
AlpEnDAC:	Environmental Analysis Data and Analysis Centre
AQ:	Air Quality
AQG:	Air Quality Guidelines
BaP:	Benzo(a)pyrene
BAFU/FOEN:	Swiss Federal Office for the Environment
BC:	Black carbon
CAMS:	COPERNICUS Atmospheric Service
CLRTAP:	UNECE Convention on Long-range Transboundary Air Pollution
CO:	Carbon monoxide
EC:	Elemental carbon
EEA:	European Environmental Agency
EU:	European Union
GAW:	Global Atmosphere Watch programme
HGV:	Heavy goods vehicle
IARC :	International Agency for Research on Cancer
NEC:	National Emission Ceilings Directive
NH_3:	Ammonia
NMVOC:	Non-methane volatile organic compounds
NO:	Nitric oxide
NO_2:	Nitrogen dioxide
NO_x:	Nitrogen oxides
OAPC:	Ordinance on Air Pollution Control
O_3:	Ozone
OH:	Hydroxyl radicals
OCP:	Organochlorine pesticides
PAH:	Polycyclic aromatic hydrocarbon
PCB:	Polychlorobiphenyls
PERC:	Perchlorethylene
$PM_{2.5}$:	Particles of diameter smaller than 2.5 µm
PM_{10}:	Particles of diameter smaller than 10 µm
POA:	Primary organic aerosol
POP:	Persistent organic pollutant
PPB:	Parts per billion
SOA:	Secondary organic aerosol
SOMO35:	for ozone, the sum of means over 35 ppb (daily maximum 8-hour)
SO_2:	Sulphur dioxide
UFP:	Ultrafine particles, of diameter smaller than 0.1 µm
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
YLL:	Years of life lost

AN OVERVIEW OF THE MOST COMMON POLLUTANTS IS PROVIDED IN THE ANNEXES page 110

EXECUTIVE SUMMARY

Legal regulations on air quality for Europe and Alpine countries as well as international conventions on air pollution are stimulating measures for a better knowledge of air pollution, to understand its mechanisms and trends and take appropriate political action to improve air quality.

Although these large-scale regulations and agreements build a very useful framework, they are not customized to the Alpine situation. The Alps are in general an area of high air quality that benefits its inhabitants and visitors: clean air is a commodity for the locals as well as a point of attraction in for all the tourists, who enjoy the Alpine landscapes and recreational activities. At the same time it needs to be stressed that low 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.

Analysing 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 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 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 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, with the exception of 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 particulate pollution. Secondary aerosols from multiple sources, among which agriculture, increase particulate pollution and nitrogen deposition on soils. Specific meteorological conditions are also present. Temperature inversions prevent the vertical mixing of air masses so that pollution is sent downwards to the ground. As a consequence there are certain spots of high pollution in the Alps. In general, the 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”.

The Report also lists a number of 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 operating to improve the air quality. These measures range from heating systems to traffic management, mobility policies, clean technology promotion and local regulations.

Lastly, and mainly based on 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 particular benzo(a)pyrene coming from wood heaters and boilers - inform the population about the health significance of wood heating.

Recommendation 2: Reduce domestic heating emissions by improving overall energy performance of buildings and renewing heatings systems towards low emitters by support and guide to all operators to by: - improving the energy performance of buildings; - replacing old heavy polluting heating systems and boilers; - substitute traditional fuel to a cleaner one.

Recommendation 3: 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, adopted after consultation and environmental evaluation.

Recommendation 4: Promote a clean mobility and zero emission vehicle strategy, e.g. by using balanced taxations and incentives to internalise external pollution cost within the real transport cost 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, - encourage implementation of alternative transport technologies and combined transport, - the integration of 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 open burning of green waste and slash in the alpine region.

Recommendation 7: 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, heating and agriculture.

Recommendation 8: Contracting parties of the Alpine convention should liaise with neighbouring countries or regions to stimulate the reduction of transboundary pollutant transport in the geographic area of the Alpine Convention

Recommendation 9: The Alpine convention contracting parties -to support the Air quality chapter of the EU green deal - to strive to achieve WHO air quality guidelines.

Recommendation 10: To 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 to the study of the influence of the sources of air pollution, and also on social and political issues linked with it.

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 the fabulous landscape, the cultural heritage and recreational facilities as well as the clean air. The Alpine Convention covers 190,700 km² across eight countries including several cities of more than 100,000 inhabitants and the area is also 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.

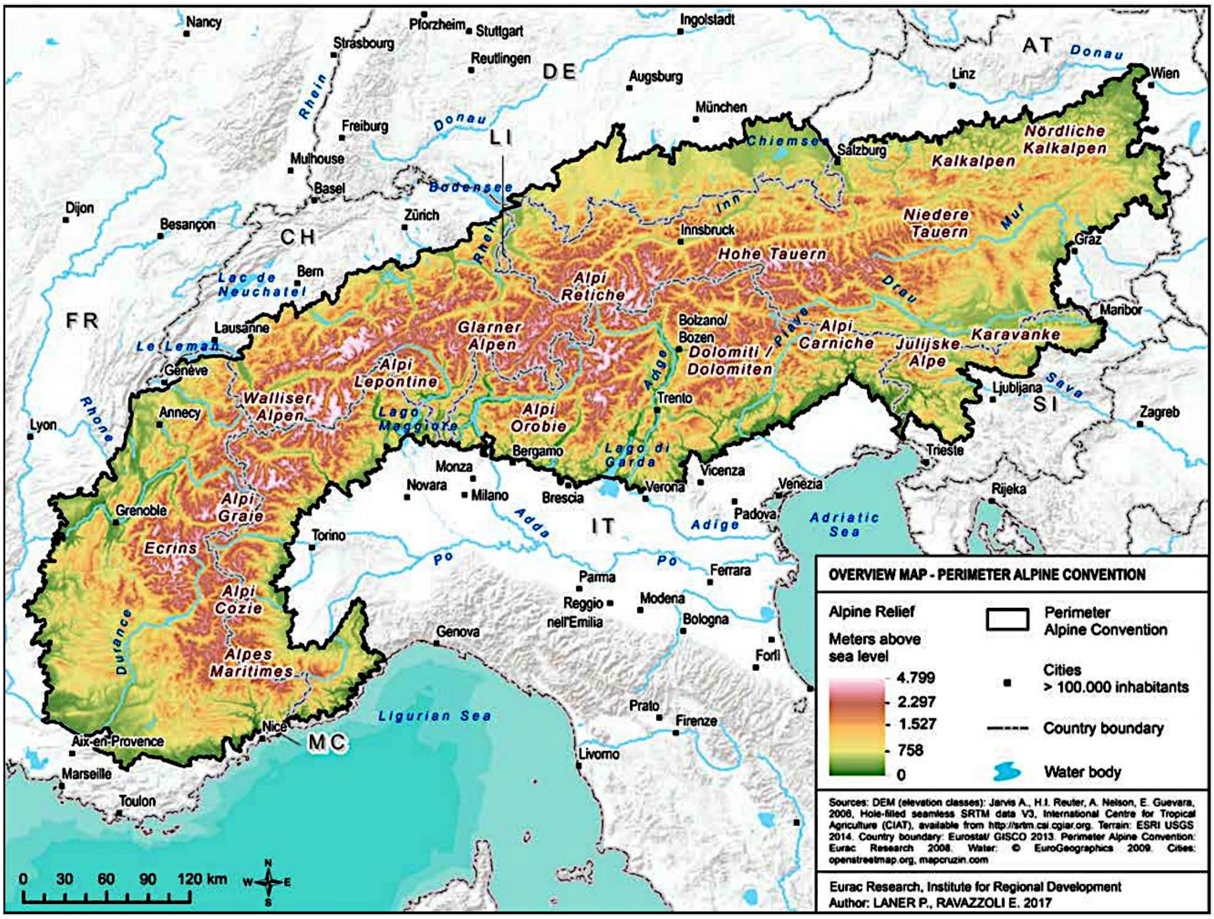

Figure 1 : Map of the Alpine Convention perimeter. (Source Alpine Convention The Alps in 25 maps)

On the whole, the Alpine region has quite good level of air quality. However, sources of atmospheric pollutants are present within the Alpine region e.g. large cities and motorways as well as emissions from wood burning and industry. In addition to this, regional and long-range transported air masses might contribute to the pollution of the Alpine air. Although some natural emissions are linked with atmospheric chemical phenomena driving air pollution, 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 complicated distribution and concentration of pollutants in the densely populated valleys. Valleys and foothills, as well as roads with high traffic, are a geographical and meteorological trap for atmospheric pollutants. Moreover, the Alpine region is an extraordinarily sensitive ecological system. Clean air is expected in the Alps for tourism, healthy recreational activities and the protection of ecosystems. Therefore, analysing the air quality in the Alps and its improvement 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 are part of the Convention on Long-range Transboundary Air Pollution (LRTAP) within which several protocols regulate further substances like polycyclic aromatic hydrocarbons, persistent organic pollutants (POPs), or heavy metals.

Following a proposal from the incoming French presidency, the XV Alpine Conference (Innsbruck, AT,3-4 April 2019) decided that the eighth Report on the State of the Alps had to address the topic of air quality in the Alps. An *ad hoc* Working Group composed of experts from all Alpine countries was launched to fulfil this task: over the following period, the Group drafted the present Report and submitted it to the XVI Alpine Conference (Nice, FR, 10 December 2020) that approved it officially. The French presidency proposal recognised 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, biodiversity and circular economy, air quality 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”. 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 four specific issues mandated by the XV Alpine Conference:

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

The regulatory framework is analysed firstly 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, the monitoring regimes, reporting requirements and the regulations for taking action in the case of exceedances. The analysis provides the 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 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. In that case where 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. Also for this reason, the World Health Organization (WHO) has formulated a set of Global Air Quality Guidelines which are currently under review. The European Commission announced in its new European Green Deal[1] 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 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 issue of air quality. The Report addresses these issues after presenting the regulatory framework. The analysis performed by the experts of the *ad hoc* working group is based on 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 data from the European Union 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 is slowly 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: it is important to give an insight on the future.

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

At the end of the Report, several recommendations, based mainly on the smart solutions, are listed. They are an attempt to address all the issues raised in the Report.

1 *European commission 2019, Eliminating pollution. The European green deal*

2 AMBIENT AIR QUALITY REGULATORY FRAMEWORK

This chapter aims to provide 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 EU legislation and similar regulations in non-EU States.

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 (NEC) Directive. This Directive outlines 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 main directives setting ambient air quality standards: Directive 2008/50/EC and Directive 2004/107/EC as 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 $PM_{2.5}$)[2] and nitrogen dioxide (NO_2) as well as arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons[3] (PAHs) (Directive 2004/107/EC). Together, they provide the current framework [4] for the control of ambient concentrations of air pollution in the EU and set standards (see table 1) to be achieved across the EU for 13 air pollutants. Since the air quality challenge is far from being solved[5], the current legal framework has recently been subject to a Fitness Check[6] focusing on the period from 2008 to 2018.

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2 PM_{10} are particles of size smaller than 10 µm; the size of $PM_{2.5}$ is smaller than 2.5 µm

3 https://toxtown.nlm.nih.gov/chemicals-and-contaminants/polycyclic-aromatic-hydrocarbons-pahs

4 The Framework Directive and the first three daughter directives were consolidated into a single Directive in 2008.

5 Infringement proceedings have been taken up against several Member States.

6 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 reducing exceedance levels. However, two shortcomings have been identified: EU air quality standards are not fully aligned with well-established health recommendations (and they 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 keep the exceedance period as short as possible.

The Ambient Air Quality Directives were adopted with the aim of laying down measures aimed at[7]:

- 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 on the basis of common methods and criteria;
- Obtaining information on the ambient air quality in order 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 other empirical techniques. In this regard, the Air Quality Directives lay down common methods and criteria for siting sampling points. Those sampling points are directed at the protection of human health, vegetation and natural ecosystems. Member States must then report the obtained air quality data to the European Commission (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 have 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.

7 *As per Article 1 of the Ambient Air Quality Directive 2008/50/EC.*

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 days per 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)[8] 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
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	
NO_2	1 hour	200 µg/m³	Limit value	Not to be exceeded on more than 18 hours per 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	
BaP[9]	Calendar year	1 ng/m³	Target value	Measured as content in PM_{10}
SO_2	1 hour	350 µg/m³	Limit value	Not to be exceeded on more than 24 hours per 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 days per year
CO	Maximum daily 8-hour mean	10 mg/m³	Limit value	
Benzene	Calendar year	5 µg/m³	Limit value	
Pb	Calendar year	0.5 µg/m³	Limit value	Measured as content in PM_{10}
As	Calendar year	6 ng/m³	Target value	Measured as content in PM_{10}
Cd	Calendar year	5 ng/m³	Target value	Measured as content in PM_{10}
Ni	Calendar year	20 ng/m³	Target value	Measured as content in PM_{10}
Air quality standards for the protection of vegetation				
O_3	AOT40[10] accumulated over May to July	18 000 µg/m³ • h	Target value	Averaged over 5 years
		6 000 µg/m³ • h	Long-term objective	
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 (European Environment Agency, 2019).

8 *AEI: based upon measurements in urban background locations established for this purpose by the member states, assessed as a 3-year running annual mean.*

9 *BaP, Benzo(a)pyrene is regarded as the lead substance for polycyclic aromatic hydrocarbons with carcinogenic potential.*

10 *AOT40 is an indication of accumulated O_3 exposure, expressed in µg/m³h, over a threshold of 40 parts per billion (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).*

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 pollutants (often referred to as NEC Directive[11]), 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 under the Convention on Long-Range Transboundary Air Pollutants (Air Convention) 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 of the Air Convention, while the NEC Directive also establishes more ambitious reduction commitments to be reached as from 2030.

The NEC Directive also requires Member States to establish, implement and regularly update a National Air Pollution Control Programme[12] 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 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 similar rules based on the respective EU Ambient Air Quality Directives. Air pollutants are regulated by the Swiss Ordinance on Air Pollution Control[13] (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 WHO recommendations of 2005, which are for some air pollutants stricter 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 (TFEU) allows, as regards legal acts adopted pursuant to Article 192 TFEU, Member States to maintain or introduce more stringent protective measures if they are compatible with EU Treaties. For instance, Austrian Federal Law on Ambient Air Quality implementing the Ambient Air Quality Directives made use of this provision and continued to set stricter national

11 for National Emission Ceilings Directive
12 The NAPCPs can be found online: https://ec.europa.eu/environment/air/reduction/NAPCP.htm
13 OAPC, SR 814.318.142.1. Online: https://www.admin.ch/opc/en/classified-compilation/19850321/index.html#app7ahref0

limit values for NO_2, PM_{10} and BaP than the respective EU limit values, 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 values, information and alert thresholds for the pollutants PM, O_3, NO_x, SO_2 and CO, with a long term WHO target for 2030.

Pollutant	Averaging period, Legal Nature	Application in	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 (BaP) in the Alpine region.

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[14], 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 1-hourly mean of 200 µg/m³ applies. Differences occur also with regard to 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 1-hourly

14 A remaining margin of tolerance of 5 µg/m³ applies as of 1.1.2010.

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 are set at 20 µg/m³ in Switzerland and Liechtenstein, in line with WHO guidelines, and 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; however, the number of allowed exceedances per year varies between 3 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 in Switzerland in line with the WHO guidelines and at 25 µg/m³ 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 exceed, with 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 in Italy the regional administrations and in Austria the provincial governments are the competent authorities for air quality planning.

2.4 INTERNATIONAL CONVENTIONS, AGREEMENTS AND COORDINATION

International organizations, national and local authorities, NGOs and other stakeholders have started to take action given the increased recognition of the effects and rising costs of air pollution (see page 16). In particular, the United Nations Economic Commission for Europe (UNECE), the WHO and the United Nations Environment Programme (UNEP) have set out global action to address air pollution.

2.4.1 UNECE CONVENTION ON LONG-RANGE TRANSBOUNDARY AIR POLLUTION[15]

The UNECE Air Convention deals with protection of the human environment against air pollution and for gradually reducing and preventing 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[16] 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 a number of 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, health, crops and materials. Moreover, it functions as an important framework for a number of task forces, centres and

15 Also referred to as “Air convention”. Online: https://www.unece.org/env/lrtap/welcome.html.html
16 1999 Protocol on the abatement of acidification, eutrophication and ground-level ozone (Gothenburg Protocol) as amended 2012

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 (AQG) that were published in 1987 and revised in 1997 and 2005. The rationale underlying those AQG is explained in chapter 4.1. Table 3 summarises the values proposed by WHO (under revision) to reduce the effects of air pollution on human health and natural ecosystems.

Pollutant	Averaging period	AQG	RL	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 (RLs). When no AQG has been set, RLs are estimated by assuming an acceptable risk of additional lifetime cancer risk of approximately 1 in 100,000 (European Environment Agency, 2019 .p. 13).

For the 2013 review of European Air Quality policies, the European Commission addressed a number of questions[17] to 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"[18]. As a result of these projects, WHO launched a review of the WHO air quality guidelines[19] in 2016. According to the latest report from the WHO/UNECE joint Task Force on Health[20], the review includes particles under 2.5 µm ($PM_{2.5}$), PM_{10}, NO_2, O_3, SO_2 and CO. The systematic reviews of evidence on health effects from these air pollutants will be the basis for the second phase of the update process,

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/key-questions-for-guidance-of-eu-policies
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
19 http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/activities/update-of-who-global-air-quality-guidelines
20 http://www.unece.org/fileadmin/DAM/env/documents/2019/AIR/EMEP_WGE_Joint_Session/ECE_EB.AIR_GE.1_2019_17-1909805E.pdf

namely to derive numerical guideline exposure values, set interim targets and other recommendations. This second phase will take 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[21]. 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), the support of cities to improve urban air quality, enhanced joint action between the financial, health and environmental sectors to enable specific actions to improve air quality and mitigate climate change and continuing the joint effort for harmonized air pollution monitoring.

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

2.4.3 OTHER UN ACTIVITIES

The United Nations Environment Assembly adopted two resolutions in 2014[22] and 2017[23] and a ministerial declaration in 2019[24] 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 the development of national environmental data management capacities. It also requests that UNEP enhances cooperation and information-sharing among countries on all levels to address transboundary air pollution.

21 https://www.who.int/airpollution/events/conference/en/.
22 Resolution 1/7 on Air Quality
23 Resolution 3/8 on Preventing and reducing air pollution to improve air quality globally.
24 Ministerial Declaration: Towards a pollution-free planet

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, local and mesoscale meteorology and morphology. 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 big differences in altitude between the valley floors and peaks determine extremely steep slopes. Most of the roughly 14 million inhabitants of the Alpine region live in the valleys, and the main roads and highways run alongside these valleys. This means that anthropogenic emissions in the Alps are 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 MF et al. 2011), and thus more than half lives in or close to mid-size towns or 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 of air masses and transport uphill, increased deposition by topographically 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 transport and dilute 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.

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 (warm) and winter (cold) 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. and Wanner H., 2001): the *high Alpine* region characterized by cold and humid weather; the *continental high Alpine*, generally drier; s*outhwestern 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* characterized by continental dry climate; the *northern and eastern Alpine foreland* with continental climate and rainy summers; the s*outhwestern foothills* with rainy transition seasons (Egger I and Hoinka K.P.,1992).

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 the 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 itself is 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. and Wanner H., 2001). During summer the mixing layer evolves rapidly during the day, due to strong insulation allowing the locally produced pollutants to be rapidly diluted and mixed.

During winter (and less frequently in the 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, since a low mixing layer height combined with low vertical mixing under the inversion reduce the dispersions and dilution of pollutants (figure 2). It is to be noted that, when occurring in the Alpine region, an inversion height at 800 m above sea level could correspond to less than 200 m over 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).

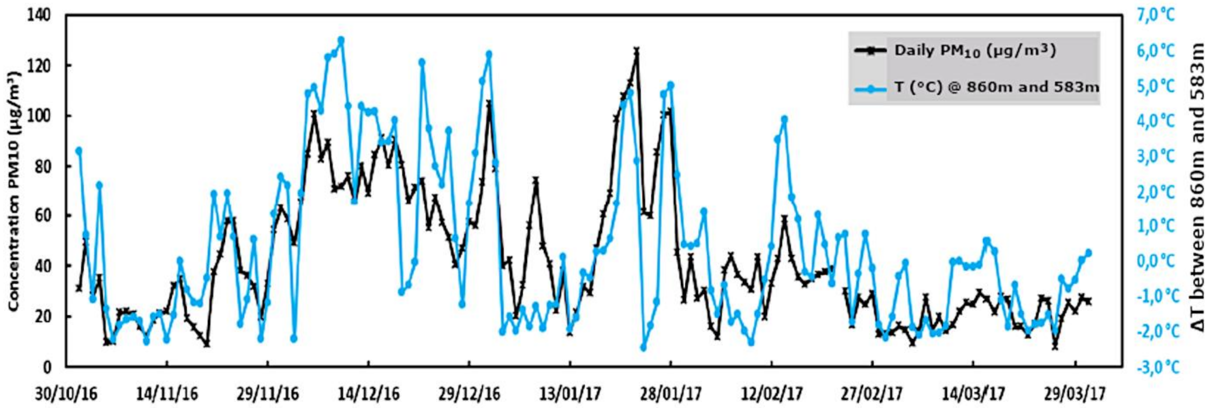

Figure 2: Correlation between temperature difference at two altitudes and PM_{10} in the Arve valley. (Favez O. et al., 2017a)

The blue line shows the difference of temperature between the altitudes 583 m and 860 m in Celsius and the black line reports the daily average PM_{10} concentration within the valley. 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.

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 vertical mixing of pollutants and leads to an accumulation of pollutants in the lower troposphere (Chemel C. et al., 2016). Within the Alpine region, the valleys are mostly characterised by atmospheric stability. This, in addition to the presence of many emitting sources, causes significant secondary aerosol (SA) 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 valley 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 the one on the right-. 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, since this reaction consumes O_3 and NO to build up NO_2.

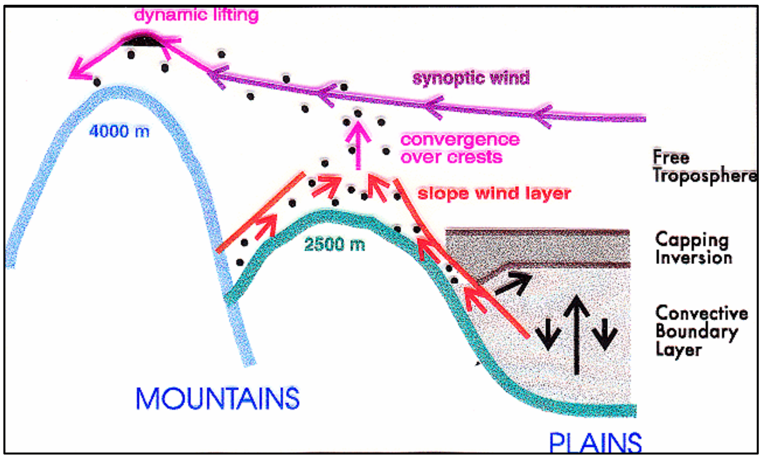

Figure 3: Schematic view of the processes transporting polluted boundary layer air from adjacent plains and valleys up to the level of the highest Alpine peaks. Pollutants can enter the free atmosphere from there. (Courtesy of Seibert, P. et al. 1996)

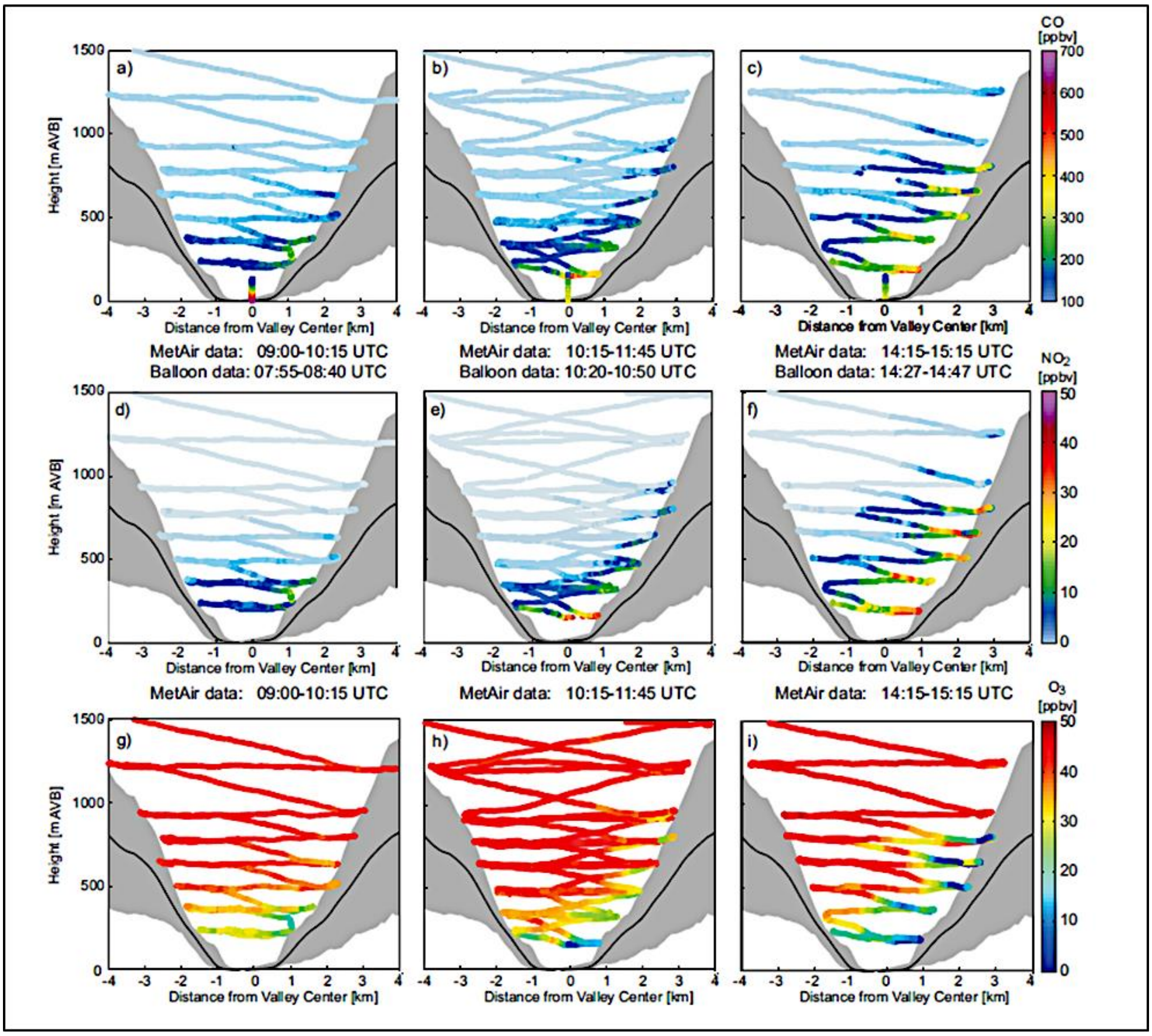

Figure 4: In the three rows, the distribution of CO, NO_2 and O_3 concentrations in the Inn Valley (Tyrol, AT) on 1 February 2006 in the morning (first column), before noon (second column) and in the afternoon (third column). The view is looking up the valley towards south west. The sunny side is thus on the right. (Courtesy of Schnitzhofer R. et al, 2009)

3.1.2 OZONE REGIMES

Of specific concern during the summer are photochemical pollutants, especially ozone. As a general rule, the processes that efficiently affect variation in ozone concentration are long distance transport by advection, vertical mixing, ozone formation triggered by UV radiation and dry deposition. A 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).

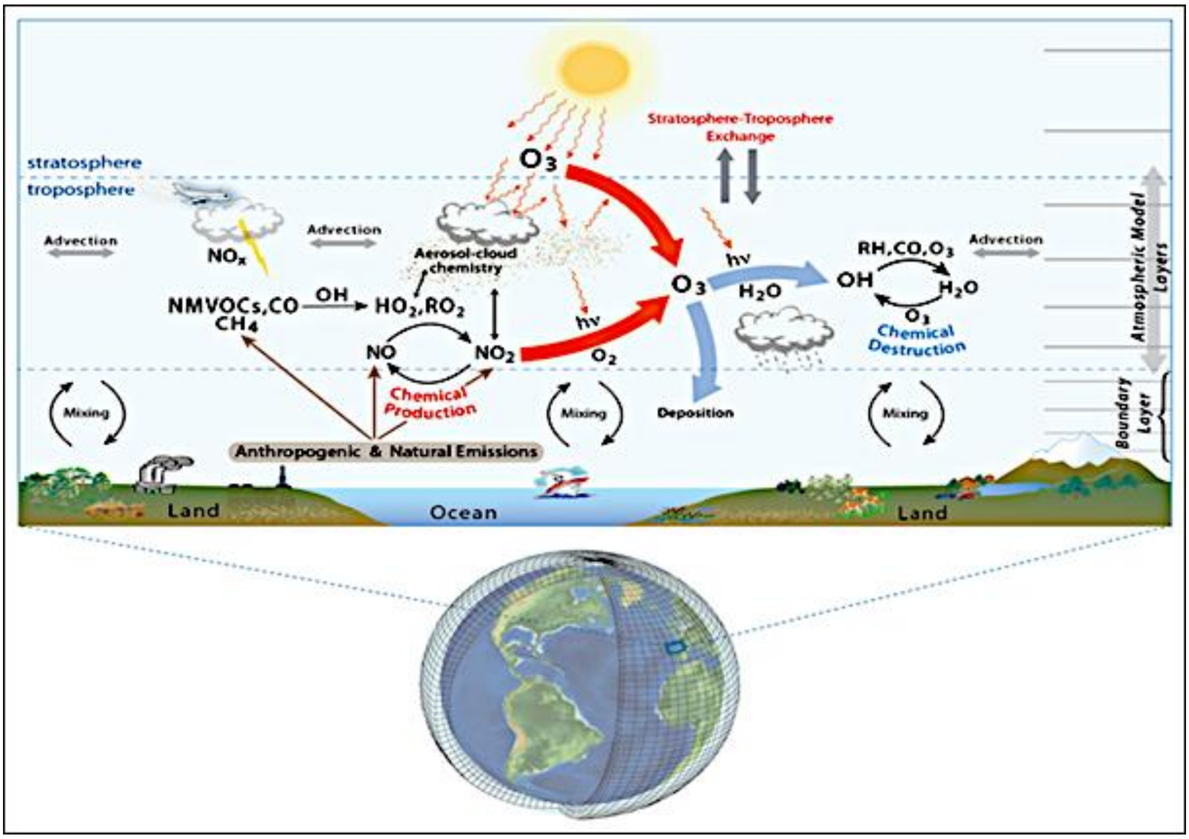

Figure 5: Schematic of chemical and physical processes responsible for tropospheric ozone.

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, PJ, et al. 2018)

On a sub-regional scale, ozone levels and their temporal pattern are triggered by the diurnal circulation pattern (valley and slope wind circulation); also the presence of anthropogenic as well as biogenic precursor emissions in nearby valleys may have a major impact. 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).

Also the presence of anthropogenic precursor emissions, as well as biogenic VOCs (such as terpene, isoprene, and others), in nearby valleys may have a major impact. The relationships between precursor availability, temporal and spatial pattern and ozone formation/depletion chemistry have been shown to be complex and non-linear. Both VOCs and NO_x limited ozone production was found in different studies (Mazzuca GM. 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 of biogenic VOC to non-methane VOC (about 59%). Owing to the deciduous and pine forests in mountains surrounding the town, biogenic emissions could in fact play a role, particularly during extremely dry conditions such as during heat waves (Chaxel E. and Chollet JP., 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 add 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 (NO) accumulated in the surface layer and 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.

Heat waves may lead to frequent future occurrences due to global warming. These events are characterized 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. and Chollet JP., 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.

POPs:

The advection of air masses from long-range transport is considered in the literature as the main factor contributing to the 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 MS. et al., 1998; Wania F. et al., 2001; Meijer SN. et al., 2003). Vegetation acts as an intermediate compartment for the exchange of POPs between the atmosphere and soils (Jaward FM. 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 episode, emissions produced by fossil fuel and biomass burning (BB) 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 Alps region is also close to the Po valley basin, from 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. Conditions favourable 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 most of all to 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 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 transport, 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 traffic and energy sector changes (see section 3.2.2). Potentially changing radical chemistry with impact on NO_x life-time is considered less important (see below).

Concerning ozone, we know of two counteracting features with a yet unclear trend. On the one side, due to anthropogenic NO_x emission reductions, we expect reduced regional and local photochemical production of ozone which is mostly NO_x-limited. On the other side, 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 speculation and cannot be estimated reliably yet. Overall, it is important to monitor the ozone system with precursor and transport changes during climate change.

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

3.2 SOURCES

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

YEAR (season[25])	Site (Country)	Valley or area	Contribution to PM_{10} (in % of PM mass) Biomass burning %	Traffic %	Secondary aerosol %[26]	References
2008 (w)	Erstfeld (Switzerland)	Erstfeld	21–30	15–30	15–25	Ducret-Stich RE. et al., 2013a Project funded by FOEN
2008 (s)			8-15	13-15	35-40	
2010 (y)	Lanslebourg (France)	Maurienne	57	31	9	Projects Lanslebourg 2010-2014 (in: Favez O. et al., 2017a, SOURCES Project Report)
2010 (y)	Lescheraines (France)	Auvergne-Rhone-Alpes	58	6	n.a.	PARTICUL'AIR (in: Favez O. et al., 2017a, SOURCES Project Report)
2010 (y)	Grenoble (France)	Auvergne-Rhone-Alpes	42	10	n.a.	FORMES (in: Favez O. et al., 2017a, SOURCES Project Report)
2013-14	Air RA (France)	Auvergne-Rhone-Alpes	21	2	~ 20	AERA (in: Favez O. et al., 2017a, SOURCES Project Report)
2013-14 (w)	Chamonix (France)	Arve	70	5	15	Favez O. et al., 2017a, SOURCES Project Report
2013-14 (s)			10	5	35	
2013-14 (w)	Marnaz (France)	Arve	64-71	4-8	8-12	DECOMBIO (in: Favez O. et al., 2017a, SOURCES Project Report)
2013-14 (s)			< 3	8	30-35	
2013-14 (w)	Passy (France)	Arve	66-74	4-8	12-15	
2013-14 (s)			< 3	5-10	40-50	
2013-14 (w)	Chamonix (France)	Arve	57-62	3-14	18-21	
2013-14 (s)			5-10	7-12	38-43	

Table 4: Contribution of biomass burning, traffic and secondary formation of aerosols to PM_{10} concentration in some Alpine valleys.

Other local sources include agriculture, and, in 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 sources due to the topography specific to the Alpine region.

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 MFD. 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.

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[25] *Winter = w; Summer = s; Annual = y.*

[26] *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.

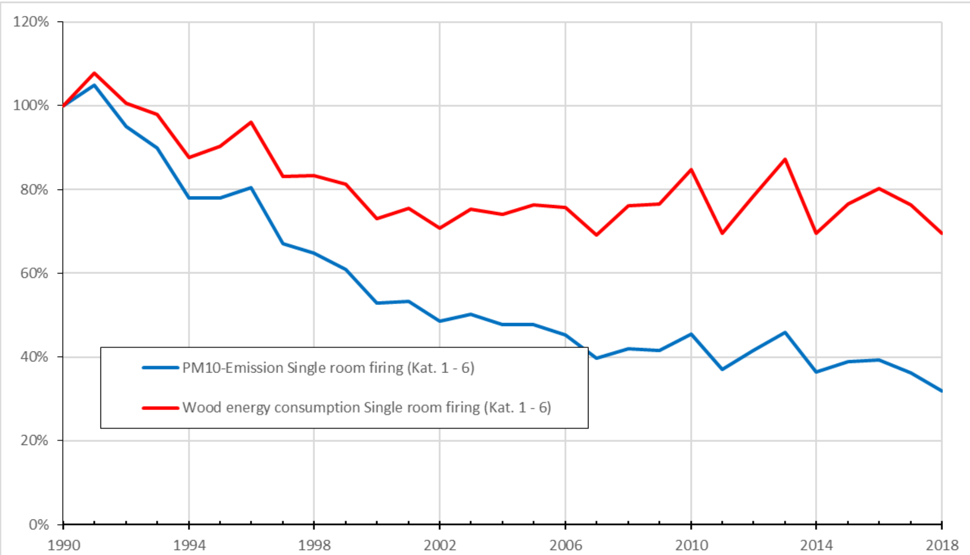

Figure 6: Evolution of the emissions of single room fire stoves in Switzerland

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 2017 and 1990, and also 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 their energy consumption decreased by 30%. The decline was achieved by a mix of measures, including awareness raising, support schemes, technology development and legal instruments. However, there are differences between provinces and regions in Austria, e.g. in Tyrol and Vorarlberg (2 provinces in the Alpine region) the decline of emissions of the domestic sector was not as pronounced as in other Austrian provinces. Indeed, during the past ten years, PM emissions generally decreased but the relative 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 both in 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: less than 100 nm) size of airborne PM, and can therefore be breathed in and reach the deepest tract of the respiratory system. Therefore, the combustion efficiency of residential stoves where biomass burning occurs is 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 BL. and Ballesta PP. 2009). In the heating period, the contribution of wood combustion to PM_{10} mass may increase sometimes 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 CA. 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[27]. Nevertheless, the contribution to the content of elemental carbon in the airborne PM by the combustion of biomasses is not negligible.

In 2014 a study compared concentrations of elemental carbon, organic carbon and PM from different studies; 23 measurement sites, most of which 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, Chamonix, Graz, Ispra, Lanslebourg, Lescheraines, Milan, Passy and Sondrio. 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 occur at the sites Ebnat Kappel, Grenoble, Magadino, Moleno, Roveredo, Zagorje and Zurich. All sites, except Zurich, are located 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 on air emissions. Use of gas oil, LPG or gas in modern technologies result 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 mar-

27 *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 (BC). 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 et al., 2019, Tuet et al., 2019)).*

ket for burning mixed-fuel wood and wood chips which are showing lower emissions compared with older systems. It should be noted that by e.g. installing small electrostatic precipitators, emissions of $PM_{2.5}$ could be further reduced. It must be taken into account that such end of pipe technologies will mean costs for investment and operation.

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) (please note: distinction between fuel technologies varies across countries, so a direct comparison of national sets of emission factors may lead to mis-interpretations)

Switzerland, Austria and Germany have already introduced legislation to minimize 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 will 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 establishing 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 (EU) 2015/1185 requires that it starts on 1 January 2022 for smaller wood heating systems known as “solid fuel local space heaters”. 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 laboratory). Implementing the eco-design directive needs to be accompanied by effective market control regimes otherwise it will allow cheaper and more polluting stoves to enter the market.

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(1)	1,500	40
Austria[28]	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 1. BimSchVStufe 2. new appliances since 01.01.2015	Open fronted	1,250	40(2)
	Closed fronted	1,250	40
	Closed fronted using pellets	250	20/30
	Cookers	1,500	40
Italy(3) 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(4)
	Cookers	1,500	40
Switzerland(6)	Open fronted	1,500	75
	Closed fronted	1500	75
	Closed fronted using pellets	500	40
	Cookers	3000	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.

(1) '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 in a chimney or fireplace opening or requires a flue duct for the evacuation of products of combustion; (2) Very rare and specific / new ones dealt with as closed fronted / old open fireplaces excluded; (3) Data for Italy regulated by a label system with separate values for 3-star, 4-star and 5-star labels; (4) First value for direct heat, second for heat to fluid; (6) 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).

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[29], diesel exhaust is proven to be carcinogenic. In addition, the road

28 *Note: The Austrian Emission Limit Values refer to the initial measurement; for type approval, stricter emission limit values apply*

29 *WHO-IARC 2012: Diesel engine exhaust carcinogenic*

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 affects the main transit routes and urban roads in valleys, but also peripheral routes connecting small villages, and a large number of off-road routes reaching semi-natural mountain areas at high altitudes. Figure 34: Transport pathways through the Alps (Source WG Transport) shows the location of the main transport routes through the Alps. Besides the permanent settlement of people living there, many tourists reach these locations along off-road mountain tracks by private car (Alpine Convention 2007: 8, 33, 129), 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 MFD. et al., 2012; Zotter P. et al., 2014). The most common form of passenger transport in the area is the private car, which is a concern to the Alpine region since it is expected to increase in the near future (Alpine Convention 2007: 64). 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 RE. et al., 2013a; Ducret-Stich RE. 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 highways 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 RE. 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 also many villages and towns in the Alps are 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 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 especially 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 coal budget. 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 it until 2054.

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

Although no specific preoccupation emerges from this analysis, pollution conveyed over long distances is an important topic which is addressed by the 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 policy makers 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. 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 secondary aerosol formation is atmospheric stability (section 3.1.1) that aids chemical reactions to continue forming particles and 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. Making up the SA composition are both inorganic and organic species.

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. On the other hand, 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 JL 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 roughly range between 0.1-0.5 $\mu g/m^3$; within this range the highest values are observed during autumn and winter (Favez O. et al., 2017a, Diemoz H. et al., 2019a). Similar values are also found for ammonia 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 $\mu g/m^3$ at Alpine pastures, and between 2-4 $\mu g/m^3$ at intensive agriculture sites, with no meaningful differences from 2000 to 2014. Since ammonium (and its precursor, ammonia) primarily derives from agriculture activities, these values reflect a generally low impact of agriculture on the Alpine region, as previously reported (Lighty, J.S. et al., 2000, Price MF et al. 2011,)

Ammonium concentrations in areas strongly impacted by agriculture activities, such as the Po Valley, are far higher, at between 5–30 $\mu g/m^3$ and averaging 5-15 $\mu g/m^3$ (e.g. Larsen 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 therefore the NH_3 burden remains only localised.

3.2.4.2 Secondary organic aerosol (SOA)

During the winter in the Alpine region, organic species of SA are formed from the emissions of biomass burning and traffic VOCs, whereas organic species of SA are formed in the summer 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 the majority of 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, recently Squizzato et al., 2013) were able to distinguish different source-contributions to SOA, and to identify the differences in chemical composition and quantity at a rural background site of the Paris region. Of these contributions, at least two originated from biomass burning emissions, and another is 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. On the other hand, 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 than vegetation to SOA formation. 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, and this supports decisions on abatement measures to be undertaken to prevent high pollution episodes, the same aspects are still largely unknown for organic secondary particulate species. In particular, knowledge should be improved concerning both chemical source profiles of VOCs (namely: which VOCs species are mainly emitted by which sources), and 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 public policies is that it enables to allocate sources of pollution to the global PM_{10} concentrations in ambient air, so that pollution can be reduced at its origin. Figure 7 clearly shows the importance of biomass burning in, at least, French Alpine valleys. Although this study does not show a great contribution of nitrate and sulphate rich particles linked with intensive agriculture, it seems to be important in other regions and needs to be checked carefully in the Alpine areas of intensive agriculture.

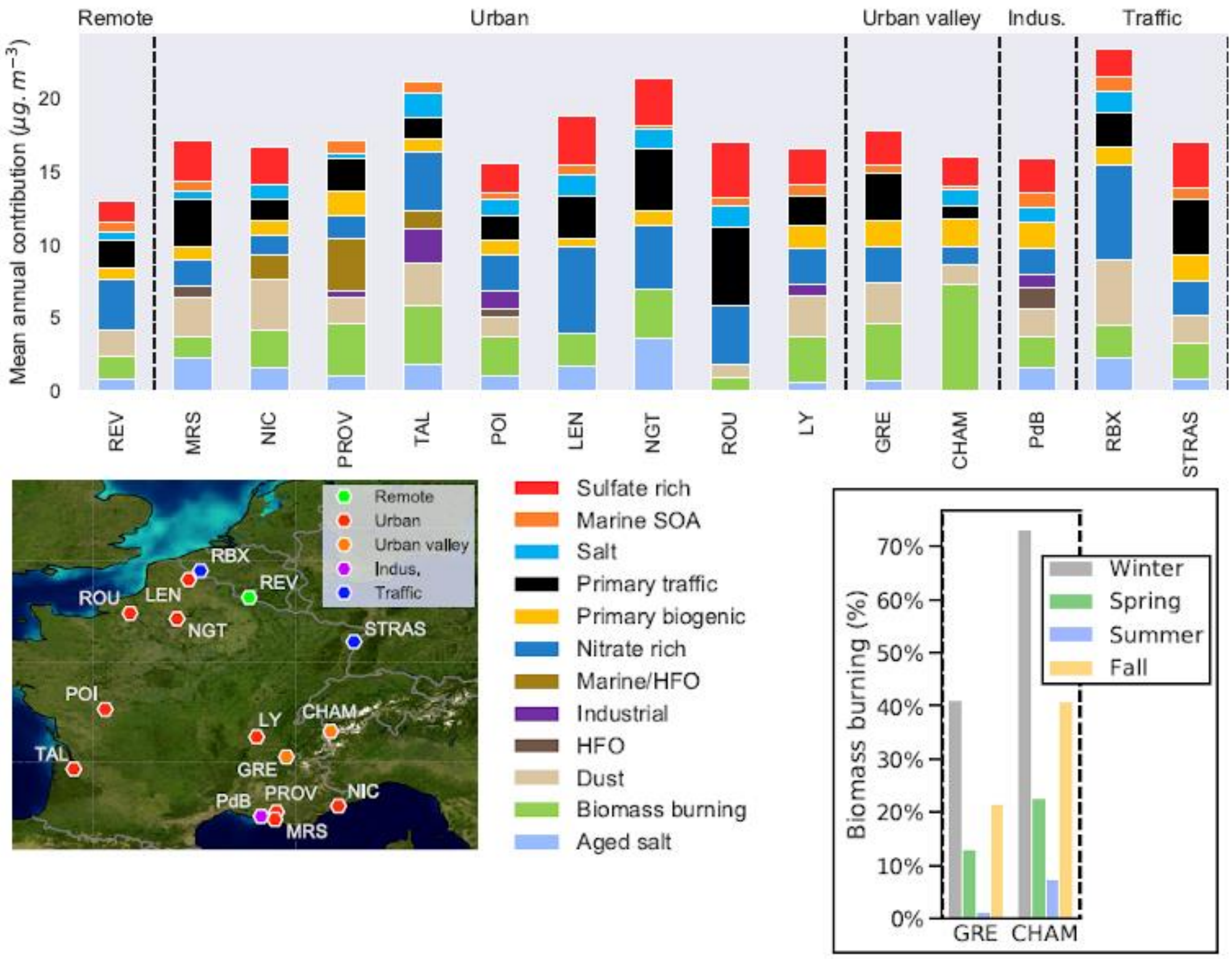

Figure 7: Results from the "Source" project showing the contributions from PM_{10} sources in different locations in France.

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 (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. (Source: Weber S. et al., 2019)

4 EFFECTS OF AIR QUALITY

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 POLLUTANT EFFECTS ON HUMAN HEALTH: MORTALITY

Mortality due to air pollution is assessed by epidemiological studies. The estimates provided by calculations like these can vary widely between different studies, depending among other things on the choice of the methods used 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 range of the estimates of reduced life expectancy due to air pollution lasts from several weeks to a very small number of years, depending on the methodology of the study and the region that is 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 (European Environment Agency, 2019). The European Environment Agency (EEA) estimated for 2016 the number of years of life lost attributable to $PM_{2.5}$, NO_2 and O_3 exposure. Information about years of life lost (YLL) 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 $\mu g/m^3$ for $PM_{2.5}$ and 16.3 $\mu g/m^3$ for NO_2. In the case of ozone, the SOMO35 (sum of means over 35 PPB[30] (daily maximum 8-hour)) with 3,811 $\mu g/m^3$ 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 average YLL per 100,000 inhabitants in all Europe are 900, 100, and 30 to $PM_{2.5}$, NO_2, and ozone, respectively. Some newer publications' estimates are twice as high as these figures (Lelieveld J. et al. 2020).

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 on.

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[30] *Parts per billion*

4.2 AIR POLLUTION EFFECTS ON HUMAN HEALTH: MORBIDITY

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. The pollutants 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, 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 the oxidizing and irritant nature of the pollutants[31].

The clearest evidence of effects on health by air pollutants are in the respiratory system, due to the direct contact of the pollutant with the human body by inhalation. Thereafter, systemic inflammation and oxidative stress caused by inflammation of the lungs 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 (US EPA).

Ozone, nitrogen dioxide and sulphur dioxide (SO_2), which are irritant gases with oxidation capacity, 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 and/or nitrogen species that are directly responsible for cellular oxidative stress also in lung tissues. It is also generally observed that the endogenous generation of reactive oxygen and/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 to be a 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 US 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 (causal relationship) can be the cause of a variety of cardiovascular diseases, including

31 *Agence Santé publique France, Sylvia Medina, June 2019, presentation to the RSA8 working group*

atherosclerotic plaque progression, decreased cardiac contractibility and output, and changes in blood pressure.

There is also a likely to be a 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 to be a 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 specialized 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 by science, and in fact many research projects throughout the world are currently addressing this issue.

4.3 HUMAN HEALTH EFFECTS OF AIR POLLUTION 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 (Austria) 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 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 highway corridors was performed in 2005 to investigate the impact of traffic exhaust on respiratory symptoms. Associations were found between living close to a highway and wheezing without cold and chronic cough. The symptoms reached background levels in populations living 400 to 500 m away from the highway (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 to quantify the health effects 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, 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 of 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 benefit in terms of mortality or life expectancy (figure 8).

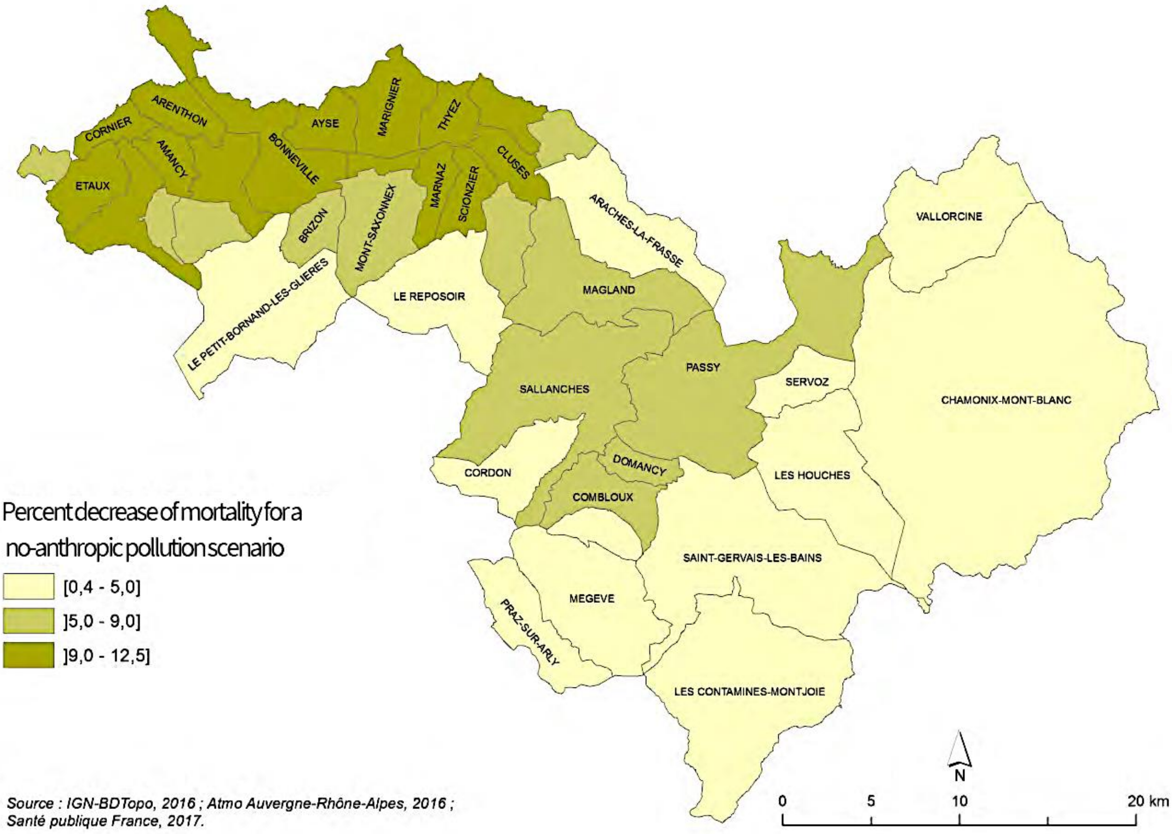

Figure 8: Map of expected mortality decrease in a non-anthropic pollution scenario in the different communes of the Arve valley

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 EFFECTS ON ECOSYSTEMS

Air pollution has a serious impact on ecosystems and biodiversity. The concept of critical load[32] 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 be no longer 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 (European Environment Agency, 2019).

Atmospheric deposition of nitrogen combines with nitrogen leaching from soils and causes eutrophication of rivers and lakes which impairs biodiversity. Paerl HW, 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 reducing growth and disturbing reproduction and therefore damages forests, crops and grasslands.

NO_x also acidifies soils, lakes and rivers. Ammonia and nitrogen oxides affect ecosystems via eutrophication (an excessive accumulation of nitrogen nutriments) and acidification via transformation in the air into nitrous acid that falls back to soil with precipitation. The impact on biodiversity is important. Nitrogen deposition has been proven to decrease species richness of grass lands by 50% in Atlantic Europe when nitrogen deposition reaches 30 kg/ha/year (Stevens et al, 2010). The 2016 report of the Convention on long-range transboundary pollution states "the overall message is 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. (eds), 2016).

The situation in the Alps is not often addressed specifically in the scientific literature. It might depend on local situations in intensive agricultural areas. However, a comprehensive study of nitrogen deposition in Switzerland 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 given in figure 9.

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

Table 7: Exceedance of critical loads of nutrient nitrogen in different protected ecosystems

32 *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.*

in Switzerland in 1990, 2000 and 2010. (Rihm B. et al. 2016).

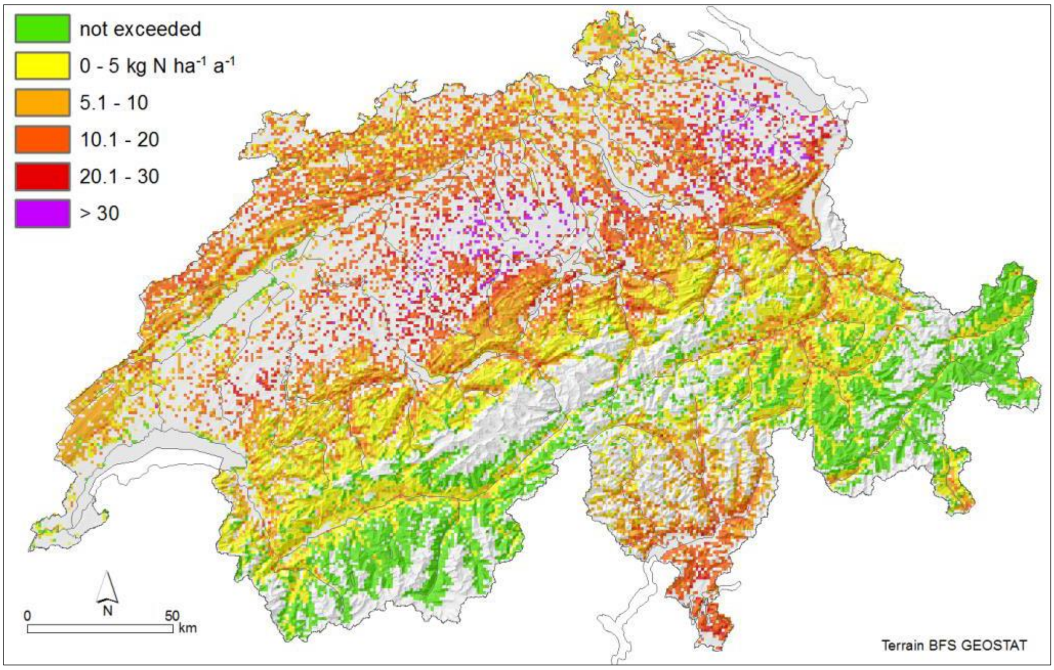

Figure 9: Maximum exceedance of critical loads in Swiss forests and (semi-)natural ecosystems by nitrogen depositions in 2010 per km². (Rihm B. et al. 2016)

An experimental study showed that there might be only a slow recovery of grassland ecosystems 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 reinforces the need for an improvement of the policies against atmospheric pollution by NO_x and NH_3 in order to prevent biodiversity loss.

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 status of concentrations in recent years is 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 to the longer term, the evolution of concentrations is examined through trends analysis.

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 makes the official air quality data from Member States and other EEA member and co-operating countries available.

Station metadata for Liechtenstein were provided by the Office for the 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 the following pollutants : PM_{10}, $PM_{2.5}$, NO_x including NO_2, SO_2, C_6H_6 (benzene), O_3, Pb (lead), BaP, Ni (nickel), As (arsenic), CO (carbon monoxide), Cd (cadmium). 14% and 7% of them are respectively located at altitudes higher than 1000 m and 1500 m. Figure 10 illustrates their geographical distribution, taking all measured pollutants into account. As displayed in table 8, two thirds of the 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 223 monitoring stations according to the station area

These stations were complemented for the same period by 45 stations belonging to the local Swiss monitoring networks (figure 11). Among them, 22 are located in a rural environment, 15 in a suburban environment and 8 in an urban environment.

Adapting an existing methodology[33], it has been estimated that approximately 85% of the stations are situated in valleys.

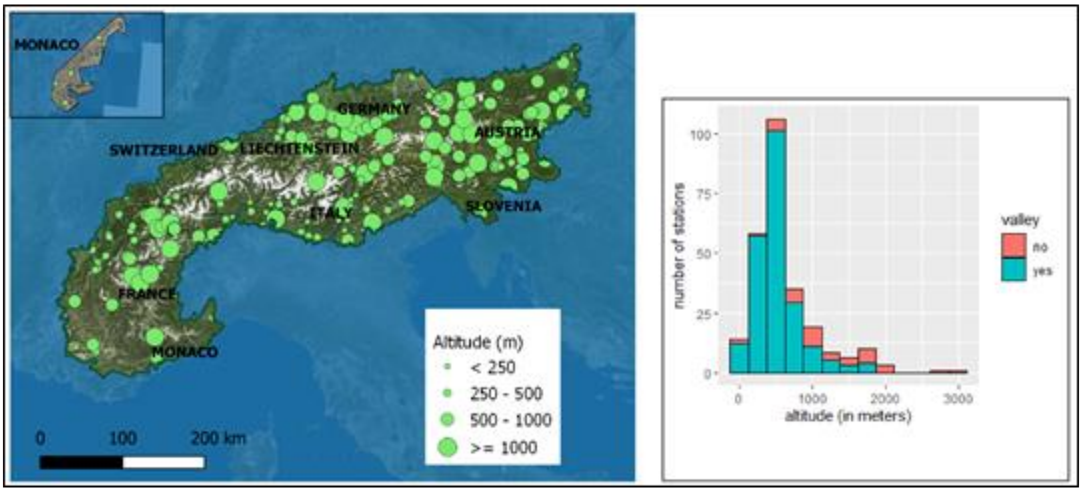

Figure 10: Geographical distribution of the monitoring stations in the Alpine region

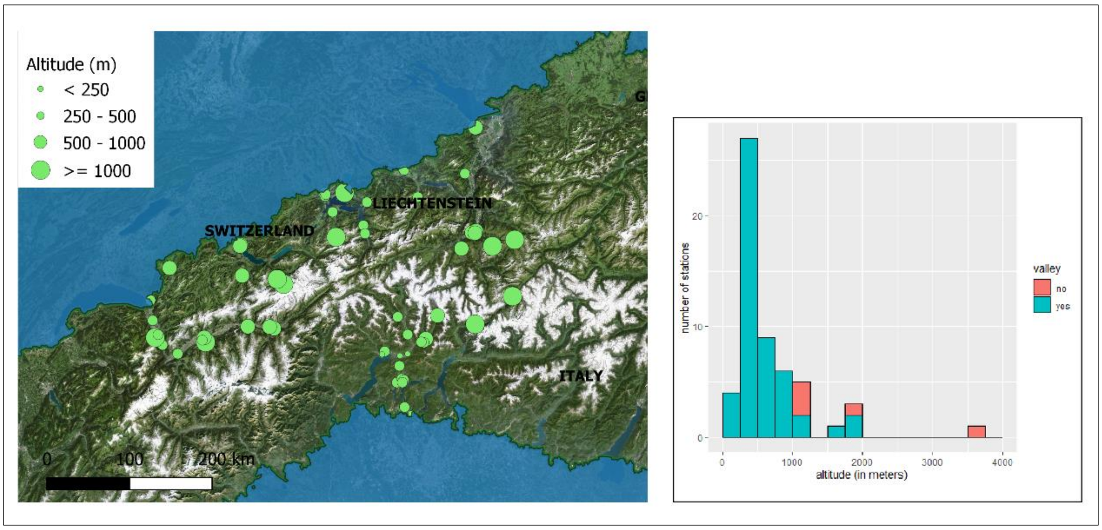

Figure 11: Zoom on Switzerland of the geographical distribution of the monitoring stations in the Alpine region –, adding stations from the Swiss cantonal and municipal monitoring networks

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

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[33] *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.*

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).

Country	Pollutant	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
Liechten-stein	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.

Note that the station type, which characterizes 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 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.

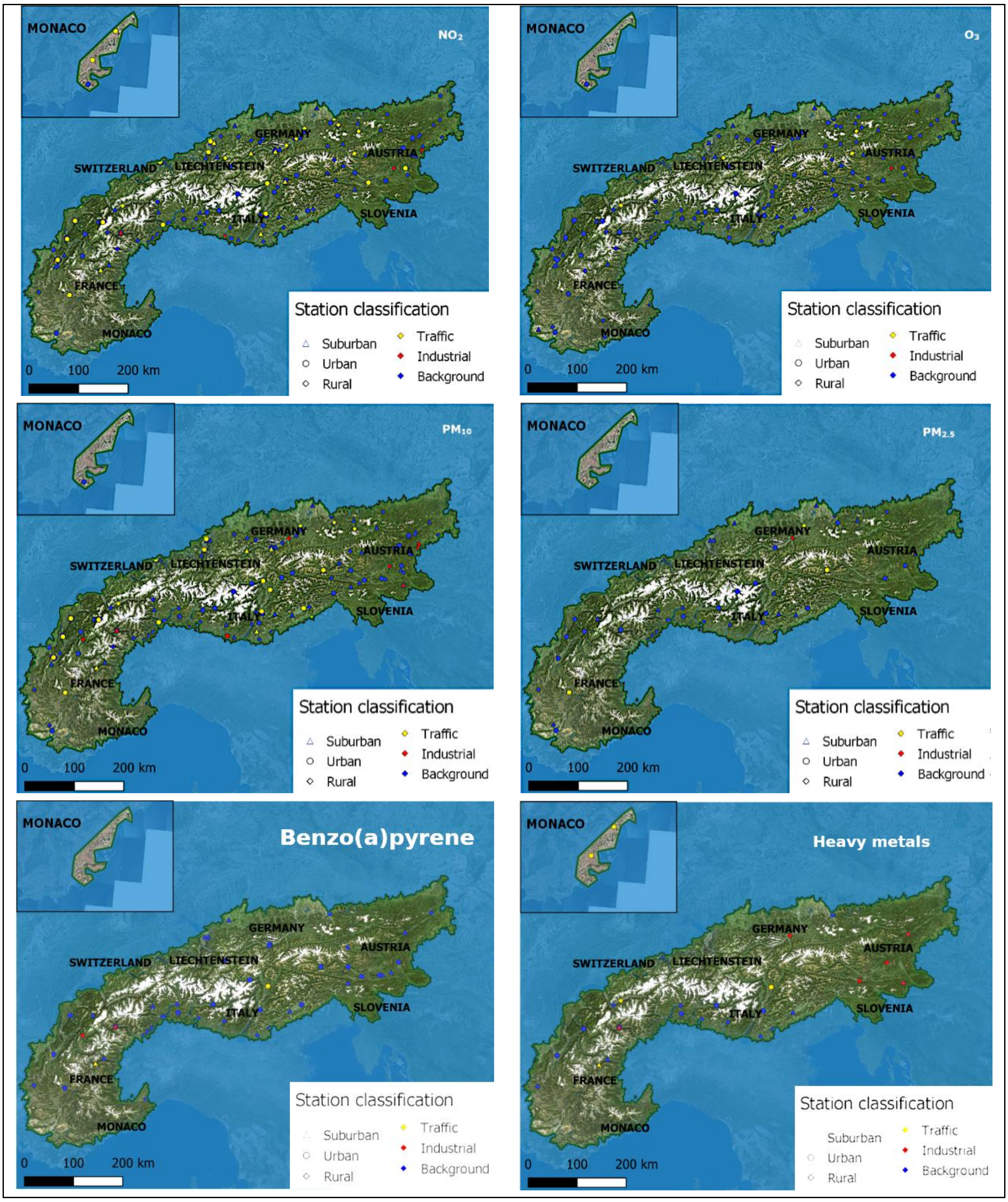

Figure 12: Maps of measurement stations in the Alps

Less frequent 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 with, however, a larger number of stations continuing 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 measurements of heavy metals 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. 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).

Nitrogen dioxide (NO_2)

Figure 13 represents the distribution of the annual mean concentrations of NO_2 in 2016, 2017 and 2018. Whatever the year, all the exceedances of the EU annual limit value (40 µg/m^3), 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 conjunction 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/m^3 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/m^3 no more than 18 times per year) was exceeded only once, at a French traffic site in 2016.

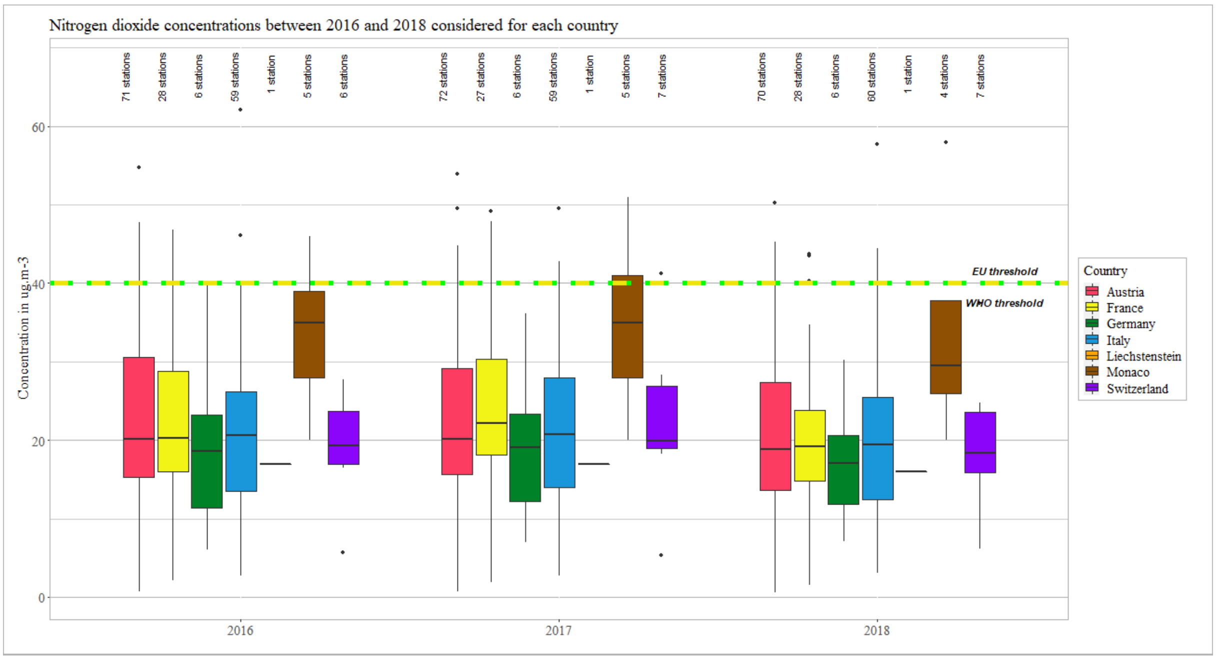

*Figure 13: Distribution of **NO₂** annual mean concentrations in **2016**, **2017** and **2018** in the Alpine region.*

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.

Ozone (O_3)

Ozone pollution largely affects the Alpine region. Figure 14 represents the yearly number of exceedances of the long-term quality objective of 120 µg/m^3 per station for the years 2016, 2017 and 2018.

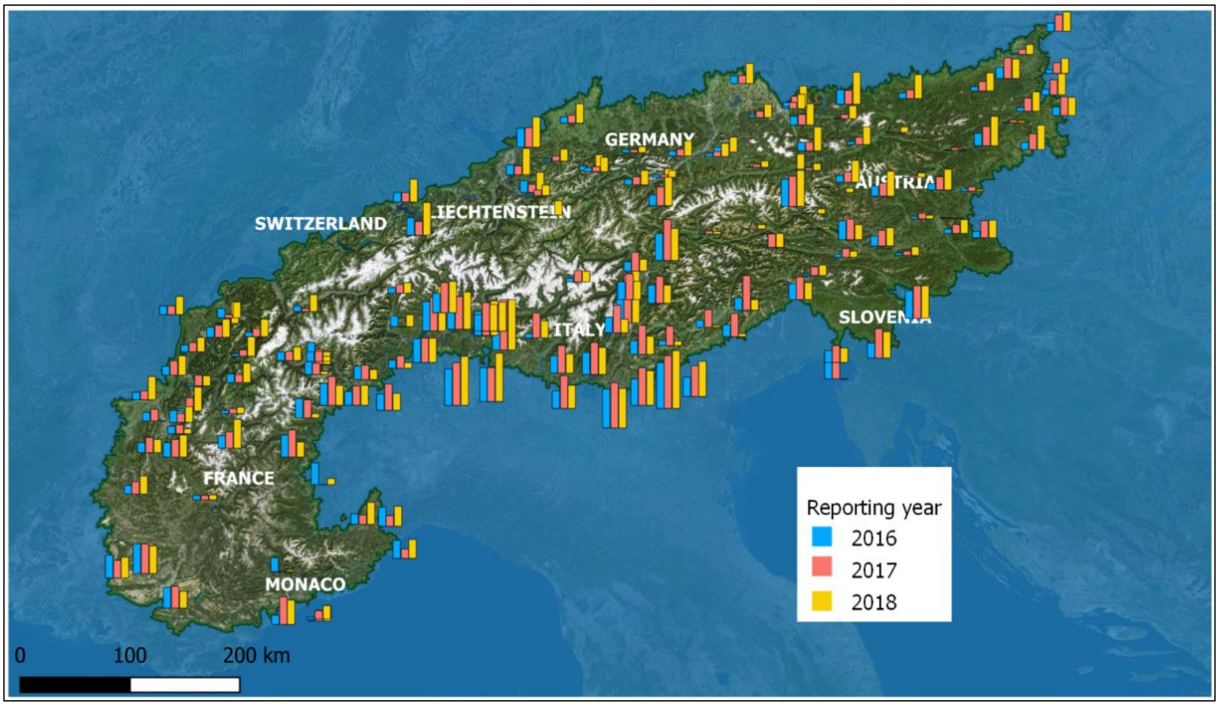

*Figure 14: Map of the evolution of the exceedance of the long-term **O₃** objective for the protection of human health in the Alpine region.*

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.

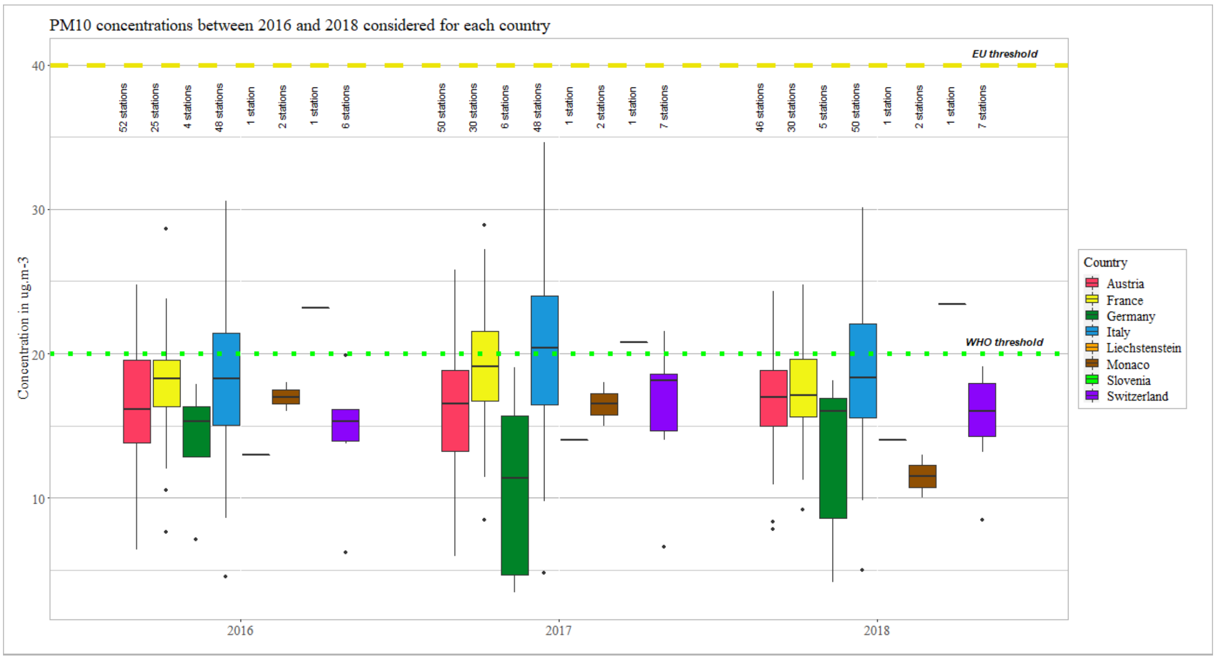

*Figure 15: Distribution of **PM_{10}** annual mean concentrations in **2016**, **2017** and **2018** in the Alpine region.*

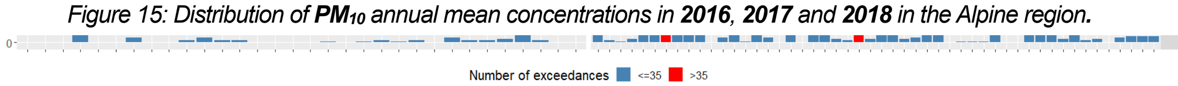

Figure 16 represents the yearly number of exceedances of the 50 µg/m³ daily threshold per station and indicates in red, the stations for which this number is strictly higher than 35 µg/m³, the European limit value. These stations are only a few (in 2018 just two of them exceeded the EU limit) and almost 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, not more than 3 days).

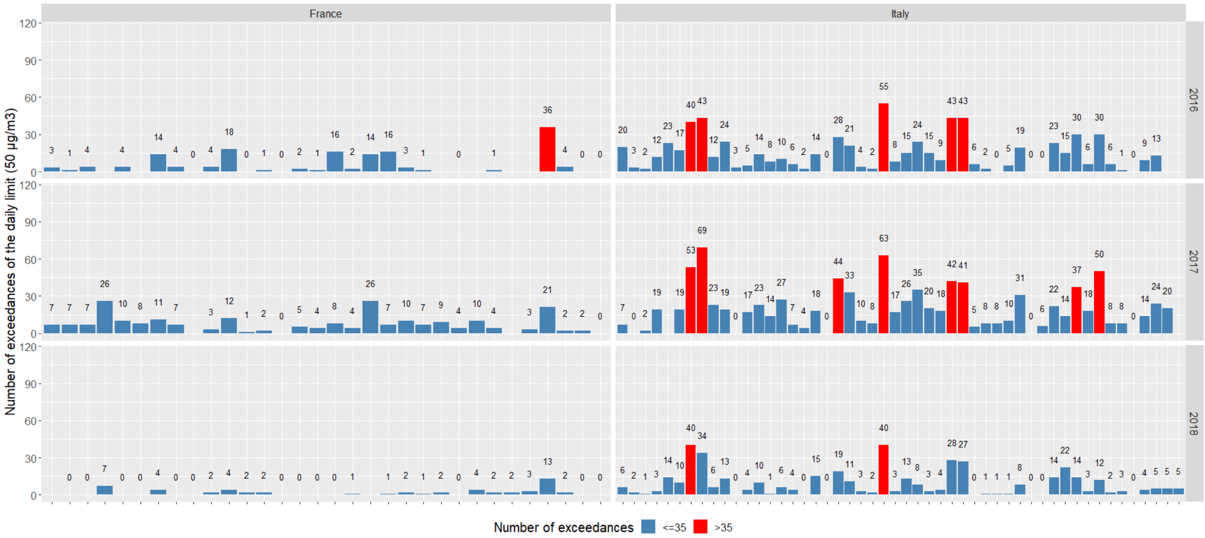

Figure 16: Exceedance of ***PM_{10}*** *daily limit value for the protection of human health in* ***2016****,* ***2017*** *and* ***2018*** *in the French and Italian parts of the Alpine region. Apart from the French and Italian areas, all the other areas in the Alpine region have less than 35 days of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

Particulate matter – $PM_{2.5}$

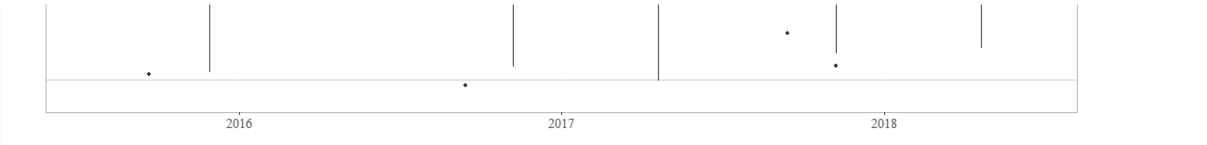

Figure 17 shows that all of them lie significantly below the annual limit value (25 µg/m^3). There are no exceedances of the legal limit values of the EU-Directive 2008/50/EC in the Alps. However, in terms of human health, the WHO AQG (10 µg/m^3) is exceeded at a majority of stations and only a few background sites (between 7 and 10 depending on the year), mostly rural or suburban, comply with it.

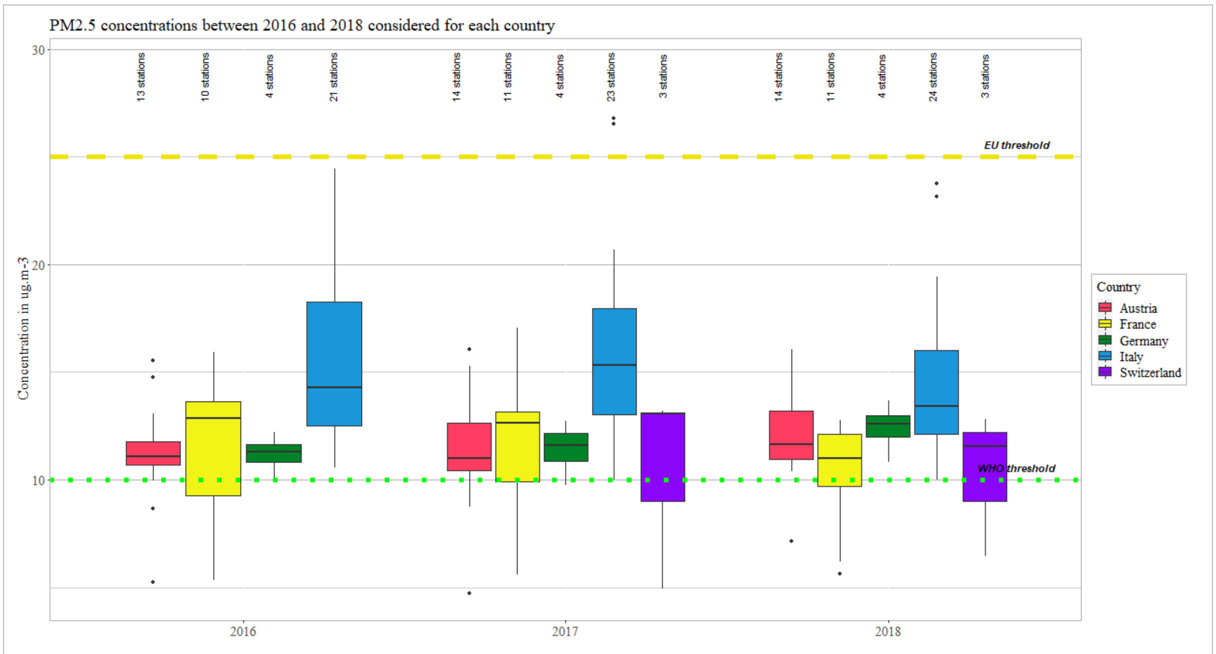

Figure 17: Distribution of ***$PM_{2.5}$*** *annual mean concentrations in* ***2016****,* ***2017*** *and* ***2018*** *in the Alpine region.*

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.

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

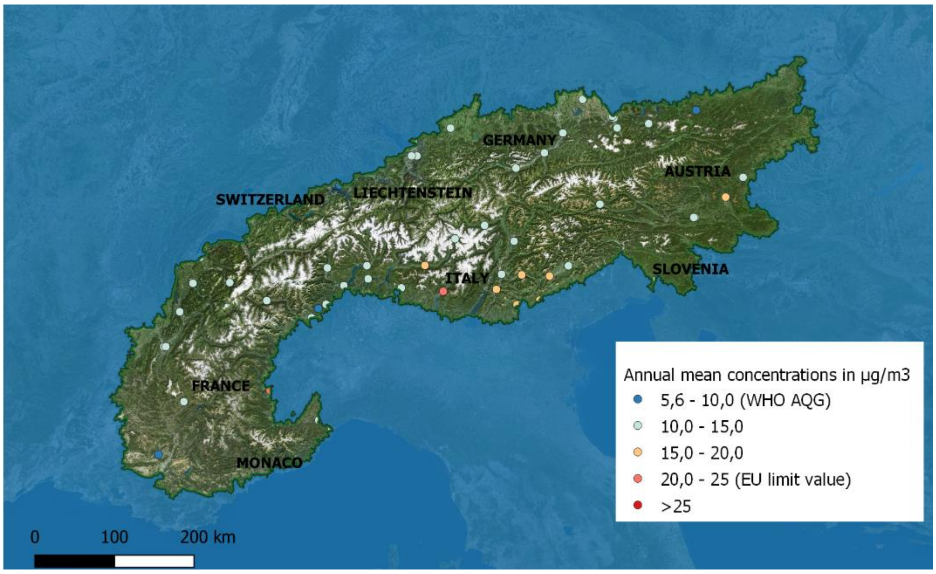

Figure 18: Map of annual mean concentration of PM2.5 in 2018 in the Alps.

Benzo(a)Pyrene (B(a)P)

Concentration levels comply with the target value (1 ng/m^3) at a majority of sites and an overall concentration decrease 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 figure 20.

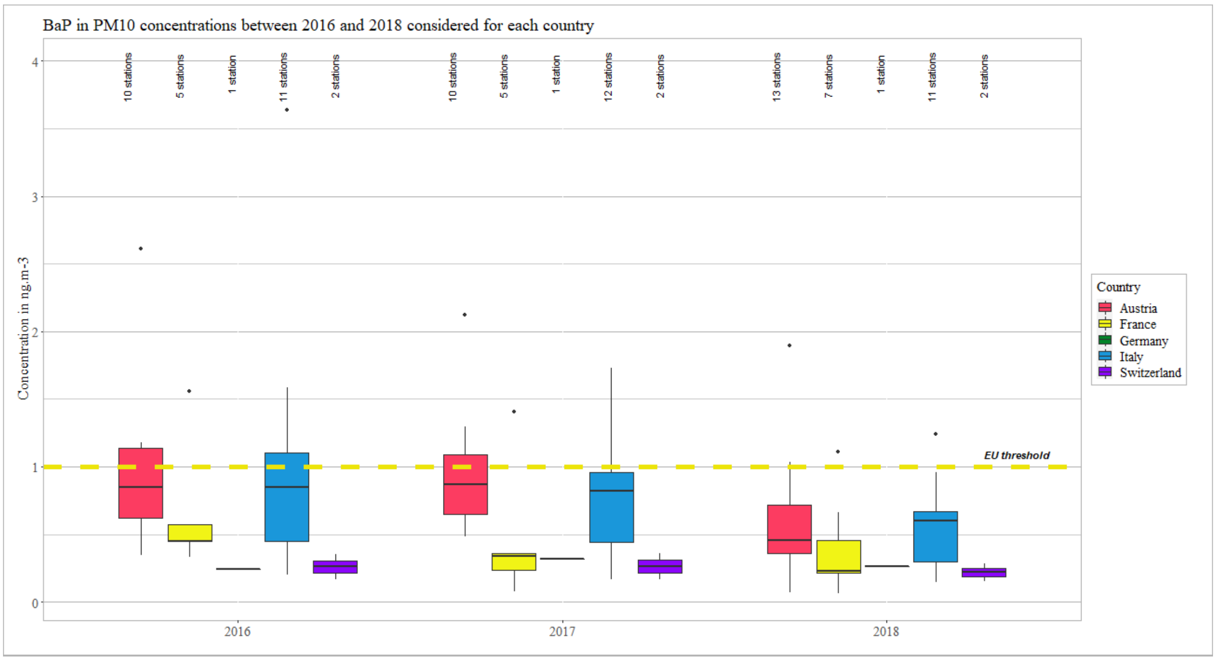

*Figure 19: Distribution of **BaP** annual mean concentrations in PM_{10} in **2016**, **2017** and **2018** in the Alpine region.*
The yellow dotted line represents the annual limit value of the EU-Directive (2008/50/EC) and the green dotted line the WHO-Guideline for the protection of human health.

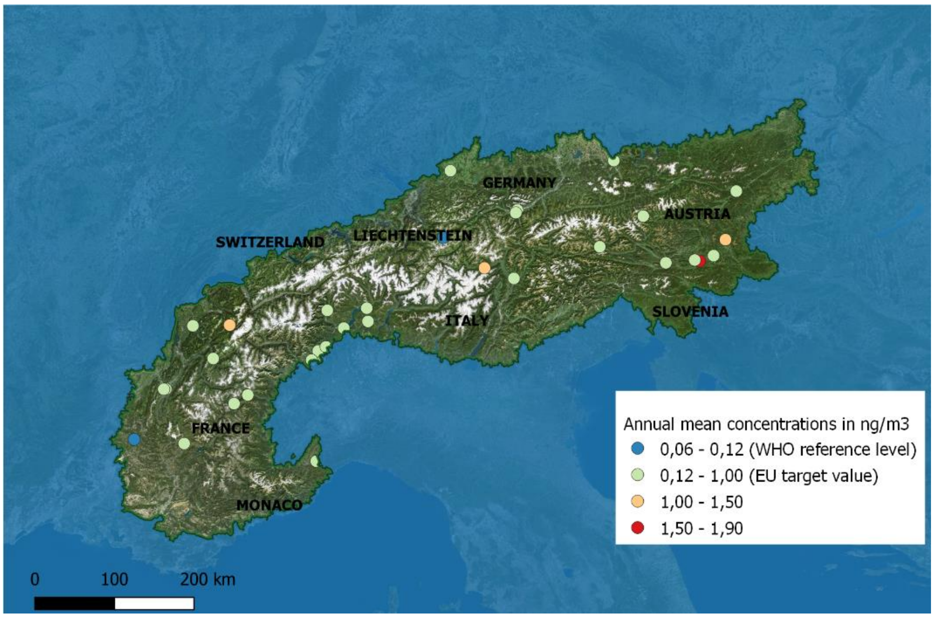

Figure 20: Map of annual mean concentration of BaP in 2018 in the Alpine region. Exceedances of the target value are plotted in red.

Below 1.5, the annual mean is rounded to 1 ng/m³ and is not considered as an exceedance according to the EU reporting rules.

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/m³) 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 of all, 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.

On the other hand, the figure for PM_{10} concentrations is more diverse. In France and, at least in 2017, in Italy, several stations can be found where the most protective WHO AQG is exceeded. According to figure 7 page 42 and owing to the conclusions of § 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 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 negative, 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.

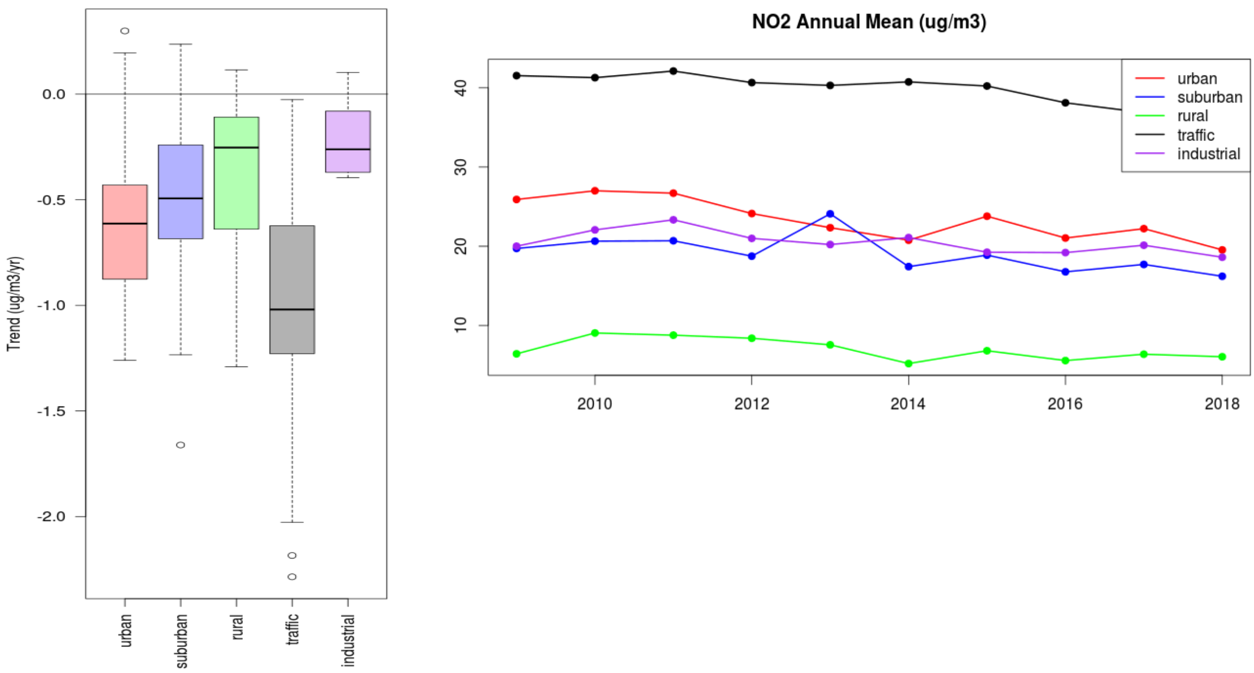

Figure 21: Change in NO_2 annual mean concentrations in µg/m³ in the Alpine Convention perimeter from 2009 to 2018. Left graph: distribution of the slope of the trend by station classification. Right graph: Evolution of NO_2 annual mean in µg/m³ by station classification between 2009 and 2018. Stations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

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 inter-annual 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.

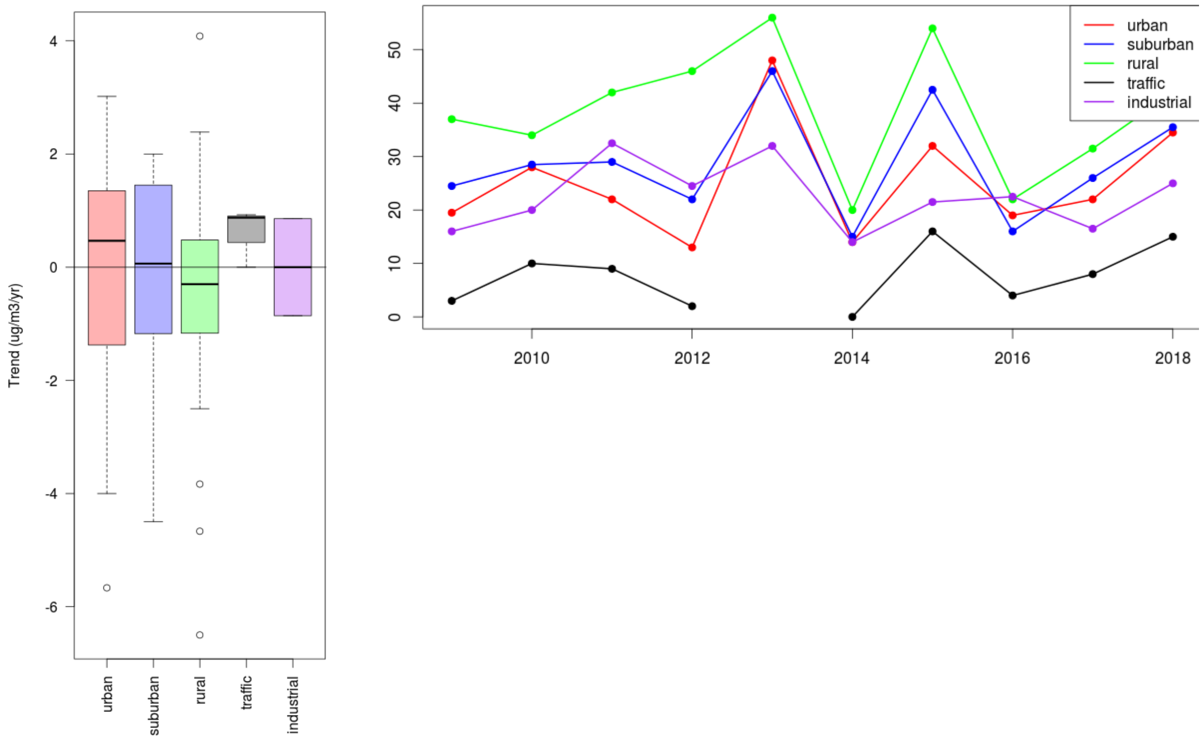

Figure 22: Change in the number of days where ozone concentration exceeded the limit of 120 µg/m³ for more than 8 h in the Alpine Convention perimeter from 2009 to 2018. Left graph: distribution of the slope of the trend by station classification. Right graph: evolution of the number of days by station classification between 2009 and 2018. Stations qualified as rural, suburban and urban are background stations

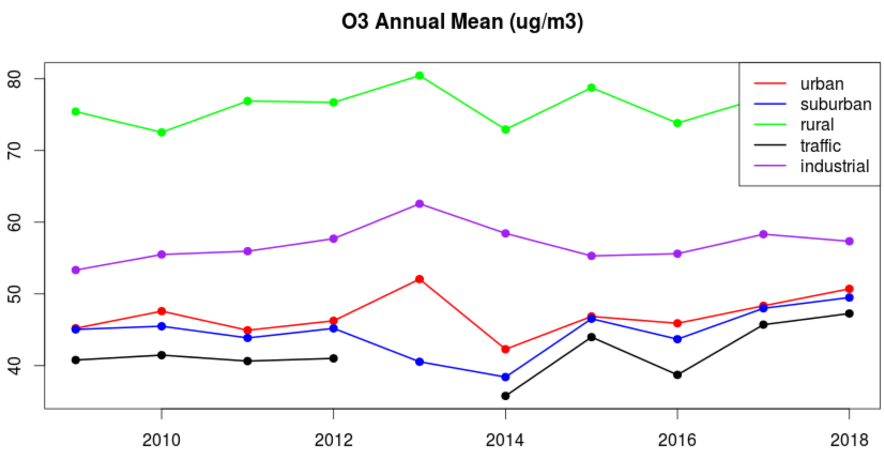

Figure 23: Evolution of O_3 annual mean concentrations by station classification between 2009 and 2018. Stations qualified as rural, suburban and urban are background stations

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 a majority of sites. There is no difference in situation between rural and urban situations or at stations representative of industry or traffic (figure 24).

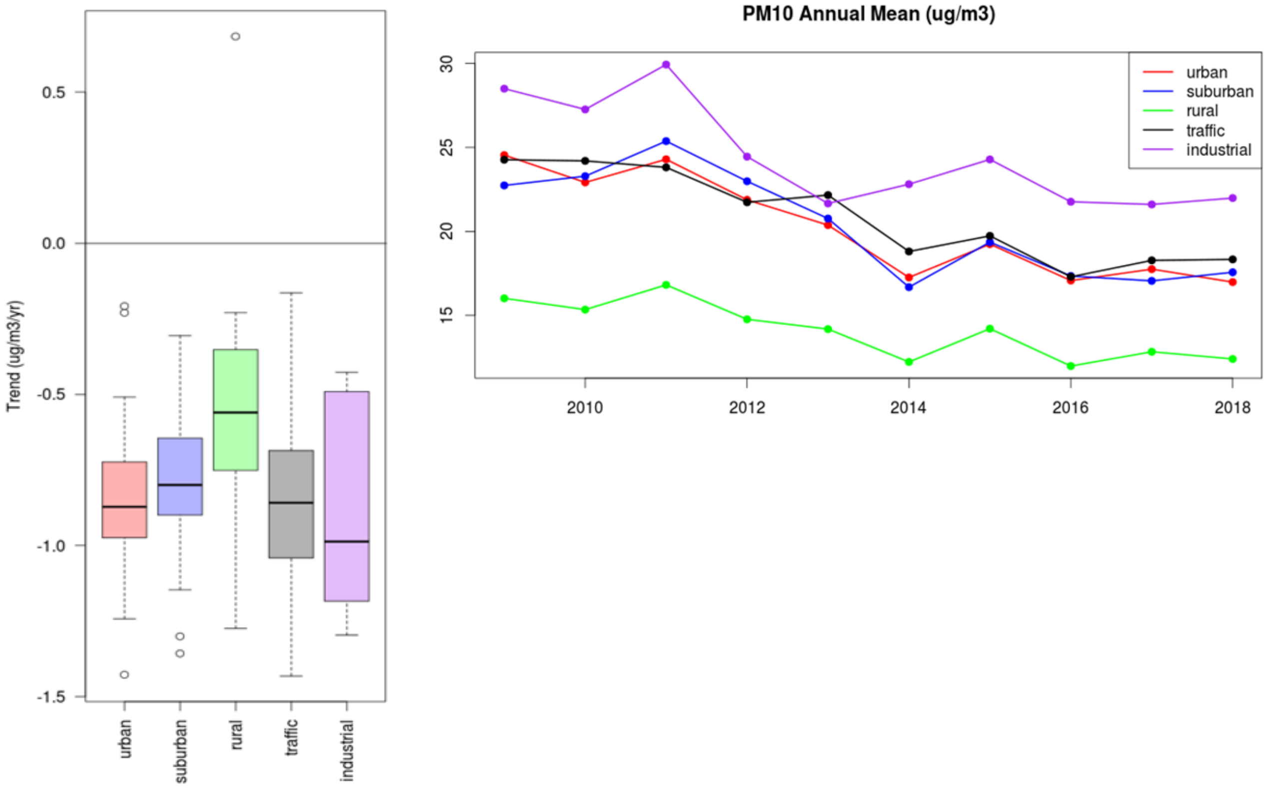

Figure 24: Change in PM_{10} annual mean concentrations in µg/m³ in the Alpine Convention perimeter from 2009 to 2018. Left graph: distribution of the slope of the trend by station classification. Right graph: evolution of PM_{10} annual mean in µg/m³ by station classification between 2009 and 2018.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

5.3.4 $PM_{2.5}$

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.

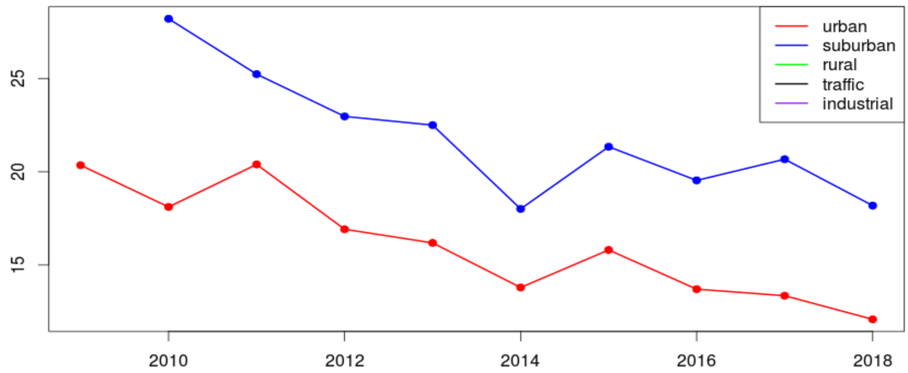

Figure 25: Evolution of $PM_{2.5}$ annual mean in µg/m³ in urban and suburban background stations in the Alpine Convention perimeter from 2009 to 2018

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 27).

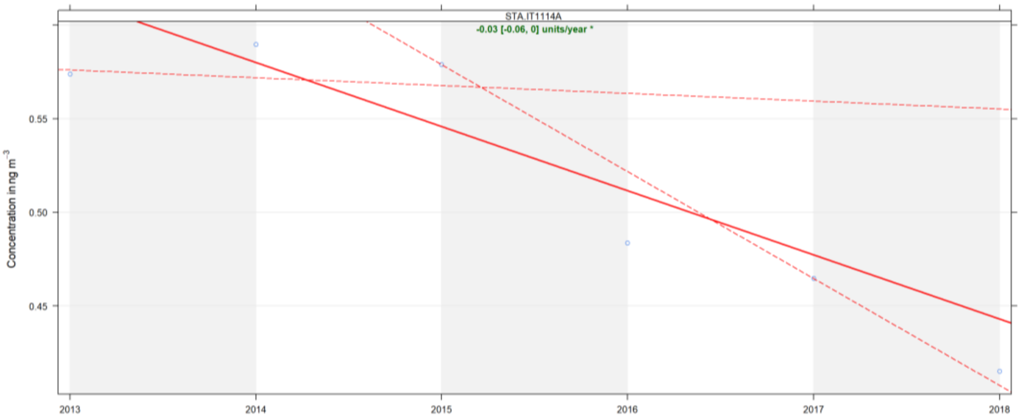

Figure 26: Recent trend of BaP at an Italian monitoring station in the Alps. The solid red line shows the trend estimate and the dashed red lines show the 95% confidence intervals for the trend. The overall trend is shown at the top-left as - 0.03 µg/m³ per year and the 95% confidence interval is -0.06–0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

The analysis of trends was focused on pollutants displaying exceedances of European limit or target values and WHO guidelines. In agreement 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 rate of change 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 with more data. This overall favourable development, combined with only a few persisting exceedances of EU thresholds or WHO guidelines, makes an encouragement to 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 on table 1 page 20, other substances will become relevant for the future of the Alpine region. This chapter looks at relevant issues currently investigated in cooperative research programmes, more details about which are given in the Annexes.

A major problem in the Alpine region, reported in several national and transnational studies and reports summarised in the annexes, are emissions and concentration levels of particulate matter ($PM_{2.5}$ / PM_{10} / UFP) from wood combustion. Wood burning is as a matter of fact 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 reaction. For the moment, information and evidence on how climate change will influence air quality, and thus also human health, are still limited. We just generally assume 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 observations 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 the Annex) 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 KP, 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 is often in a similar order of magnitude. This means that even remote Alpine areas are no longer free from environment 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) No 1907/2006) and the Stockholm Convention, some pollutants have decreased their ambient air concentrations in the Alps. These pollutants include the largely banned organochlorine pesticides. By contrast, so far the concentration of dioxins in the ambient air have only slightly decreased or, in the case of PCB, not at all. 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.

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[34]

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, namely: Zugspitze at Schneefernerhaus (UBA Germany, see figure 28), Hohenpeißenberg (Germany (DWD) and Jungfraujoch (Switzerland), Sonnblick (Austria see figure 29) and Plateau Rosa (Italy). The special locations in Europe and in the Alps make these stations of special interest for science research and monitoring tasks, e.g. long-range transport of pollutants, monitoring of airborne persistent organic substances for the aims of the Stockholm Convention on POPs[35], physical and chemical changes in the atmosphere, intrusion of air masses (and pollutants) from the stratosphere to the troposphere, and generating and transport of pollutants. Most of the above stations form part of the Global Atmospheric Watch Programme of the World Meteorological Organization (GAW WMO), the European Monitoring and Evaluation Programme (EMEP)

34 *PureAlps – Monitoring of Persistent Pollutants in the Alps; brochure published by Bavarian Environment Agency, Augsburg, and Environment Agency Austria, Wien; 2019, page 5*

35 *Stockholm Convention on persistent organic pollutions (POPs)*

network, and the ACTRIS programme (Aerosols, Clouds, and Trace gases Research Infrastructure Network). Italy takes part in these programmes also 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 European Monitoring and Evaluation Programme (EMEP) and Global Atmosphere Watch (GAW) Monitoring Network. These countries are also working intensively together in the Global Atmosphere Watch (GAW) programme to collect data on worldwide atmospheric processes in the fields of components affecting transnational, transboundary climate.

Figure 28: Umweltforschungsstation Schneefernerhaus (UFS) at Zugspitz ©Markus Neumann (UFS)

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

Figure 29: Sonnblick Observatory © ZAMG/SBO Ludewig

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

6.3.1 GERMAN ULTRAFINE NETWORK

There is a measuring station for ultrafine particles (UFP) at Umweltforschungsstation Schneeferner Haus (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 particle formation compared to anthropogenic particles.

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 (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 (NM-VOC), 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 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-time O_3 probably builds up either due to local anthropogenic emissions and favourable weather conditions or is transported long-range from the troposphere and then exchanged to the troposphere. 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

Michael Bittner, Ehsan Khorsandi, Frank Baier, Thilo Erbertseder
Deutsches Zentrum für Luft- und Raumfahrt, Earth Observation Center, Oberpfaffenhofen.

The Virtual Alpine Observatory, VAO[36], 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 VAO.

Within the framework of VAO, air quality in the Alpine and pre-Alpine regions is also monitored. For this purpose, measurements from ground-based stations, from satellite-based instruments (in particular the ESA Sentinel Programme[37], figure 30) as well as data from the European COPERNICUS Atmospheric Service[38] (CAMS) are used.

For the daily forecast of air quality near the ground (currently two days ahead), DLR[39] uses a numerical model system consisting of a meteorological model (WRF[40]) and a chemical transport model (POLYPHEMUS/DLR[41]), which takes into account the special conditions of the Alpine region. The distribution of air pollutants is predicted within administrative districts (counties) hourly and with a horizontal resolution of 6 km. By 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[42]).

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36 https://www.vao.bayern.de
37 https://sentinel.esa.int/web/sentinel/home
38 https://atmosphere.copernicus.eu/
39 Deutsches Zentrum für Luft- und Raumfahrt / German Aerospace Center
40 https://www.mmm.ucar.edu/weather-research-and-forecasting-model
41 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
42 https://www2.mmm.ucar.edu/eulag/

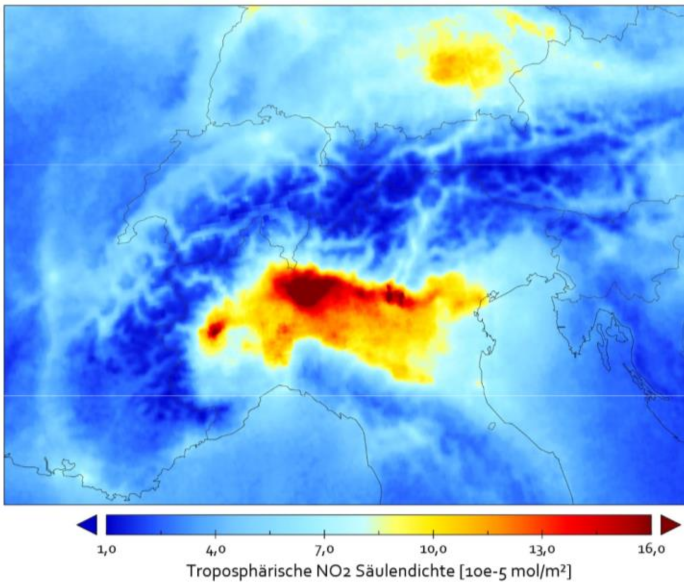


Figure 30: Mean concentration of the tropospheric NO_2 column for the period from January to June 2019 over the Alpine region (satellite-based measurements from ESA's Sentinel 5P, German Aerospace Center (DLR).

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[43]".

All results are available daily to the public via the Alpine Environmental Analysis Data and Analysis Centre[44] (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 concentrations) 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 (BioCliS). This provides average daily values as well as a time series of air pollutants, meteorological parameters and the influence on well-being over a period of four days aggregated in districts. Figure 31 shows a screenshot of the BioCliS web page.

43 http://www.utci.org/isb/documents/windsor_vers04.pdf
44 https://www.alpendac.eu/

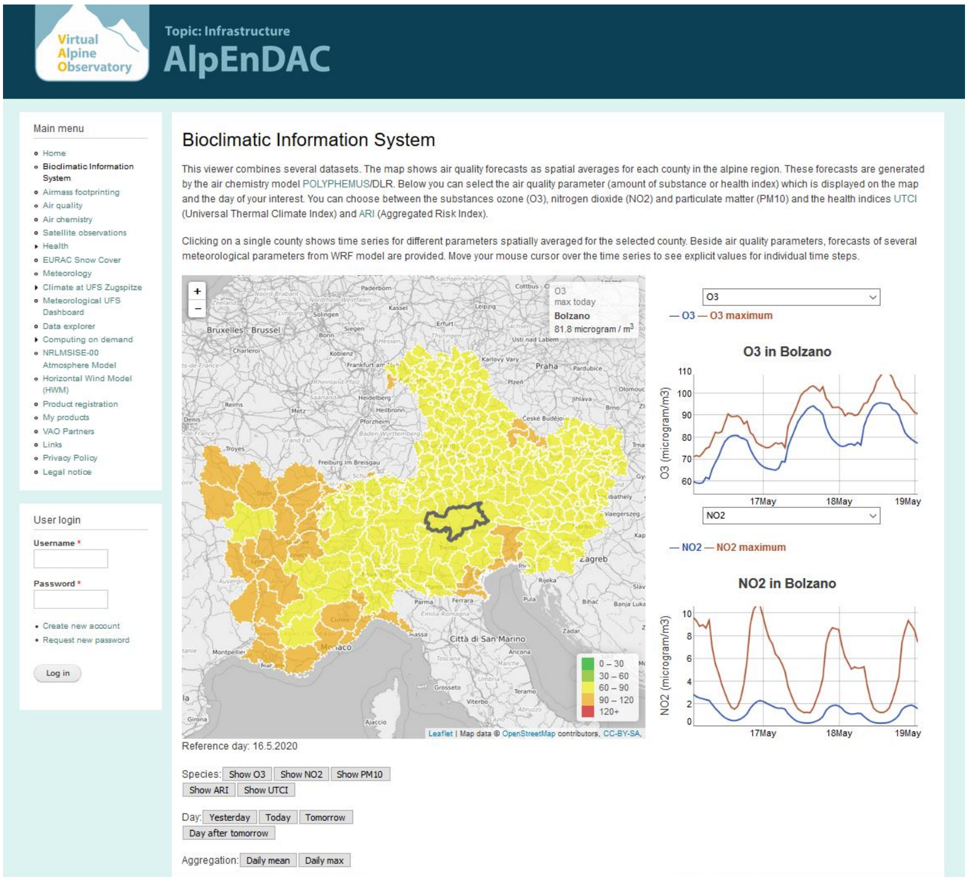
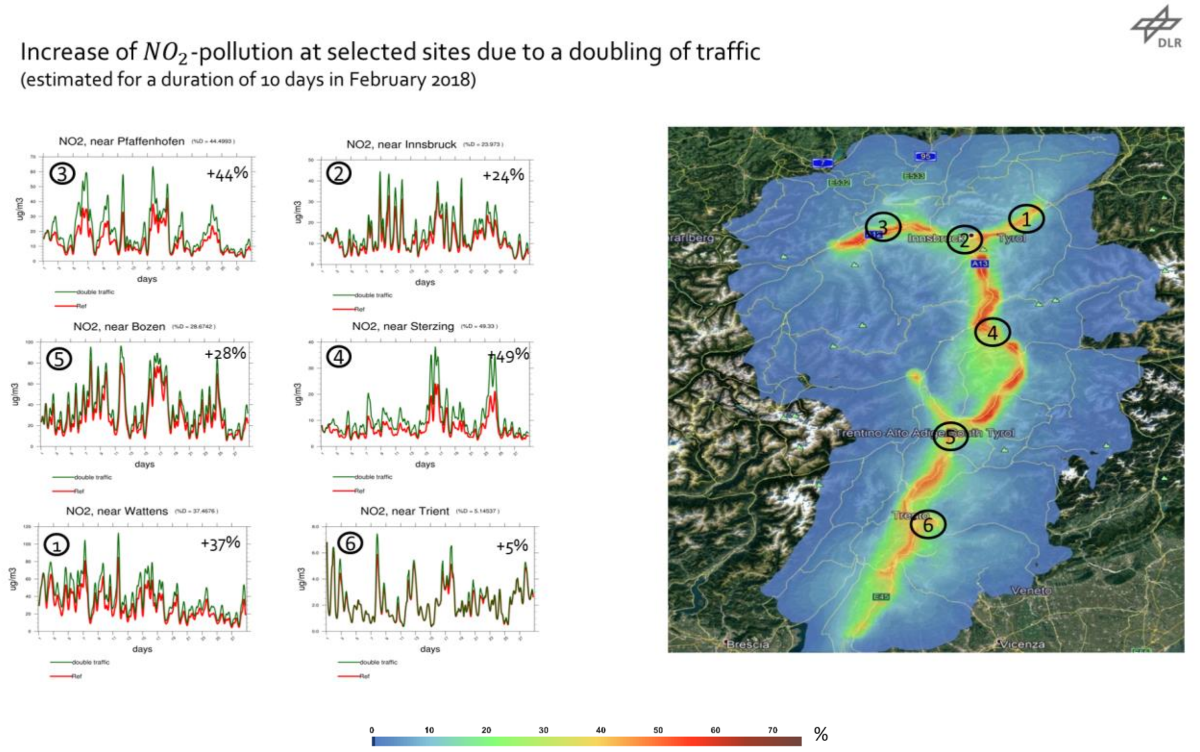


Figure 31: Bioclimatic information system by district
(https://www.alpendac.eu/landkreis-tool)

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 fine particulate matter (PM_{10}) as would possibly result from a doubling of road traffic via the central Alpine transit routes. The figure shows the hypothetical situation for a period of 10 days in February 2018, indicating the percentage increase of NO_2 load compared to the normal situation. For selected locations the small graphics show the expected higher NO_2 load. It should be noted, however, that for instance near larger cities such as Innsbruck the impact of doubling highways traffic might be less due to the influence of high local emissions from many sources. The lower graph in figure 32 shows the situation for particulate matter (PM_{10}).

Another example of a typical investigation is shown in figure 33. The lockdown due to the Covid-19 pandemic has 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 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 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 about 30 micrograms per cubic metre can be clearly seen, corresponding to a decrease of up to about 45% compared to the normal state.



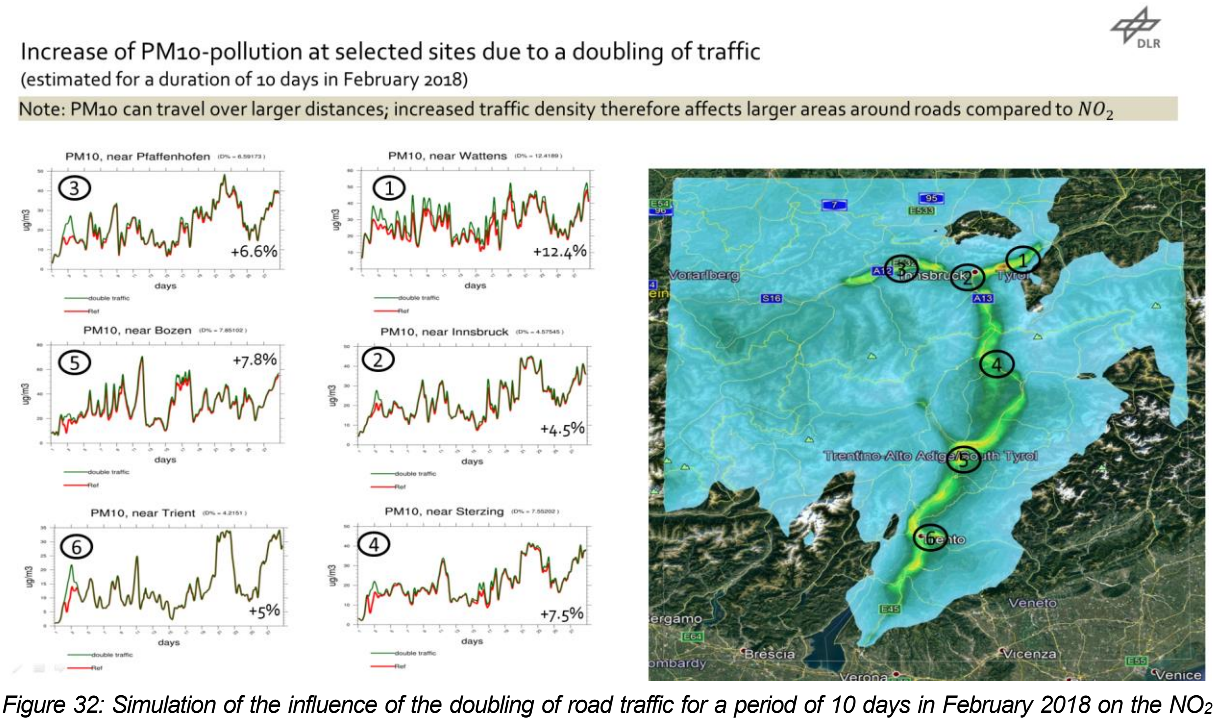


Figure 32: Simulation of the influence of the doubling of road traffic for a period of 10 days in February 2018 on the NO_2 concentration (top) and on the fine dust concentration (PM_{10}) (bottom).

Data are given for normal traffic (red) and for doubled traffic (green). Right: The map gives the mean deviation between normal and doubled traffic (on the highway only) induced pollution for the first 10 days in February 2018.

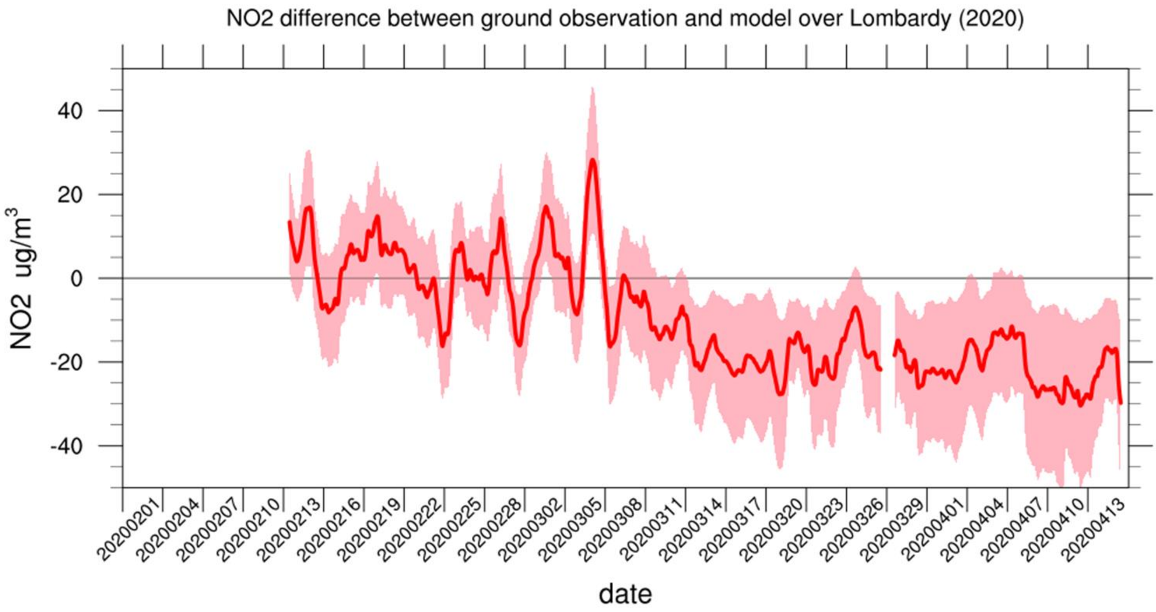


Figure 33: Difference between the NO_2 concentrations measured at 25 ground stations in Lombardy and the WRF-POLYPHEMUS/DLR model for the period from 1 February 2020 to 13 April 2020

6.5 WHAT FUTURE FOR THE MONITORING OF AMBIENT AIR POLLUTANTS

The measurement and monitoring of trace pollutants such as POPs, F-gases, halogenated gases and also of ultrafine particles at high altitude measuring stations are necessary and urgent. The special characteristic of the Alpine region of being highly sensitive to pollutants, of showing a good dispersion of pollutants while also being a trap for pollutants requires additional attention. In that context, the Alps can also be seen as a "sentinel" to detect emerging pollutants and alert on future impacts of new 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 gained. Further research is therefore needed on UFP and its effects on human health and the environment.

In addition to collecting precise data about the air pollutants, the measuring stations need to be arranged representatively also 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 § 6.4. Such an observatory will give a better picture on 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 provided by the experts of the Working Group. These solutions 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 understand, 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). On the other hand, 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, decarbonisation of the Alpine economy might co-benefit air quality when cleaner transportation systems are implemented but could also have adverse effects when 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 chapter 2. Smart solutions for reducing emissions from heating activities, particularly wood based, start by setting out guidelines and thresholds for building heating. 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 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

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 can have access to these funds whatever their income, which gives the population an incentive to replace their old heating systems. These funds are backed by communication campaigns to the populace to improve their knowledge about good practices in this respect.

A simple but effective measure was needed for areas polluted by particulate matter. It was decided to implement an economic incentive in one Alpine region, testing it for over 4 years. 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 from 4% to 12% of PM_{10} when replacing less than 30% of inefficient heating systems was observed after 4 years in the pilot project.

Thus, this measure was a success and was expanded to 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 influencing air quality are: to use wood as a domestic and renewable resource for raw material and energy wisely and efficiently; to efficiently process and use round timber from Slovenian forests in Slovenia, 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

Cercl'Air is an association of Swiss authorities and academics in the field of air quality and non-ionizing radiation. It fosters and promotes, in the complex federal system, inter-cantonal coordination of the implementation of air quality protection law 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. Therefore, an agreement[45] has been signed between the Ministry of Environment, Land and Sea and AIEL (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 and installers and maintainers of biomass systems. The association promotes the energy exploitation of biomass from agriculture and forestry.

This agreement promotes and encourages 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 particulate matter and benzo(a)pyrene. It activates

[45] https://www.minambiente.it/sites/default/files/archivio/allegati/inquinamento_atmosferico/Protocollo_Intesa_MATTM_AIEL.pdf

appropriate training processes for updating and providing professional qualifications to installers and maintainers of wood-based biomass plants. It also foresees information campaigns for producers and users and encourages adding a "quick guide to 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, providing as commitments for these Administrations both the intensification and strengthening of operations for controlling civil thermal biomass plants, and more constant information to the public.

7.1.3 DISTRICT HEATING

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

The Plan for Maintaining Air Quality[46] 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 all buildings in the area to them;
2. setting up shared small wood biomass combustion units where conditions permit and connecting all buildings in the area to them;
3. substituting outdated small wood biomass combustion units with modern ones and in dispersed settlement areas with heat pumps ;
4. providing information, communicating and educating people about good practices, and demonstrating and promoting positive effects on air quality in areas where outdated small combustion units are still in use.

7.1.3.2 District wood heating system, Disentis-Mustér (Switzerland)

By establishing a district heating network in the municipality of Disentis-Mustér in the Canton of Grisons (GR), fine dust emissions can be significantly reduced compared to those of decentralised heating systems through correct operation of the system and through filter systems. Wood, the fuel of choice, 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 is then distributed throughout the village. A welcome side effect of this measure is that particulate emissions can be reduced compared to emissions from a situation where each building has an individual wood heating system. 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 of 1,955 kW. The pipeline network

[46] After public consultation in the beggining of 2020 the Government will adopt the Plan by the end of 2020.

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[47]. 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 fall considerably below the fine dust limit values of 20 mg/Nm³.

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 a. 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 a. Königssee, Berchtesgaden and Bischofswiesen. Coupled with the technical performance to overcome 150 m of altitude, the inter-communal district heating supply of Bioenergie Berchtesgadener Land is a showcase project for the use of renewable energies in a rural area[48].

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

7.1.4 ENVIRONMENTAL SUPPORT SCHEME FOR BIOMASS DISTRICT HEATING IN 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.

47 https://www.gr.ch/DE/institutionen/verwaltung/bvfd/aev/dokumentation/EnergieeffizienzEnergieaperoDokumente/EA81_Sac.pdf
48 http://www.bioenergie-berchtesgadenerland.de/das-fernwaermeleitungsnetz.html

Thermal input	≤ 500 kW	0.5 – 1 MW	1 – 2 MW	2 – 5 MW	5 – 10 MW	> 10 MW
NOx (mg/Nm³; 10% O_2)	200	275	275	220	220	110
Dust (mg/Nm³; 10% O_2)	40	83	36	22	11	11

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

7.2 REDUCTION OF VOC/OZONE 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 NMVOC REGULATION IN 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 of 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[49].

7.2.2 STRICTER REGULATIONS FOR VOC EMITTING INSTALLATIONS IN GERMANY

For reducing Ozone concentrations there are several Directives for lowering the emissions of volatile organic compounds from installations. For example, Chapter V IED (2010/75/EU), 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.

49 Source: Much, but not all of the text, was taken from Switzerland's Fourth Biennial Report under the UNFCCC 2020

Examples:

Implementation of Chapter V EU Industrial Emission Directive in German ordinance regarding the reduction of VOC emissions resulting from the use of organic solvents in specific installations – 31st BImSchV[50]

- 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.
- German TA Luft emission values for organic compounds of class I No 5.2.5 have to be applied for stack emissions: 20 mg/Nm^3 (compared with Chapter V IED: only for halogenated volatile organic compounds 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/m^3.

Implementation of Petrol Stage I/II Directives in 20th and 21st BImSchV[51] –

- 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

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 reduction of air pollution. Most of these types or categories of 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.

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

Nevertheless, in case of necessity, the regional authorities within the perimeter of the Alpine Convention may introduce strong specific measures which counterbalance and remedy a situation where pollutants exceed 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

Transalpine freight transport is a major challenge regarding air quality (and noise) for the inner Alpine Arch A. Four main road axes crossing the Alps have significant impacts in terms of air pollutant emissions (Fréjus, Mont Blanc, Gotthard, Brenner) (figure 34).

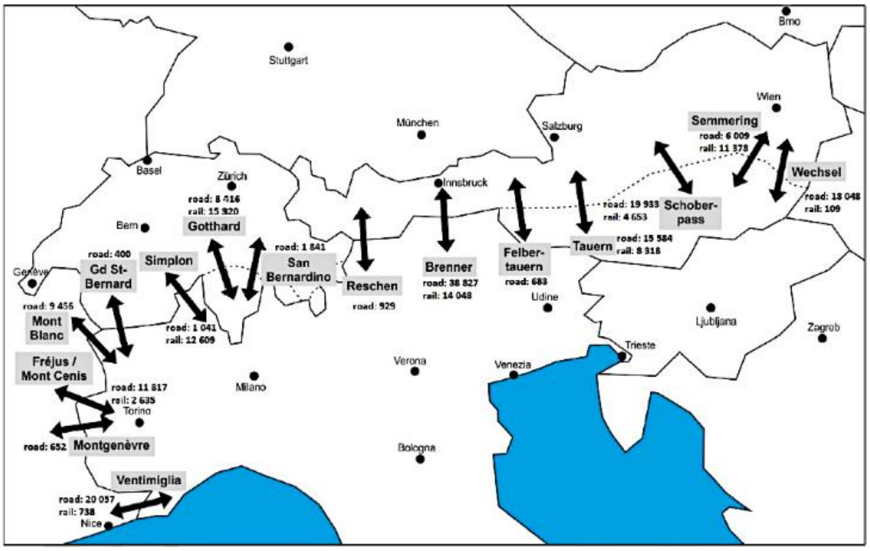


Figure 34: Transport pathways through the Alps (Source WG Transport)

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 sector, 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 inter-modality 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 the Alpine area.

A comparison of emissions between rail and road freight transport is given by the updated Handbook of emission factors, summarised in table 11, taken up also by the German Federal Agency for the Environment (Umweltbundesamt)[52]. The last line provides an average surface land use factor (high speed train vs. highway):

52 https://www.hbefa.net/d/index.html and https://www.umweltbundesamt.de/themen/verkehr-laerm/emissionsdaten#emissionen-im-guterverkehr-tabelle

Air pollutant (g/t.km) / land use (dimensionless)	**HGV (>3.5t)(1)**	**Freight train(2)**
NO_x	0.269	0.037
PM(3)	0.004	0.000
VOC(4)	0.037	0.003
CO_{2equiv}	112	18
Land use factor[53]	3	1

Table 11: Comparison of emissions between rail and road freight transport. Reference year: 2018; g / t.km: incl. transformation processes.

(1) Mix of different types of Heavy goods vehicle (HGV) > 3.5t up to 40t, mono-truck, lorry with trailer, semitrailer. (2) basis: average mix of electricity in Germany. (3) Without abrasion of tyres, brakes, road surface, overhead contact. (4) Without methane.

Moreover, the Grace study of 2006 and the more recent EUSALP, (2017) study 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 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.

	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.

The values in brackets indicate the sensitivity intervals (lower and upper level). n.a.: not available / no data available.
* for visual intrusion, the GRACE study suggested a factor of 10.7 for road transport and 5.3 for rail transport.

Table INFRAS.

Figure 35: Comparison of additional external cost factor for road and rail transport in Alpine areas (Fac simile from Eusalp)

7.3.1.2 Modal shift policy in transalpine freight transport in Switzerland

In Switzerland, the modal shift policy in the freight transport sector has been a key issue for 25 years. A Constitutional Act was triggered by a popular initiative established by the Alpine Protection Act in article 84 of the Federal Constitution in 1994, followed by Federal laws regarding the introduction of the performance-related Heavy goods vehicle Fee. The modal shift law specifies the maximum number allowed of heavy vehicles in transalpine transport (650,000/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. Push and pull measures are:

53 https://www.allianz-pro-schiene.de/themen/umwelt/flaechenverbrauch/

- Infrastructure construction as an alternative to road transport = new railway base tunnels through the Alps,
- Introduction of performance related heavy goods vehicle 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 NOx 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+rail) has a positive impact on air quality and transport efficiency[54].

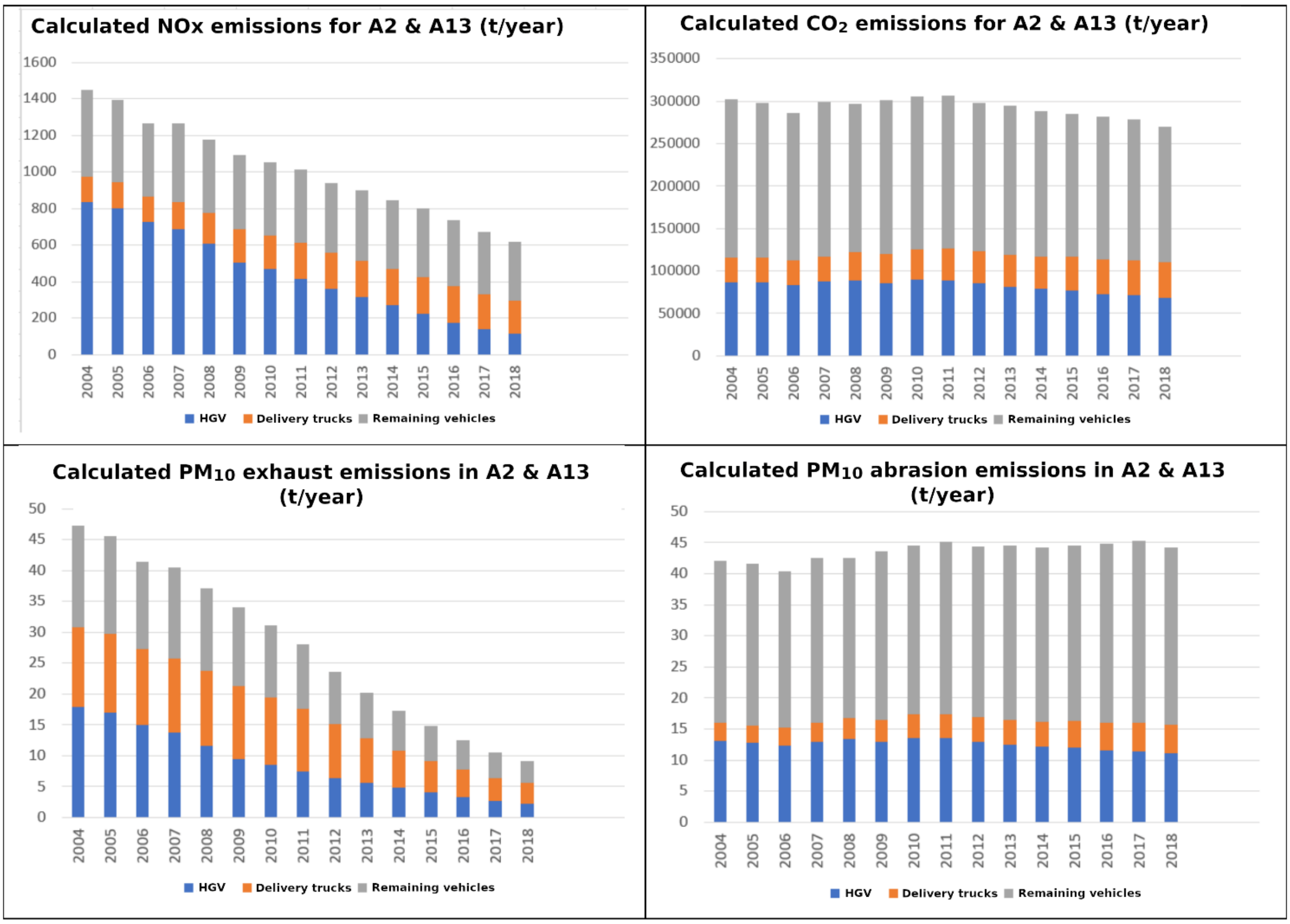


Figure 36: Evolution of air pollutants and CO_2 emissions between 2004 and 2018 on the A2 & A13 highways in the Alpine region

[54] *See chapter 3 (Umweltkapitel) in 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 in Austria

Austria offers important examples from the transport sector, specifically in Tyrol which is very much affected by the main transit route Inntal and Brenner Highway (A171 and A13 from Kiefersfelden/Kufstein 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 principal 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 heavy goods vehicles (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 the future answer in Europe to a modal shift policy for rebalancing the transalpine freight flows on the Scandinavian-Mediterranean corridor.

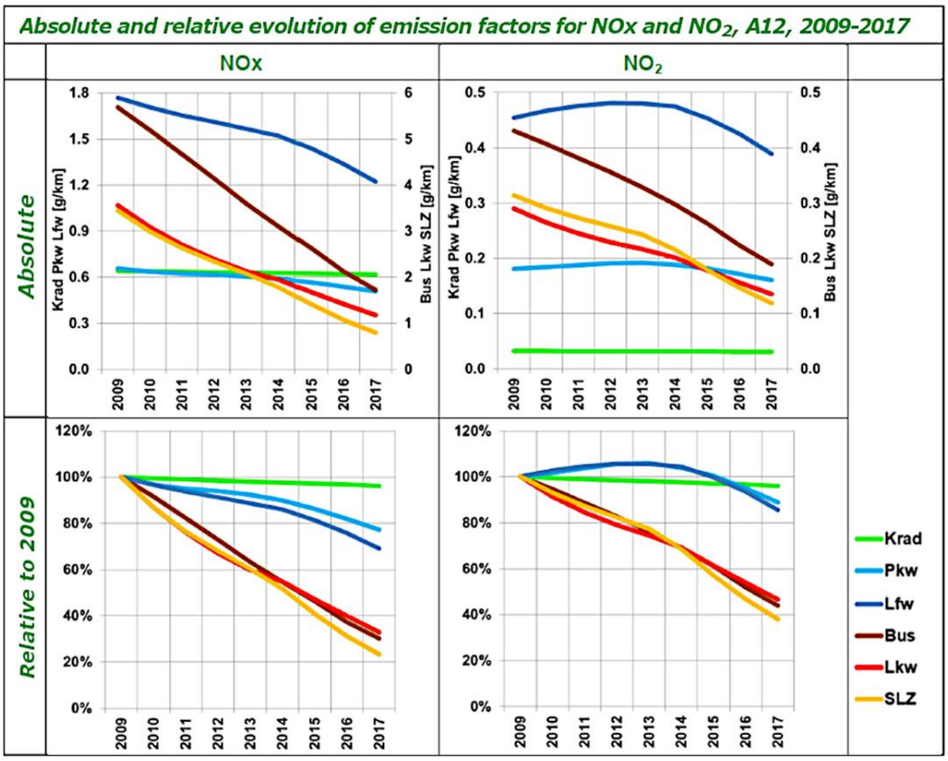


Figure 37: Evolution of the emission factors for NOx and NO_2 on the highway A12 in Austria[55].
Krad: motorcycles, PKW: passenger cars, Lfw: delivery vans; Bus: buses; LKw: trucks; SLZ: truck-trailer combination

[55] https://www.tirol.gv.at/fileadmin/themen/umwelt/umweltrecht/Luftseiten/Luft/Evaluation_der_LKW-Massnahmen_auf_der_A12_Euroklassenfahrverbot__Nachtfahrverbot__Sektorales_Fahrverbot.pdf

7.3.1.4 Low Emission Zones and vehicle conversion bonus in France

The introduction of Low Emission Zones (LEZ) affects municipalities and private individuals. The Low Emission Zone is an area restricting certain types of polluting vehicles and there are currently 220 LEZ in Europe[56]. 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 which is a subsidy given to citizens to change their old vehicles to new models producing less pollution (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 in 10 cities and is now in place in 27 cities as of February 2020[57]. The most heavily polluting vehicles cannot enter these cities with the exception of highways. 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 which is the main source of pollution in urban areas.

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

Setting a controlled emission area in the Mediterranean Sea provides a further push to the strategy adopted by the International Marine Organization (IMO) in Marpol, (see Annex VI). This measure has already been applied successfully in the Baltic Sea and the North Sea. The general public and local politics alike are aware of the impact of maritime transport on air quality and are favourable to such a project. Therefore ensuring this project's success is essential for improving the air quality in this region. The measure would set out a combined zone to reduce SO_2 and NOx 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 minimize 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

[56] *https://urbanaccessregulations.eu/userhome/map*
[57] *https://www.grenoblealpesmetropole.fr/761-la-zone-a-faibles-emissions.htm*

Marine Leger (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 SOx, 80% for PM, 51% for Black Carbon and 5% for NOx compared to 2015-2016.

7.3.1.6 Dynamic regulatory measures in Italy – BrennerLEC

The Life BrennerLEC project aims to create a "Lower Emissions Corridor" (LEC) along the Brenner motorway axis in order to sharply improve the environment in terms of air and climate protection as well as reducing noise pollution[58].

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 in order 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; the latter one obtaining still significant but reduced effects.

In any case, 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 air quality. The reduction of nitrogen oxide concentrations along the sides of 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 nitrogen monoxide and about 2-3% for nitrogen dioxide with an average speed reduction for light vehicles of about 5 km/h, compared with reductions of 10% for both species with mandatory limits, causing 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 behaviour with a view to shifting from individual motorized transport to more sustainable mobility systems. Since the 1990s, this approach has been increasingly gaining attention as a part of efforts to balance mobility demand against negative impacts and environment quality as a whole. In many cases, mobility management is also linked to integrated land use planning, in which mobility issues are considered as the most important basic elements for any spatial and land use planning at local, regional and national level.

The appeal of mobility management as an approach for dealing with mobility issues lies in the numerous potential benefits it can generate, including:

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[58] *https://brennerlec.life/it/home*

- Less congestion, resulting in a reduction of air pollution and noise and in 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 life styles and less stress, thanks to more active modes of transport like cycling & 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 (SUMP) 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 Switzerland: institutional framework for sustainable mobility by a Coordination Office (COMO)

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[59]:

- IT Solutions
- Sharing mobility
- Leisure time mobility
- Pedestrian and cycling traffic
- Public transport
- More efficient private motorized 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 Ecodrive" (QAED), initiated back in 1999 by the SFOE and Energy Switzerland as a partner association to implement good practices in Ecodriving and as a multiplicator for

59 https://www.energieschweiz.ch/page/de-ch/komo-projekte *(in German, French, Italian)*

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 Switzerland mobility for car-free travelling throughout Switzerland linking tourism, leisure, hotel accommodation and points of interest

Switzerland mobility / Schweiz mobil is the national network, initiated in 1998, for non-motorized individual transport especially for leisure and for tourists. A route planner on the web and a smartphone application[60] (since 2012) linked to summer and winter leisure / cultural events, museums, sports areas etc. and hotel accommodation makes possible car-free travel by public transport (rail, road, cable car, boats, etc.) and human powered active mobility (biking, hiking).

The network and planner was created and supported as a foundation by numerous organisations like Swisstourism, Veloland Schweiz, Swiss Hiking paths, 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, and 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 Austria: Mobility Management Concept in Carinthia

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 of 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.

60 https://www.schweizmobil.ch/en/summer.html

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

Bavaria has been showing specific examples targeted on reducing people's reliance on personal motorized vehicles and increasing the attractiveness of the public transport system, for both the local population and tourists. The target is a reduction of the motorized individual traffic, increasing the attractiveness of the public transportation system

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.

The district of Miesbach has decided to allow pupils with a valid RVO[61] student card or a valid pupil card to travel on public transport free of charge, beginning from November 1st 2019. This offer is valid for all pupils without age restrictions, resident in the district. The RVO transports pupils of the participating districts 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" is referring exactly to the bus lines where it has been taken. The RVO provides quarterly statistics on the number of users. These tickets are valid on holidays, weekends and public holidays all day. On school days, these tickets are valid from 14:00.

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, which operates the majority of all bus routes in “Oberland”.

by an ambitious financial subsidization of public transportation

As an example of reduction of motorized individual traffic and of environmental pollution and increase of the attraction of public transportation, the city of Sonthofen has set itself the longer-term goal to increase the attractiveness of the city bus (line 1 (21) and line 2 (22)). 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 by free use of the public transport (within the municipality and surrounding local communities) “Stadtwerke Bad Reichenhall” KU are 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

61 RVO: Regional Traffic for Upper Bavaria; regional public bus transportation for Bavarian uplands at local and regional level for tourists with (electronic) guest card, avoiding many individual car trips and reducing emission 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 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 (BY), 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 of 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. Also trips to Salzburg (bus line 840) and Bad Reichenhall (bus line 841) are 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 Alp 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 to tourists as well as a climatic healing health resort. 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 motorized traffic and reducing the lack of parking space.

7.3.2.5 Liechtenstein: mobility concept including S-Bahn project: Transport sector:

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+rail), specifically the new project of the S-Bahn FL-A-CH linking Feldkirch (AT)-Schaan-Vaduz to Buchs (CH), which has big potential for shifting commuters from road to rail[62].

7.3.2.6 Austria: Promotion of cycling in Salzburg

Cycling is one of the most energy and space-efficient modes of transport and the fastest and most efficient mode of travel for distances of up to five kilometres. A substantial percentage of daily car trips might be replaced by cycling, as 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 motorized individual transport.

62 *https://www.mobilitaet2030.li/*

Salzburg, the capital of the country (Land) with 156,159 inhabitants has recently focused on the improvement of the conditions for cycling. The cycle path network has been progressively extended over the last 30 years. There are now 187 km of trails for cyclists and over 6,000 bicycle-parking facilities. More than two-thirds of all one-way streets are open to cycling and can be used by cyclists also in the opposite direction. 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 a day in Salzburg.

Important measures in the cycling strategy are:

- Development of a safe and comfortable main cycle path network with optimisation of the winter service
- Introduction of the rental bike system "S-Bike", in its first stage with 50 stations and 500 bicycles
- Implementation of a first “Premium Cycle Path” in the region Salzburg to Freilassing (Bavaria) with a new bridge over the river Saalach as a "model" for the importance of cycling also 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 Germany: General Promotion of use of bicycles instead of motorized vehicles in Bavaria

The reduction of motorized individual traffic and of environmental pollution increases the appeal of areas to tourists and in terms of being a climatic healing health resort. It also reduces the lack of parking space. Municipalities have different approaches for encouraging the use of bicycles instead of cars, such as:

- Preparing and implementing realisation a concept for bicycling that ensures a safe and well signalled connection between and within municipalities
- Setting up of stations for rental bikes
- Expansion of bicycle infrastructure

Examples:

- Garmisch-Partenkirchen (BY): 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 (BY): Cycle path to connect Jachenau with Lenggries.
- Jachenau (BY): Rental bike stations partially offering discounts to guest cards.

- Sonthofen (BY): Between 2017 and 2019, the cycling infrastructure in Sonthofen has been 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 is promoting low-emission commercial traffic from 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 awarded by the Bavarian State Ministry of Housing, Building and Transport on November 22, 2019.

7.3.2.8 Switzerland: Promotion of Smart Mobility within Swiss PostAuto for increasing modal share of public transport

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[63]. The areas with most potential for a possible increase of public transport use is in rural and mountain / tourist regions since use of public transport is generally already very high in urban and suburban areas. A focus is set 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 space 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 of changing mobility patterns and behaviour in the long-term.

7.3.2.9 Principality of Monaco: enhance soft mobility

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:

- 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 aiming to have an electrical bus fleet within 2025
- Development of multimodal clean transport: free-floating electric car sharing, electric bike-rental all over the Principality
- Incentive rate to encourage the use of car parks (about 15 500 parking places) at the entry to the Principality, and then the use of public transport

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[63] Smart Mobility von PostAuto

- 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 SmartNation, 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 framework directive on the deployment of the alternative fuels infrastructure (2014/94/EU, AFID). In short, Member States have 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 minimize dependence on oil and to mitigate the environmental impact of transport. This Directive shall foster low-emission fuels such as electricity, hydrogen, compressed natural gas (CNG/Bio-CNG) or liquefied natural gas (LNG/Bio-LNG)". 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 Switzerland: 2050 energy strategy / energy savings

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 and increase its use of renewable energy and, at the same time, reduce its 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 by 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[64].

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 which means that in 2020 every 10th new passenger car registered in Switzerland and Liechtenstein should be a battery electric vehicle (BEV) or plug-in electric hybrid 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 [65]

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

In March 2019, the National Council (parliamentary chamber) of Switzerland accepted proposal 19.3000 "Helping non-fossil modes of transport to break through on public roads". The Federal Council (government) had 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[66].

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 installed in which all actors concerned 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 being particularly focused on since these are places where the potential applications are smaller 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 example routes in clusters, including challenging rural and mountain routes. From examinations of 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 needs to also be addressed.

64 http://www.sccer-soe.ch/en/home/
65 https://www.auto.swiss/themen/alternative-antriebe/branchenziel-1020
66 https://www.parlament.ch/de/suche#k=Postulat%2019.3000

7.3.3.3 Bavaria/Germany: Promotion of e-mobility

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 (BY) has been continuously equipping its fleet with electric and hybrid vehicles. Vehicles with electric drive replace disused vehicles with combustion engine. Both passenger cars and commercial vehicles will be replaced. 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, such as traffic monitoring, 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, CO_2-neutral, municipal electric car sharing system, citizens as well as local industry/commerce will be motivated to no longer use second cars. The result is a considerable cost advantage because of saving 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 (BY) 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 (BY) participates in the project "Intelligent charging infrastructure" funded by the State of Bavaria between 2011 and 2016 as a model municipality. The aim was to develop a barrier-free charging infrastructure (possibility of implementing different charging options; networking of different charging infrastructure or stand-alone solutions...) with interfaces for integration into a municipal smart grid system with cross-system processes and data flows.

In the city of Sonthofen it has been possible to recharge e-cars since 2011 at public charging stations. Charging stations are located centrally in the city centre. Sonthofen is constantly expanding and modernising the charging infrastructure. Designated parking spaces in the city centre are reserved for e-vehicles. Thus, nine modern, public normal 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 (BMVI) 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 prepared 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 on the road. The statistics for the two Franco-Italian tunnels are shown in figure 38.

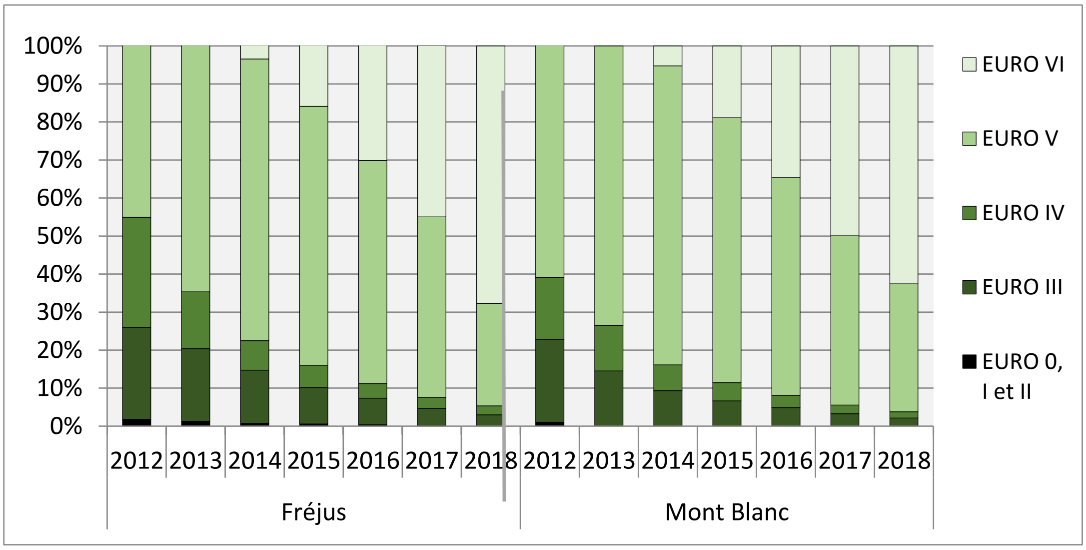

Figure 38: Observation and analysis of transalpine freight transport flows in two Transalpine tunnels. Euro 0 to VI are the EU emission limits of trucks: the NOx level, for instance, decreased from 14.4 g/kWh to 0.4 g/kWh between Euro 0 and Euro VI. (Source: ATO, November 2019)

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

In the medium term, the outlook is obviously more open. Some "weak signals" should be perceived. Electrification of heavy goods vehicles is no longer an unachievable goal. According to recent analyses by the French ministry of ecological and inclusive transition, the cost (in t.km) for the transporter of a 40-ton 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 to 500 Wh / kg in 2040. By this time, a 4-ton 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 / road contact and by brake residues. In France, it is estimated to account for at least 40% of particulate pollution emitted by road traffic. 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 ...).

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 heavy goods vehicles, 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 the most possible natural resources and limiting negative impacts on environment and health.

In the EU the Air Quality Directive requires air quality/action plans in areas where air quality limits are exceeded. In Switzerland, by the Federal Ordinance on Air Pollution Control (Luftreinhalteverordnung) and environmental protection act, every canton is required 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 SPATIAL CONCEPT SWITZERLAND (RAUMKONZEPT SCHWEIZ)

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 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 infrastructure (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 (cycling + walking), 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 (infra + 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)[67].

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 2001, the Bernese Traffic contingency model has served as a planning instrument for many municipalities since its implementation. 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).

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

The Swiss *Raumkonzept*[68] is especially recommended for the spatial development in the Alps:

- 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.

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67 https://www.admin.ch/opc/en/classified-compilation/19850321/index.html
68 https://www.are.admin.ch/are/de/home/raumentwicklung-und-raumplanung/strategie-und-planung/raumkonzept-schweiz.html

- 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.

7.4.2 IN FRANCE, AN INTEGRATED ATMOSPHERE PROTECTION PLAN

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 geomorphology of the region, air pollution is a problem to its inhabitants. Thus, an atmosphere protection plan [69] 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 the following:

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 on their impact on air quality and about new methods with minimum impact.

Urbanism:

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

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 carpoolers.
- Improvement of public transport capacity and efficiency and promoting active mobility
- Increase of the transfer of freight from road to rail by reducing the traffic load on roads in the region

[69] Link to the Atmosphere protection plan of Arve valley

7.4.3 IN ITALY: COMMON REGIONAL PROGRAMME FOR CLEAN AIR, DIFFERENT SECTORS, E.G. TRANSPORT SECTOR

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[70]. 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.

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; survey on availability of bike infrastructures in railway stations; improvement of bike infrastructures; geo-tracking of bike lines 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 the public and private stakeholders in order 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 programme,

70 https://www.lifeprepair.eu/?lang=en

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

As part of its Agricultural Policy 2014-2017, Switzerland has set a target of reducing ammonia emissions from agriculture to a maximum of 41,000 tons 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 emissions of a maximum of 25,000 tons 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. 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 tons per year by 2017, livestock units would have had to fall by more than 130,000 units (around 10% of 2007 stock) in the corresponding period.

In order to reduce the environmental impact 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 mean that ammonia emissions have only decreased slightly (see also § 4.4 pp. 47-47). In addition, feeding measures and the use of drag hoses are only of limited use or feasible, 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. Also 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 few 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 justice to the situation of mountain regions. 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 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 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 by means of 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 MEASURE AND INFORMATION

Information campaigns on the health impact of particulate matter and BaP and information campaigns on proper heating with wood should be based on the ability to measure PM emissions and its sources and to make this information available to the public. Emission measurement should be complemented by monitoring campaigns for $PM_{2.5}$, BaP and black carbon over at least one heating season. Information for citizens needs to be supported by measurementsadapted 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...). With respect to the topographic and climatic situation and the heterogeneous distribution of population and 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 a specific diagnosis, 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 usually 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 by support and guidance to all operators by:
- improving the energy performance of buildings;
- replacing old heavily polluting heating systems and boilers;
- substituting traditional fuel with a cleaner type.

8.2 PROMOTING CLEAN MOBILITY

As shown by the previous chapters of this report, especially in 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 experience is an incentive for all countries to learn from their partners' experience, customizing 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 effect on air quality of shifting to active modes…) to demonstrate the link between mobility choices, air pollution and human health. Discussions and debates with the citizens concerned using 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, adopted after concerted consultation and environmental evaluation could help transform wishes and needs into public policies.

Recommendation 3: 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, adopted after consultation and environmental evaluation.

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 and also 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, regulation or real cost-based taxation systems designed to promote clean mobility. Such tools, within national or regional policies, including 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 also to provide the conditions for innovative solutions to reach the market.

Recommendation 4: Promote clean mobility and zero emission vehicle strategy, e.g. by using a balanced taxation and incentives system to internalise external pollution cost 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,

- encourage implementation of alternative transport technologies and combined transport,
- the integration of 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: Effects on ecosystems 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 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[71].

8.4.1 SETTING UP AIR QUALITY INITIATIVES IN THE ALPS

The aim is to encourage initiatives from local and regional policy makers. It might also help for a better understanding of differences and trying to eliminate inequalities regarding mobility, air pollution and housing. Setting up air quality plans is an obligation in the EU for areas

[71] *For instance it is easier to cycle or walk for people who can afford to live close to urban facilities than for people living in suburbs where housing costs are lower.*

where the EU concentration limits are exceeded (Directive 2008/50/EC). The Alpine-Convention would like to encourage additional initiatives, already inspired by the WHO air quality guidelines.

Recommendation 7: 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, heating 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 on February 25, 2015 (UNECE 2015), involves the parties taking appropriate measures to prevent, reduce and control adverse transboundary effects of their activities. In the 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 the 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 environment, this aspect is already European law. Pollution of the Alps can also originate from outside the Alpine Convention area as exemplified by the convention on long-range transportation of atmospheric pollutants.

Recommendation 8: Contracting parties of the Alpine convention should liaise with neighbouring countries or 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 the objective "c" of the Alpine Convention[72], 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;
- should strive to achieve WHO air quality guidelines.

8.5 INCREASE KNOWLEDGE ON ANTHROPOGENIC CAUSES OF AIR POLLUTION

This report has been sourced from official reports from mandated agencies: EEA, WHO, US EPA, from former reports of the Alpine Convention and also from scientific publications many of them being the result of collaborative European research programmes listed in the

[72] *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 people, animals or plants.*

annex page 110. Most of them were launched during the last two decades. It would not have been possible to write chapters 3, 4 and 6 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 air quality could be better understood by social and political scientists involved in consultations processes. 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 discussion 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, and also on social and political issues linked with it.

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10 ANNEXES

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 odor. 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.[73]

Benzo(a)pyrene (B(a)P): 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.[74]

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.[75]

Carbon monoxide (CO): CO is an odorless, tasteless, poisonous gas, that results from the incomplete combustion of carbon. Inhalation in high concentrations causes central nervous system damage and asphyxiation.[76]

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 the formation of 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. NO_2 is also the main source of nitrate aerosols, which form an important fraction of $PM_{2.5}$ and of ozone.[77]

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. On the other hand, ground level (or tropospheric) ozone is a harmful air pollutant.

[73] https://pubchem.ncbi.nlm.nih.gov/compound/222
[74] https://pubchem.ncbi.nlm.nih.gov/compound/Benzo_a_pyrene
[75] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014JD022144 https://www.hindawi.com/journals/amete/2014/179301/
[76] https://pubchem.ncbi.nlm.nih.gov/compound/281
[77] 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
https://en.wikipedia.org/wiki/NOx

It is not emitted directly into the air but is 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, but 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.[78]

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: PM10 (diameter of 10 micrometres (µm) and smaller), PM2.5 (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.[79]

Perchlorethylene (PERC): PERC is a colorless 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), cleanup activities are more difficult than for oil spills.[80]

Persistent organic pollutant (POP): POPs are 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-magnify and bio-accumulate 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.[81]

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. 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. However,

[78] 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
[79] https://www.epa.gov/pm-pollution/particulate-matter-pm-basics
https://www.nature.com/articles/s12276-020-0403-3
[80] https://pubchem.ncbi.nlm.nih.gov/compound/31373
[81] https://www.who.int/foodsafety/areas_work/chemical-risks/pops/en/

these effects have not been seen in humans. PAHs are a concern because they are persistent and can stay in the environment for long periods of time.[82]

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, 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 sulfur. The main anthropogenic source of SO_2 is the burning of sulfur-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.[83]

Volatile organic compound (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 odors 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.[84]

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82 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
83 https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
84 https://en.wikipedia.org/wiki/Non-methane_volatile_organic_compound
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
https://en.wikipedia.org/wiki/Volatile_organic_compound

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 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 LEC BRENNER 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 measures are 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)

The Espace Mont Blanc Transboundary Cooperation programme is an initiative of transboundary cooperation bringing together Savoie, Haute-Savoie, the Aosta Valley, and Valais. They commit themselves to the protection and enhancement of an emblematic territory, where the exceptional natural and environmental heritage lives alongside economic and tourist activities international in scope.

Espace Mont-Blanc project is a cross-border cooperation initiative bringing together Savoie, Haute-Savoie, Aosta Valley and Valais, engaging in the protection of the exceptional natural and environmental heritage and joint economic and tourist activities. Espace Mont-Blanc has launched a cross-border air measurement campaign since 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 implementation steps to reduce this load (phase 2). The Alps represent a significant sink and a barrier for long-range transported persistent organic pollutants (POPs). This is the most prominent finding of the Monarpop project.

The project investigates Alpine air pollution with POPs and other organic components. 12 partners in the network cooperate via an Alpine Space ProgrammeProgram of the European Union. Plants, soil and air are 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 contributes 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, NOx (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 programmeprogram 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 characterization 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 UND VOTALP II VERTICAL OZONE TRANSPORT IN THE ALPS (SWITZERLAND, AUSTRIA, GERMANY, EU)

Votalp (Vertical Transport of Ozone 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: 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. Funded by the European Commission under Framework Programme IV, Environment and Climate, and by the Government of Switzerland.

The main objectives of Votalp are to investigate the vertical pollutant exchange over Alpine foothills by aircraft measurements including ozone explorations. The "city flags of pollutants" of Milan and Munich in the Alpine region will also be investigated by aircraft measurements and compared with earlier campaigns. A significant increase in concentration can be observed above the Alpine foothills. With these studies the vertical exchange of pollutants over the foothills was characterized 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 almost unique research opportunities.

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

The Global Atmosphere Watch (GAW) programme of the World Meteorological Organisation (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 (HALCIM) / AGAGE MEASUREMENT OF HALOGENATED GREENHOUSE GASES AT JUNGFRAUENJOCH

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 FOEN (Swiss Federal Office for the Environment). Since 2018 in the CLIMGAS-CH project, commonly managed by Empa and FOEN, all non-CO_2 greenhouse gases (halocarbons, methane and nitrous oxide) are analysed and their regional emissions are estimated. This activity is also contributing the common measurement technique of GCMS (gas chromatograph – mass spectrometer) to the AGAGE network. Therefore 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 (BC) and fine particulate matter (PM) 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 [SCIENCE REPORT]

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 PM10 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 gain of 16 points; 57% reduction in particulate matter. When renewing an old appliance with a pellet appliance: energy efficiency gain 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 characterization 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 PM10 concentration levels but also of EC and PAH concentrations. On the other hand, concentrations of PM from biomass combustion do not show any significant trend. Their relative contribution to PM10 has therefore increased: in winter this contribution has risen from 20% in 2009-2010 to 30-35% in 2016-2017. Those 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 PM10 IN METROPOLITAN FRANCE

This study is based on measurements taken as part of the national "CARA Program" (a programme for the characterization 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 Factorization. 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 harmonized 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 stiff reliefs and in conditions of atmospheric stagnation, when the concentrations exceed the regulatory thresholds for air quality.