NILU

Annual report 2020

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Front page photo: The new mast at the Birkenes observatory – seen from above. Photo: Chris Lunder, NILU.

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Editorial

Managing Director Kari Nygaard. Photo: StudioF2, Ingar Næss.

NILU got off to a good start in 2020 with a solid project portfolio. But like many other organisations, we were forced to move most of our operations to home offices, even as our employees strove to keep activities in the chemical and technical laboratories running as normally as possible. The coronavirus epidemic really put NILU's long-term commitment to IT infrastructure and digitalisation to the test.

The employees quickly adapted to the "new normal" of strict infection control measures and demanding working conditions. NILU managed to get through 2020 with surprisingly good adherence to the original plan, achieving both high production and a solid financial result. This would not have been possible without the impressive efforts of all our employees; both those who worked from home and those who kept our laboratories running deserve accolades for helping ensure near-normal operations!

The pandemic has led to behavioural changes – with both positive and negative consequences. This annual report briefly describes some research related to emissions during the coronavirus pandemic. At our flagship observatories in Svalbard, Birkenes, and Trollhaugen, we monitor long-term changes in greenhouse gases and long-range transported pollutants. The major trends continue unabated, with record high levels of greenhouse gases in the atmosphere, and we can only hope that this year will have taught us lessons we can use to help reverse those trends.

NILU does a lot of exciting research related to the indoor environment – and those results become acutely relevant with people spending so much time at home. We can contribute a lot toward achieving a healthier society, despite continued difficulty of obtaining funding for this type of research. However, we perceive a growing interest in the topic, and are determined to contribute actively.

Another priority area where we expect much activity in the next few years involves the circular economy and recycling. NILU is currently expanding its efforts in this field, and we already have several exciting projects underway.

We are happy to note that 2020 was a good year, despite everything. As always, profits from our commissioned assignments are reinvested in research for a better environment.

Happy reading!

Kari Nygaard
adm.dir

Atmospheric research in the time of Covid-19

What happens to air quality and CO2 in the atmosphere when countries close their borders, airplanes are grounded, and commuters stop driving to work? In 2020, the scientists at NILU had an opportunity to find out.

Christine Forsetlund Solbakken
Head of Communications

The Norwegian measures against the coronavirus implemented in March 2020 had major impact on local air quality, according to calculations by scientists at NILU. In the time from 13 to 31 March, transport-related emissions fell by about 15-20% for road traffic and 70-80% for air traffic.

Strong local coronavirus effects

"On Friday 13 March 2020, data from the Norwegian Public Roads Administration's automatic traffic sensors showed a 20% decrease during morning rush hour on Oslo's roads, compared to the previous three Fridays. This led to a 12-13% decrease in exhaust emissions," says Henrik Grythe, scientist at NILU's Urban Environment and Industry Department (INBY).

The volume of traffic was lowest around 18 March, when the average reduction was about 36%. After that, Public Roads Administration data show a slow but steady increase in traffic in all Norwegian cities. During Easter in particular, the number of people out driving in the main cities was unusually large (for the pandemic period). In July there was at times a lot of traffic in the cities, whereas in the autumn there was less traffic than usual, albeit much more than before the summer.

Aided by the emission model HEDGE, Henrik Grythe estimated how the reduction in traffic has affected total NO_2 emissions in Norway. The calculations show a

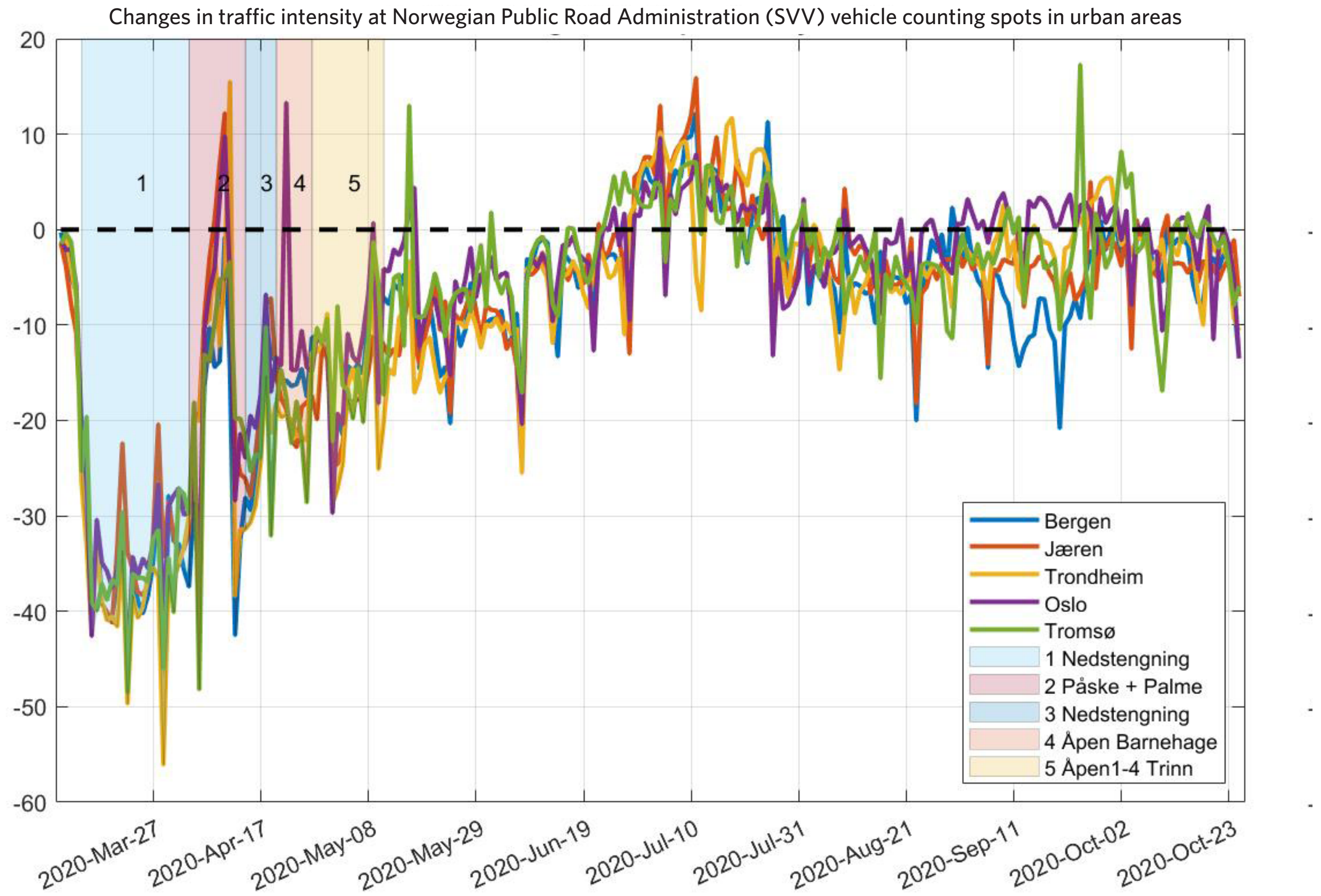


Fig. 1: Changes in traffic intensity at Norwegian Public Road Administration (SVV) vehicle counting spots in urban areas. Data for the largest cities is available starting in March 2020. Note how traffic intensity changed in the four largest cities from March to October. Pastel shading/number codes: 1=Lockdown; 2=Palm Sunday + Easter; 3=Lockdown; 4=Daycare reopens; 5=Primary schools (years 1-4) reopen. (Source: SVV)

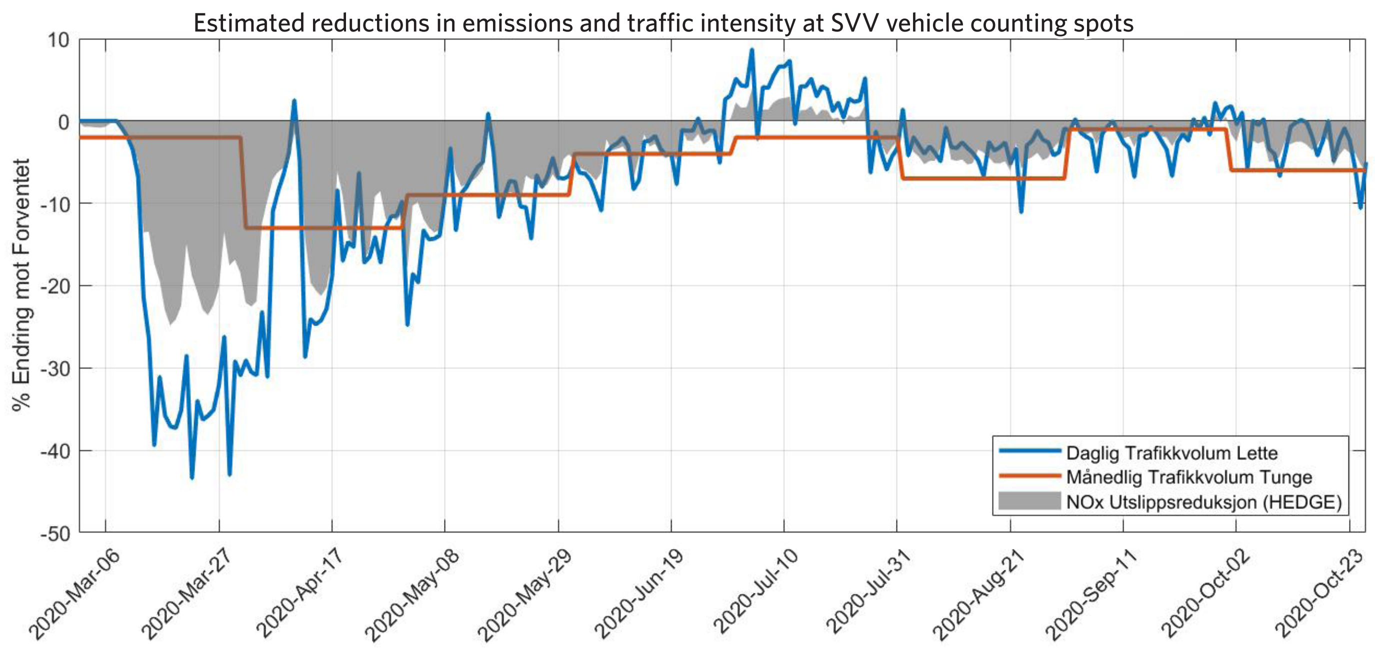


Fig. 2: Estimated reductions in emissions and traffic intensity at Norwegian Public Road Administration (SVV) vehicle counting spots. The blue line shows reductions in small vehicle traffic on a daily basis; the red line shows reductions in heavy vehicle traffic on a monthly basis. The grey area shows an estimate of how NOx emissions fell as a result of reduced traffic after 13 March. (Source: SVV)

marked reduction of NOx emissions after 13 March, but during the Easter holidays we were back to almost normal emission rates. After Easter, the reduction shrinks as traffic intensifies.

Pandemic responses seen from space

Many readers will recall the satellite images showing how NO_2 levels in the atmosphere over industrial parts of China and northern Italy changed during lockdown. Senior scientist Philipp Schneider (INBY) tells us that researchers have been using satellites to monitor air quality since the 1990s. Back then, the spatial resolution of satellite data was extremely coarse, but all that changed when the Sentinel 5P satellite was launched a little more than two years ago.

"Sentinel-5P is equipped with the TROPOMI instrument, specially constructed to study a range of pollutants in the atmosphere," says Schneider. "It measures the visible part of the spectrum but also far into the

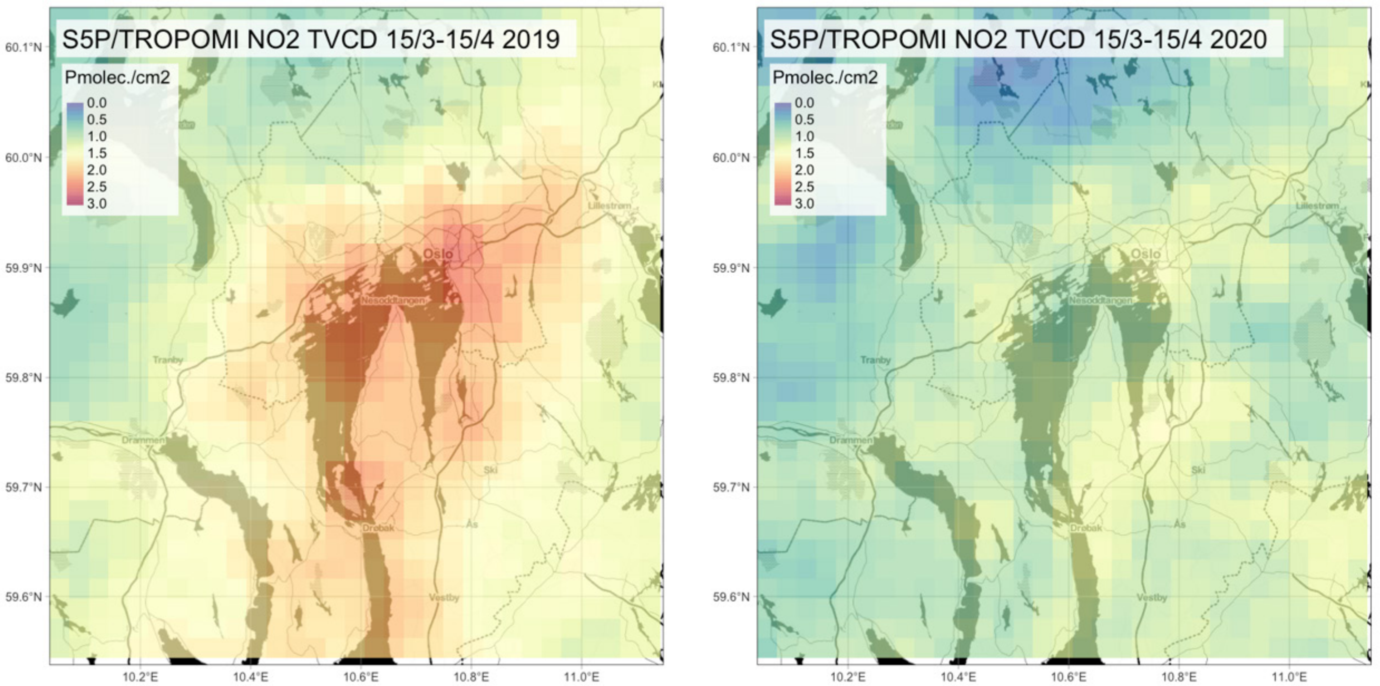


Fig. 3: The maps above are based on the average of all satellite images taken over Oslo between 15 March and 15 April 2019 (left) and the corresponding period in 2020 (right). The reduction in NO_2 concentrations is quite clear, but since pollution levels are relatively low in Norway compared with the rest of the world, the satellite instruments are working at their detection limit. That causes relatively strong uncertainty in the underlying data. (Source: NILU, based on data from Sentinel-5P/TROPOMI)

ultraviolet part of solar spectrum and short-wave infrared radiation."

These detailed data about the wavelength spectrum make it possible for scientists to estimate the concentrations of various atmospheric pollutants, including NO_2.

This type of data can be used to visualise the substantial reduction in NO_2 levels after Covid-19-related restrictions were implemented last year. The satellite images below show NO_2 concentrations in the atmosphere over Oslo in 2019 and 2020.

Schneider emphasises that the estimates of changes in NO_2 levels resulting from pandemic responses are fraught with uncertainty. The reduction does not necessarily result solely from measures to stop the spread of the coronavirus; changes in meteorological conditions could also play a role.

"Data from satellites aren't directly comparable with observations from ground-based measurement stations," he says. "But they give us a unique spatial perspective. To conduct a complete analysis of how Covid-19 affects air quality, we must compile data from satellites, measurement stations, and models."

European air quality in spring 2020

All European countries report national air quality data to the European Environment Agency (EEA). They all use the same measurement methods, and are subject to the same strict quality control. Thus, all European air quality data can be compared across national borders. In the annual report "Air Quality in Europe", for which Research Director Cristina Guerreiro from NILU's Department of Environmental Impacts and Sustainability is main author, summarises the status of European air quality each year.

"In connection with the report for 2020, we decided early on that we had to include a separate chapter focusing on changes in air quality resulting from steps taken to control the coronavirus," says Guerreiro.

All 31 countries report their weekly and monthly data on both NO_2 and the particulate matter fractions $PM_{2.5}$ and PM_{10} to EEA. The EEA "viewer" presents this information in a way that makes it easy to see trends in the largest cities in each country. Figure 4 below shows monthly NO_2 data from January to April 2018, 2019, and 2020 in Norway's largest cities:

Used a NILU model for coronavirus calculations

Guerreiro and her colleagues Sverre Solberg, Sam-Erik Walker, and Philipp Schneider used the Generalised Additive Model (GAM), a statistical model developed by NILU, to calculate how strong an effect the lockdowns in spring 2020 had on European air quality.

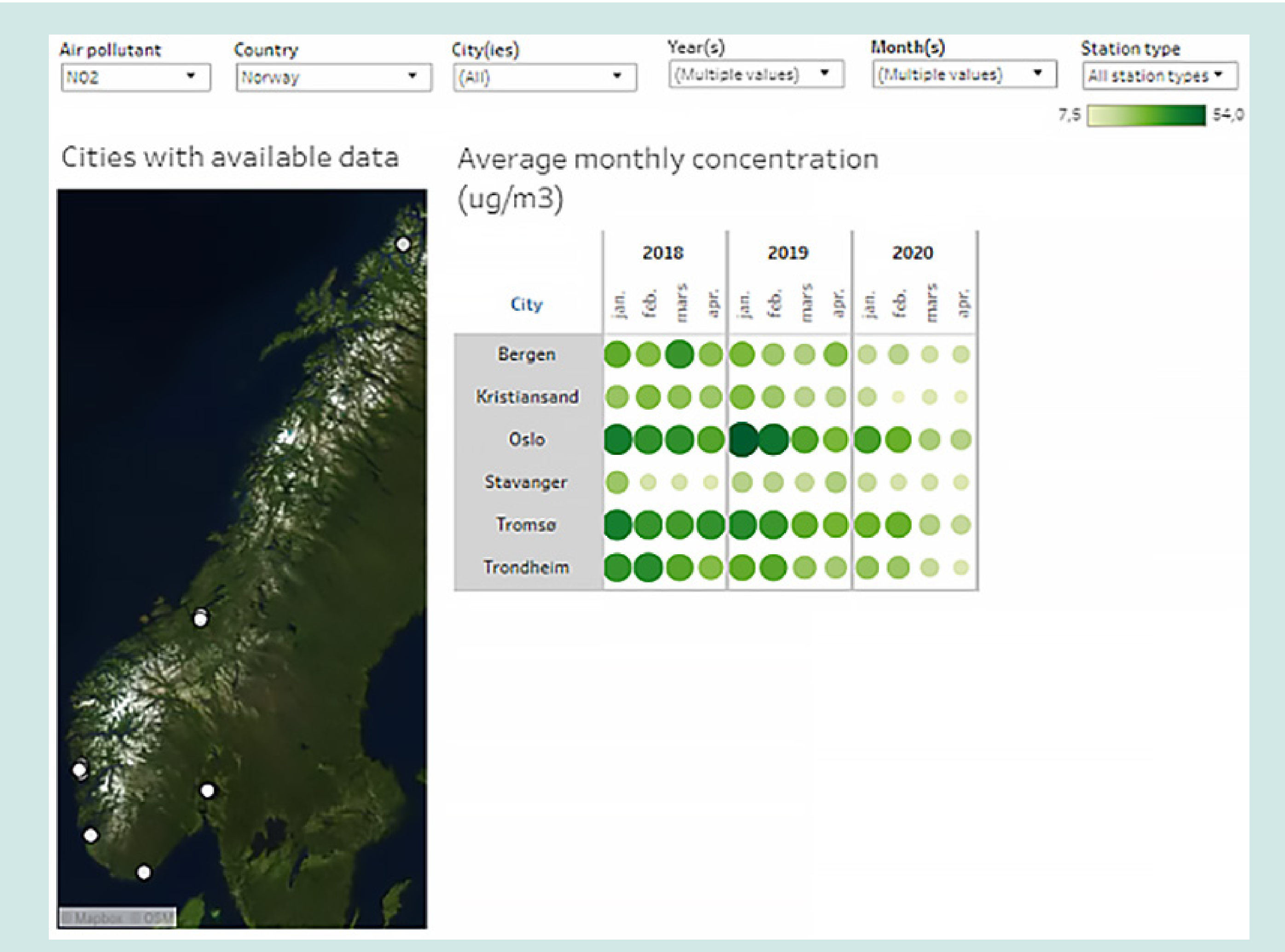


Fig. 4: The figure shows monthly NO_2 data from January to April 2018, 2019, and 2020 in Norway's largest cities:

GAM predicts the concentration of various pollutants at measuring stations all over Europe, while also factoring in meteorological variations. This work resulted in an article published in the scientific journal Atmosphere, entitled "Quantifying the Impact of the Covid-19 Lockdown Measures on Nitrogen Dioxide Levels throughout Europe».

Figure 5 below shows the calculated changes in NO_2 concentrations in a selection of European countries in April 2020:

Source: EEA briefing "COVID-19 and Europe's environment: impacts of a global pandemic"

The calculations reveal substantial differences between countries. The greatest changes in NO_2 levels are found in Spain and France, with average decreases of 61% and 52%, respectively. For comparison, the model indicates that NO_2 levels in Norway fell by 39%.

This agrees well with the traffic counts done in Norway's largest cities (Norwegian Public Roads Administration, 2020). These counts show a 30-40% reduction in traffic during the first week of April, and 10-30% in the last week of April, compared to 2019. (The weeks between cannot be compared because of the Easter holiday.)

"Several European countries – Spain and France, for example – implemented strict lockdown regulations prohibiting people from going out. That led to a sharp decline in the number of vehicles on the roads, and since automobile traffic is the main source of NO_2 pollution in cities, the difference was enormous in some places," says Guerreiro.

What will happen to the air now?

During the summer of 2021, we will hopefully see the end of the Covid-19 pandemic in Norway and elsewhere in Europe. That also means we can gradually get back to "everyday life", commuting to and from work and flying within and outside Norway.

"We won't know the overall effect of the pandemic restrictions until we can see all the emissions calculations plus measured and calculated concentrations of atmospheric pollutants for all of 2020 and 2021," says Henrik Grythe. "When industries and transport activities return to normal, emissions will rise. The question is whether this extraordinary period of limited mobility will have any lasting effect on people's travel habits and, by extension, on air quality."

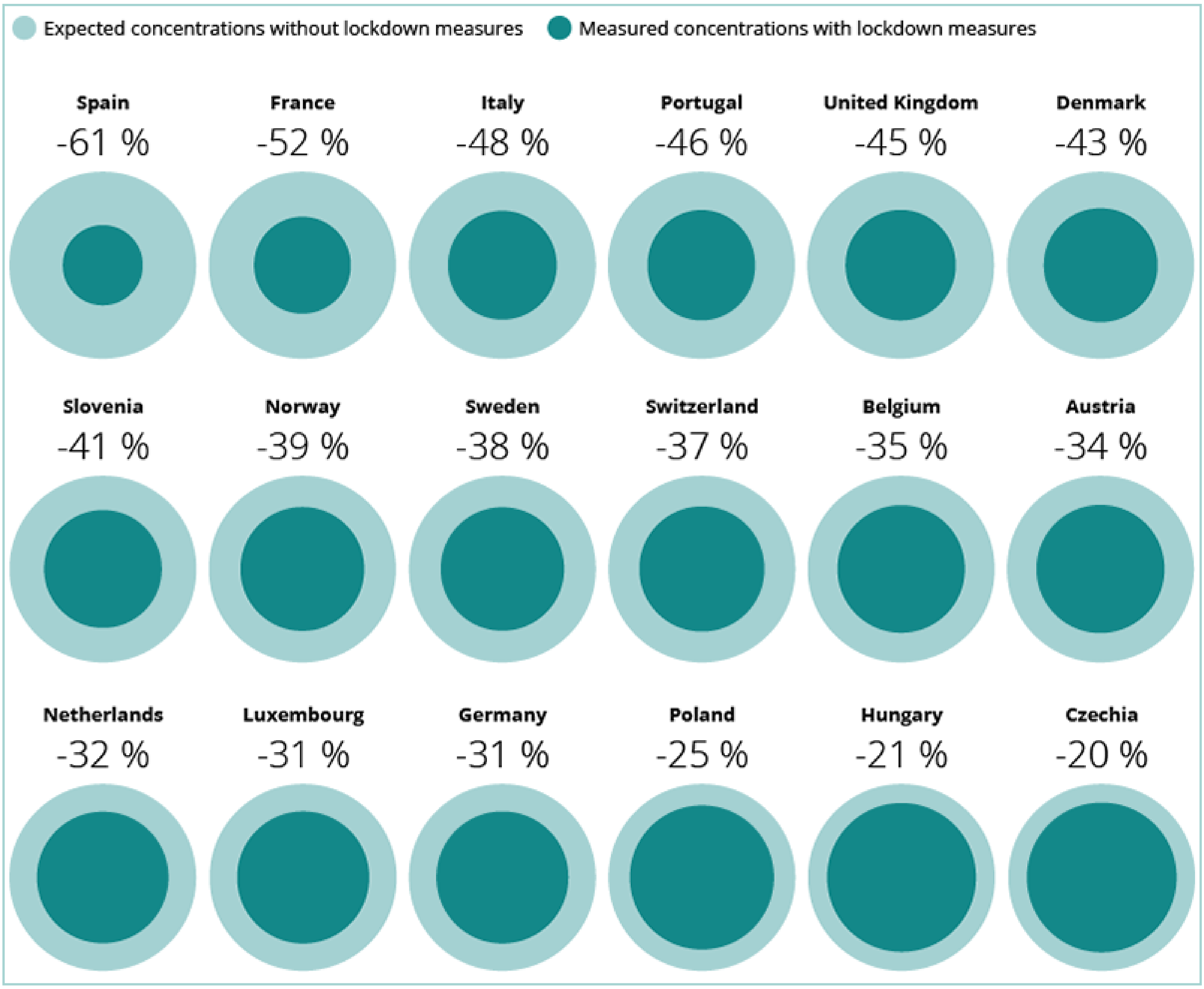


Fig. 5: The figure shows the calculated changes in NO_2 concentrations in a selection of European countries in April 2020. Source: EEA briefing "COVID-19 and Europe's environment: impacts of a global pandemic".

Monitoring at Zeppelin and Birkenes:

New records 19 years in a row

Zeppelin, Svalbard. Photo: Oye Hermansen, NILU

In 2019, the concentrations of carbon dioxide (CO_2) and methane in the atmosphere over Norway were once again record high. For CO_2, it is the nineteenth year in a row, and the year's increase in methane levels was the largest since monitoring began.

Christine Forsetlund Solbakken
Head of Communications

The Norwegian Environment Agency published the latest report from its monitoring programme for greenhouse gases and particles in the atmosphere on 20 November 2020. The measurements are carried out by NILU on commission from the Environment Agency.

All year long, the concentrations of greenhouse gases are monitored at the Zeppelin observatory in Svalbard and the Birkenes observatory in Aust-Agder. These stations and their measurement data are part of a global network of stations that monitor greenhouse gas trends in the atmosphere.

New CO_2 records every year since 2001

"We have measured record high CO_2 levels at Zeppelin every year since 2001," says senior scientist Cathrine Lund Myhre, who oversees the programme. "As long as the amount of CO_2 we emit exceeds the amount that disappears, atmospheric levels will continue to increase."

The observations from 2019 show an annual average CO_2 concentration of 411.9 ppm (parts per million) at Zeppelin Observatory near Ny-Ålesund, Svalbard. That is 2.6 ppm higher than in 2018, consistent with the increasing global average reported by the World Meteorological Organization (WMO).

At Birkenes in Agder, the concentration is 416.1 ppm, 0.9 ppm higher than the year before.

CO_2 levels too high to meet the goal of the Paris Agreement

An important goal of the Paris Agreement is that global warming should be kept below 2 degrees C, and preferably below 1.5 degrees C. If we are to attain the 2-degree goal, CO_2 concentrations must stabilise at a level below 400 ppm. To meet the objective of the Paris Agreement, the atmospheric concentration must not merely stop rising: it must decrease.

According to WMO, the global annual average passed 400 ppm in 2015. Unfortunately, atmospheric measurements over Norway show that both CO_2 and methane levels continue to increase year by year.

Largest annual increase in methane since 2001

The concentration of methane has also increased in recent years. Methane is 30 times more effective as a greenhouse gas than CO_2, but does not remain in the atmosphere as long.

"With methane emissions increasing this much, we will have to reduce CO_2 emissions more than we originally assumed if we are to have any chance of reaching goal of the Paris Agreement," says Lund Myhre.

The annual average methane level was measured as 1961.2 ppb (parts per billion) at Birkenes, and 1952.9 ppb at Zeppelin.

Relative to the 2018 levels, this represents a 14.3 ppb increase at Zeppelin – the largest annual increase ever measured. The increase at Birkenes was also substantial, at 8.2 ppb.

The increase in the global average methane concentration from 2018 to 2019 was equally large, 8 ppb, corresponding to the increase at Birkenes, but considerably smaller than at Zeppelin.

Methane sources uncertain

"This increase in methane levels is still a bit of a mystery to climatologists. We don't know for sure whether the increase can be attributed to emissions caused by human activity, or if climate change has triggered natural processes that release more methane into the atmosphere," says Cathrine Lund Myhre.

Anthropogenic methane emissions include release from combustion of coal, oil, natural gas, and biomass, leakage from pipelines and other petrochemical installations, release from ruminants, rice paddies, and landfills.

On top of that comes methane released from natural sources. These contribute an estimated 40% of total annual methane emissions.

"A warmer and wetter climate can release more methane from natural sources, like increases in wetlands and thawing of permafrost in taiga and tundra. If more methane is released from these sources, it will be difficult for us to stop it. It could also have a positive feedback effect, leading to additional climate change," says Lund Myhre.

The consequences Lund Myhre is referring to include increased risk of flooding and extreme precipitation events leading to property damage, rising sea level, drought, and changed living conditions for humans and animals. Other effects we have not yet predicted may emerge and they can surprise us.

Global greenhouse gas report from WMO

The World Meteorological Organization (WMO) published its Report on Greenhouse Gases for the year 2019 on Monday, 23 November 2020. It is based on the annual averages of measurements taken around the world, including the Norwegian stations in Svalbard and Agder.

About the units used for greenhouse gas concentrations

CO_2 is measured in ppm (parts per million). Thus, when the atmospheric concentration is 400 ppm, there are 400 molecules of CO_2 for every million molecules of air.

Correspondingly, methane is measured in ppb (parts per billion), in other words per thousand million, 10^9. When the atmospheric concentration is 400 ppb, there are 400 molecules of methane for every thousand million molecules of air.

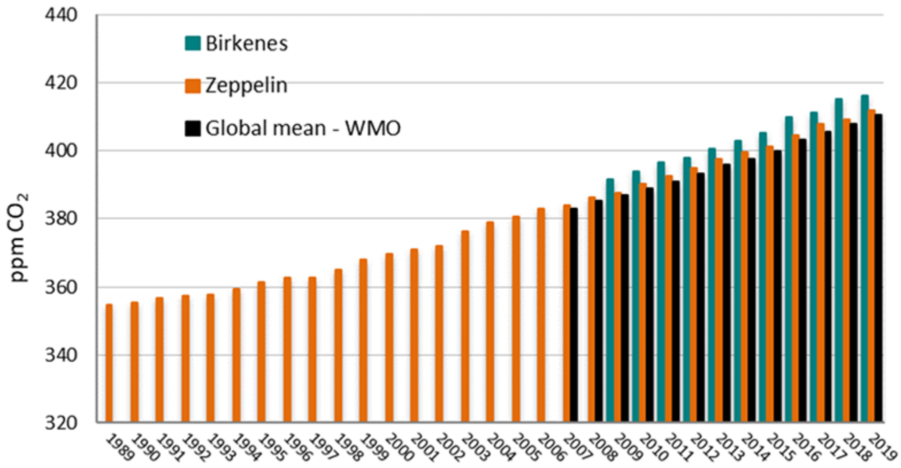


Figure 1: Annual mean value for carbon dioxide (CO_2) on Zeppelin (orange bars) and Birkenes (green bars), compared to global mean value from the World Meteorological Organization, WMO (black bars). Source: NILU / Norwegian Environment Agency

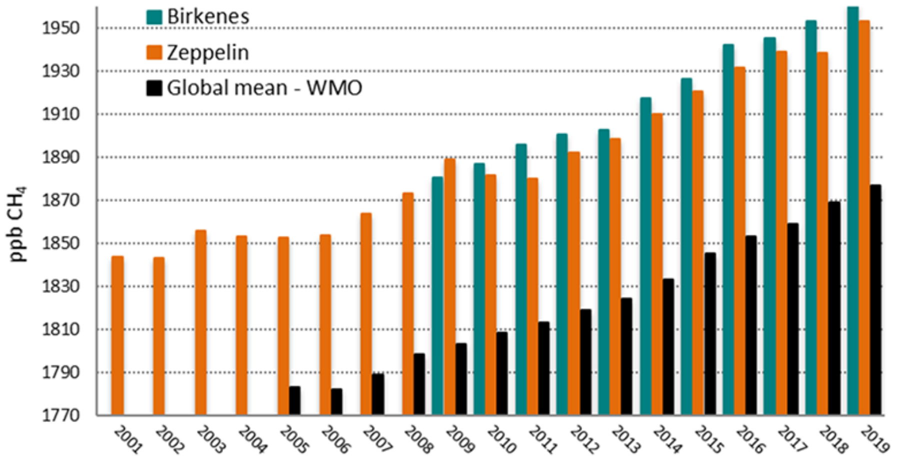


Figure 2: Annual mean value for methane (CH_4) on Zeppelin (orange bars) and Birkenes (green bars), compared to global mean value from the World Meteorological Organization, WMO (black bars). Source: NILU / Norwegian Environment Agency

Birkenes. Photo: Harald Willoch, NILU

Monitoring at Zeppelin and Birkenes: New records 19 years in a row (continued)

Meet the record holders

The observations from 2019 reveal new record high levels of most of the 46 greenhouse gases included in the monitoring programme. The largest and most worrying increases involve the greenhouse gases CO_2, methane, and nitrous oxide (also known as laughing gas). All of them are natural constituents of the atmosphere, and are important in our planet's biogeochemical cycles.

Greenhouse gases absorb heat radiated from the earth and keep the warmth close to the surface. Without this phenomenon, often called the greenhouse effect, life on Earth would not be possible.

But greenhouse gas monitoring shows that human activities are generating excess CO_2, methane, and nitrous oxide and emitting them into the atmosphere. Rising atmospheric concentrations of these gases lead to a gradual increase in temperature, which in turn causes imbalance in the systems that regulate Earth's climate and environment.

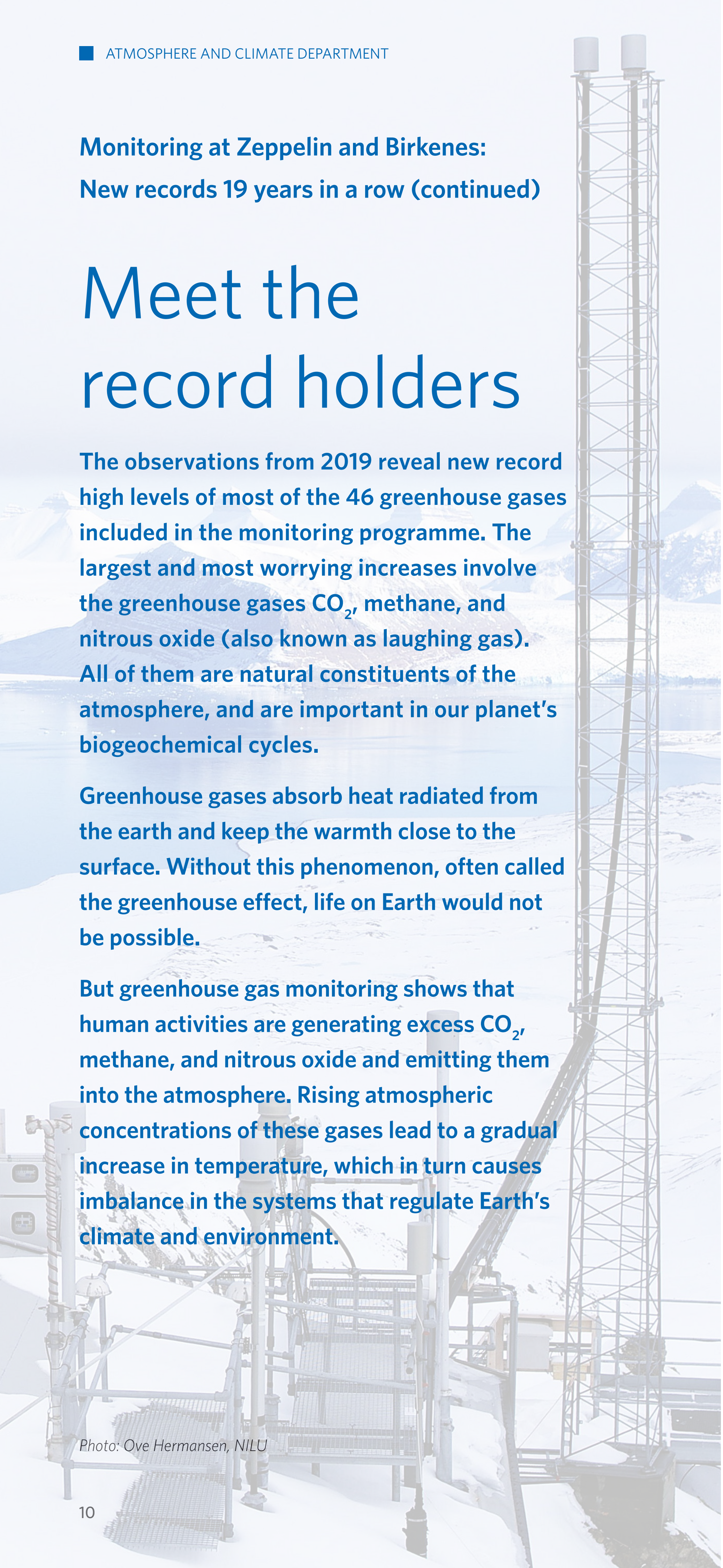


Photo: Ove Hermansen, NILU

Carbon dioxide CO_2 – world champion of greenhouse gases

Main sources:
Anthropogenic sources of atmospheric CO_2 are mainly related to combustion of fossil fuels such as oil, gas, and coal. Other sources include various industrial processes and deforestation. Natural sources of CO_2 include various processes in forests, oceans, and on land.

Carbon dioxide is the most important of the greenhouse gases and is the largest contributor to human-induced climate change (about 65%). This means that reducing emissions of CO_2 is the most important course of action towards meeting the 2-degree goal.

Scientists state that in pre-industrial times, before 1750, atmospheric CO_2 concentrations were about 280 ppm. For the year 2019, the World Meteorological Organization reported a global average of 410.5 ppm.

Over the past 60 years, the annual increase in atmospheric CO_2 has proceeded 100 times faster than during natural increases in the past, such as those that occurred at the end of the Ice Age 11 000-17 000 years ago.

According to the Global Carbon Project, emissions of CO_2 from fossil fuels during 2019 were 61% higher than in 1990. However, emissions are likely to be 7% lower in 2020 than in 2019, partly because of the pandemic.

Sources:

- Global Carbon Project, the Global Carbon Budget 2020: https://www.globalcarbonproject.org/carbonbudget/
- https://www.environment.no/

- WMO Greenhouse Gas Bulletin (GHG Bulletin) - No. 16: https://public.wmo.int/en/resources/library/wmo-greenhouse-gas-bulletin-no16-november-2020
- Lindsey, Rebecca. *Climate Change: Atmospheric Carbon Dioxide:* https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide, accessed October 2020
- Monitoring of greenhouse gases and aerosols at Svalbard and Birkenes in 2019: https://www.nilu.no/pub/1850243/

Methane

CH_4

– more than just cows

Main sources:
Methane comes from both human activities and natural sources, which respectively contribute about 60% and 40% of emissions in the atmosphere today. Anthropogenic sources include oil and gas installations, coal mines, fires, landfills, rice paddies, and domesticated ruminants. Natural sources include wetlands, wild ruminants, termites, and possibly thawing permafrost in taiga and tundra.

Methane is considered the second most important greenhouse gas. Seen over a full century, methane has 32 times greater warming effect on the atmosphere than CO_2, so it is an important part of the climate budget. Over shorter time spans, it is even more important.

However, methane in the atmosphere breaks down in about a decade – much more quickly than CO_2. Consequently, if we manage to reduce methane emissions, the effect will quickly become apparent.

If methane concentrations continue rising at the current rate, far greater reductions in CO_2 emissions will be needed to limit global warming to 2°C. This has not been factored into the strategies designed for reaching the Paris Agreement goals.

Prior to the industrial revolution, around 1750, methane levels in the atmosphere were about 700 ppb. After that, levels began rising until the end of the 1990s. Monitoring data from both Zeppelin Observatory in Svalbard and from the rest of the world show essentially stable methane levels from 1998 to 2006. In 2007, levels began rising again by an average of 6 ppb per year. In 2014, the increase accelerated to 7-10 ppb per year.

At present, atmospheric scientists are not sure what has been causing methane levels to rise in recent years. Clearly, however, it is incredibly important to figure out whether the increase is caused by climate-induced changes in natural sources, or by emissions related to human activities. Only the latter can be regulated: natural emissions are beyond our power to control.

Sources:

- https://www.environment.no/
- https://nilu.com
- Monitoring of greenhouse gases and aerosols at Svalbard and Birkenes in 2019: https://www.nilu.no/pub/1850243/

Laughing gas

N_2O

– no laughing matter

Main sources:
The most important sources to N_2O (dinitrogen oxide/nitrous oxide) related to human activity are production and use of nitrogen-based fertilisers. Other sources include manure, biomass burning, sewage, compost, and catalytic converters in the transport sector. Nitrous oxide is also emitted naturally as a result of processes in oceans, forests, and rainforests.

Nitrous oxide is perhaps the least well known of the important greenhouse gases. Of the total global warming caused by "the big three" (carbon dioxide, methane, and nitrous oxide), nitrous oxide contributes about 7%.

Seven percent may not sound like a lot, but emissions of nitrous oxide owing to human activities (mainly agriculture) have increased worldwide by 30% since the beginning of the 1980s.

The rate of increase has outstripped all the emission scenarios outlined by the IPCC. Nitrous oxide emissions constitute a threat to achieving the Paris Agreement goal to limit global warming to less than 2°C.

If current nitrous oxide emission trends continue, even greater reductions of the other most important greenhouse gases – CO_2 and methane – will be required to limit warming to 2°C.

Most anthropogenic emissions of nitrous oxide are caused by use of nitrogen-based fertilisers. Synthetic fertilisers are needed to produce enough food for the world's entire population. This makes reducing agricultural nitrous oxide emissions quite problematic.

One possibility is to use nitrogen-based fertilisers more effectively, as has been done in Europe since the 1990s. But increased effectivity in use of synthetic fertilisers is not enough to reduce nitrous oxide emissions: we must do more. We must also reduce food waste and adjust our dietary habits, for example by eating less meat. That would in fact have a beneficial effect on both nitrous oxide and methane.

Sources:

- Tian, H., Xu, R., Canadell, J.G. et al. *A comprehensive quantification of global nitrous oxide sources and sinks.* Nature 586, 248–256 (2020). https://doi.org/10.1038/s41586-020-2780-0
- Thompson, R.L., Lassaletta, L., Patra, P.K. et al. *Acceleration of global N_2O emissions seen from two decades of atmospheric inversion.* Nat. Clim. Chang. 9, 993–998 (2019). https://doi.org/10.1038/s41558-019-0613-7
  https://www.environment.no/

The benefits and costs of generating energy from renewable sources

Renewable energy sources (RES) such as wind or water have become increasingly important for the energy sector in recent decades. But does increased use of RES for electricity production have exclusively positive impacts?

Sonja Grossberndt
scientist

Moving from fossil fuels to renewable energy sources is a key part of climate change mitigation strategies worldwide. In 2020, NILU studied the environmental costs and benefits associated with the increased use of renewable and low-carbon energy sources for electricity production in the European Member States (EU-27). The study was part of NILU's work carried out as partner in the European Topic Centre for Climate Change Mitigation and Energy (ETC/CME). The Topic Centre was funded by the European Environment Agency (EEA).

Environmental footprint of electricity production

"In order to estimate the environmental footprint of an economic activity, such as generation of electricity, we use the method Life Cycle Assessment (LCA)," explains Dr Evert Bouman. Bouman is senior scientist at NILU's department for Environmental Impacts and Sustainability and leader of the ETC/CME study.

"LCA assesses environmental impacts associated with all stages of a product's lifetime, such as the extraction of raw materials, processing, manufacture, distribution, use, and its disposal/recycling. This process covers all stages in the life cycle – from 'cradle to grave'," continues Bouman.

Using an LCA model, life cycle environmental impacts were calculated for annual electricity production in the EU-27 across a range of impact categories, such as climate change and particulate matter formation. The results were subsequently compared to a "no-action" counterfactual scenario, which describes a European electricity system where the level of electricity production from renewable sources was kept the same as it was in 2005.

Comparing the life cycle impact potentials in the two scenarios allowed Bouman to calculate benefits and costs associated with the increased introduction of renewable energy sources in the European electricity mix.

Reduced impacts through RES...

"Our results show that the impact of electricity production differed considerably depending on the energy source being assessed. In addition, impact indicator values for single energy sources varied considerably across different Member States and years. This depended, for example, on the annual variation in efficiency of fuel combustion and utilisation of available electricity production capacity," explains Bouman. "Overall, we see that the increased use of renewable energy sources has led to an absolute decrease in potential negative impacts for most impact indicators investigated in the study."

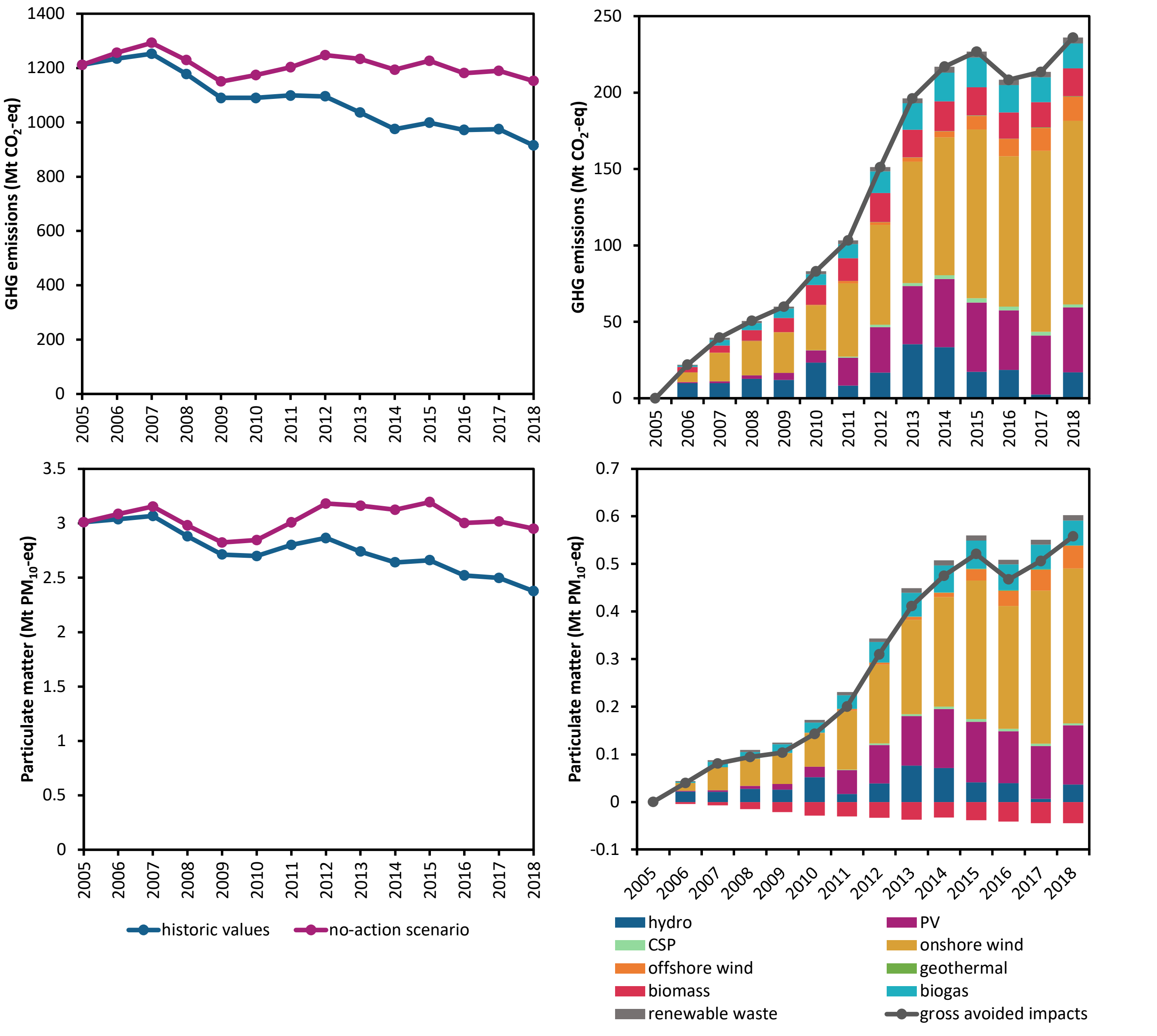
He explains that there are two key contributing factors. Firstly, the use of renewable energy sources (RES) is generally less polluting than the use of fossil sources for energy generation. Secondly, the share of RES in the European electricity mix has increased considerably in the period 2005-2018. The increased production of onshore wind power and solar photovoltaic power, followed by electricity production from bioenergy sources biogas and solid biomass, thus contributed to lower life cycle impacts, as indicated by a decrease in total greenhouse gas or particulate matter emissions.

...but there are trade-offs

The figures below show that the use of RES has led to a decrease in greenhouse gas (GHG) emissions. The difference between the two scenarios presented on the left can be interpreted as "gross avoided impacts".

The figures on the right show the individual contribution of RES to the annual avoided impacts. All electricity from renewable sources contributes to avoided impacts in terms of GHG emissions. For particulate matter formation, however, the increased combustion of biomass such as wood contributes negatively to avoided emissions. This trade-off of biomass combustion for electricity is however more than compensated for by positive contributions from the other renewable energy sources.

Bouman's study revealed other effects caused by the increased use of



The figures on the left show developments in greenhouse gas emissions (expressed as Mt CO_2-eq) and formation of particulate matter (expressed as Mt PM_{10}-eq) due to annual electricity production in the EU-27 for both the actual emissions and the "no-action" counterfactual scenario.

RES, such as heightened potential for ecotoxic releases to freshwater (e.g., related to value chains associated with the production of solar photovoltaic power) and a larger "land footprint" associated with electricity production. The "land footprint" refers to the area of land occupied over time and is mainly related to electricity production from solid biomass, for example through the area dedicated to growing trees for fuel. These effects are also called "environmental problem shifting" – unforeseen negative consequences in the use of renewable energy sources.

The way forward

"The report shows that the increasing production of electricity from renewable sources has decreased greenhouse gas emissions significantly in the period between 2005-2018, as it has substituted the use of fossil fuel," concludes Bouman. "We could also identify avoided formation of particulate matter, acidification and eutrophication."

However, Bouman says that these benefits come at a cost of increased toxicity and land occupation. Despite trade-offs, Bouman could also demonstrate that the positive effects of individual renewable energy sources can compensate for negative effects associated with other renewable energy sources. The report shows the importance and necessity of assessing RES holistically, since most climate change mitigation options have an upside and a downside, which then has serious consequences for environment and humans.

"The report has been published by the ETC/CME. We hope that it provides valuable information for policy makers as they continue shaping the use of renewable energy sources in Europe," Bouman concludes.

Read more in the report "A life cycle perspective on the benefits of renewable electricity generation", ETC/CME EIONET report 4/2020: https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-report-4-2020-a-life-cycle-perspective-on-the-benefits-of-renewable-electricity-generation.

Photo: Jøran Solnes Skaar, NILU.

Innovative infrastructure for air quality monitoring in Norwegian municipalities

Low-cost sensor networks for air quality are currently of great interest to many municipalities. These networks could potentially provide air quality data with high temporal and spatial resolution, and offer municipalities novel means of providing environmental information to the public.

Sonja Grossberndt
Scientist

To support this, NILU is currently developing an appropriate infrastructure for managing data collected by these sensors. Ultimately, the goal is that the infrastructure should be able to manage data from different environmental sensors.

"At NILU, we have been working with low-cost sensor platforms for a decade now. What we know is that, from a research perspective, these platforms still face several challenges", says Dr Nuria Castell. She is senior scientist at the Urban Environment and Industry Department at NILU and has been working with application of low-cost sensor platforms for many years. Currently NILU is leading a number of projects that focus on the use of low-cost sensor platforms.

Cost-effective and open

"Based on our experience, the quality of data from low-cost sensors is still not comparable with data from the official monitoring stations", Castell explains. "In addition, sensor networks require adequate infrastructure to guarantee connectivity and a smooth transfer of data."At the same time, municipalities have their own requirements.

"For us, it is important to have control over the urban air quality data from the network of sensors owned by the municipality", explains Susanne Lützenkirchen from the Agency for Urban Environment in Oslo. "We need to have a good overview over the data flow and data processing – from the sensors to the platform and then to the users. It is also crucial to know the quality of the data to understand what the data can be used for."

Oslo municipality is cooperating with NILU in the iFLINK project. In iFLINK, NILU is helping municipalities to deploy sensor networks and is developing a novel data infrastructure to collect, store, analyse, visualise and disseminate environmental sensor data in near real time. Both the network and the infrastructure are being tested in Bergen, Bærum, Drammen, Kristiansand, and Oslo.

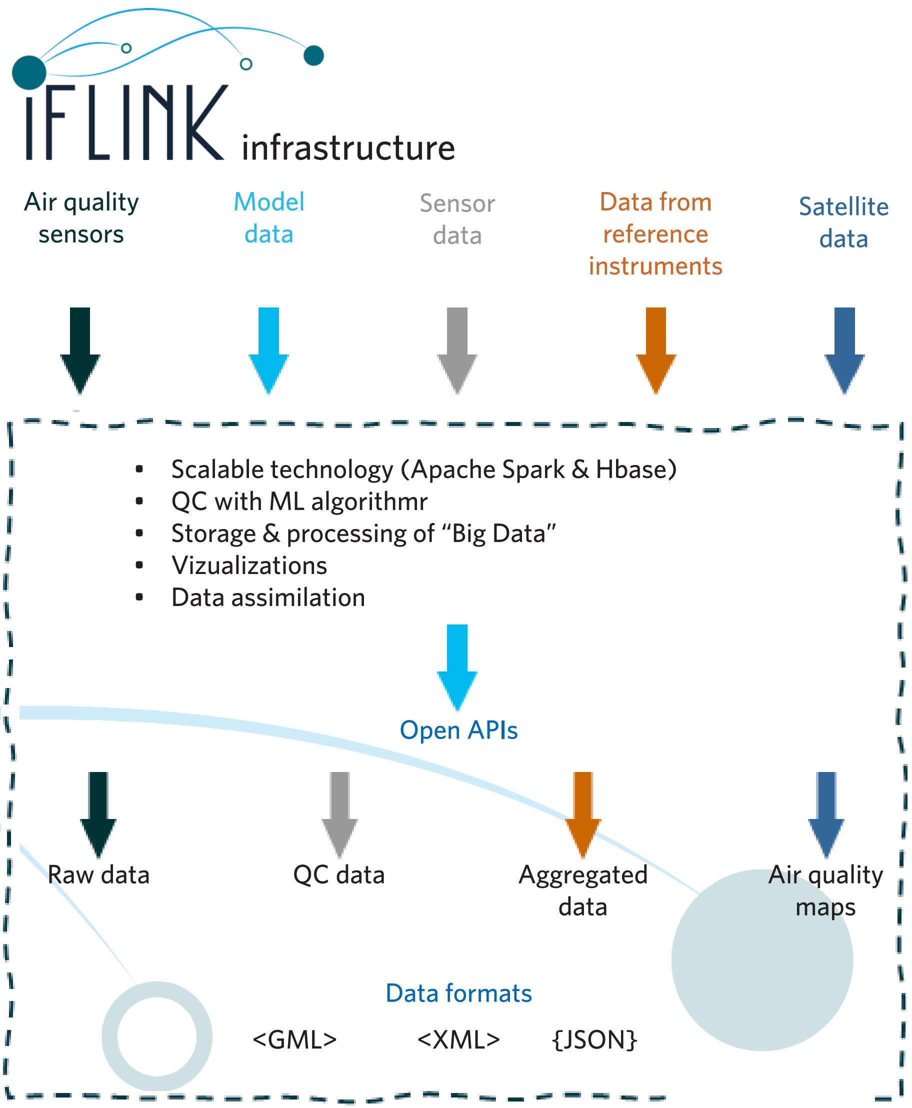
Great expectations

"We have to ensure the quality of the information we provide to the public; it must be reliable and scientifically sound", Lützenkirchen continues. "We also require open access to the data at any time during the process to be able to use them in the format we need

In the long run we hope that we can use sensors for measuring a range of different environmental factors (e.g., noise, greenhouse gases, water quality, traffic) and combine several data sets in order to obtain an even better overview and provide even better information to the public."

Faced with this laundry list of requirements from both a scientific and a user perspective, the NILU scientists took on the challenge and started working on a low-cost sensor network infrastructure. It should be open, scalable, and able to integrate and quality control data from different sensors, while simultaneously delivering high-resolution outputs. The data should be available in different formats and at various processing stages for municipalities and – eventually – also for citizens and other users.

The work focused on two interconnected parts: the low-cost sensor network and the data infrastructure.



Setting up a low-cost sensor network

"First, we had to comply with the municipalities' public procurement process, which can be quite time-consuming. We then had to define the sensor specifications and requirements that were important for our infrastructure and met the needs of the municipalities", explains Castell.

This required specifying not only which air quality parameters should be monitored, but also, and more importantly, issues related to data collection and transfer.

"Many companies provide a 'black box' where the data processing and quality control procedures are not transparent", she continues. "But for our purposes it is important that we know what is done to the data inside this 'black box', so we know which algorithms we have to apply for smart calibration and quality control. For this reason, it was important that we chose sensor platforms that could push the data to our platform, and that the data would be openly accessible."

Once the sensor platforms arrived, Castell and her colleagues had them tested against reference instrumentation. Sensor units from six different manufacturers were tested, and for some atmospheric components (nitrogen dioxide [NO_2] and small particles [$PM_{2.5}$]) the sensors showed good agreement with the reference data. However, the sensors had limited ability to correctly measure other components, such as PM_{10} (coarse particles from road dust, for instance). Also, data quality varied depending on meteorological conditions, type of particle that was being measured and concentration levels.

For example, sensor readings of particles were affected by high relative humidity, and NO_2 sensors did not function well when concentrations were very low or ozone concentrations were very high.

"For these reasons, NILU applied our own suitable regression and machine learning algorithms to develop smart calibration algorithms to improve the data quality. Our aim is to develop standard operating procedures and computational algorithms that can be applied in other municipalities", Castell explains.

Innovative data infrastructure

Based on these requirements, NILU has developed standardised infrastructure for collecting sensor data and processing them.

The software interface "REST API" is web-based, allowing connection of different types of low-cost sensors regardless of their data format and location. Sophisticated data assimilation algorithms integrate large amounts of different sensor data with a variety of existing data sources in real time. All data are available at different stages of processing (raw data, GIS data, etc.) through another API. This allows the municipalities to provide effective and efficient information solutions to their citizens, such as climate dashboards (panels that show a compilation of different data) and pollution maps.

In the long run, this solution can help public and private actors develop real-time environmental services related to e.g., air quality, climate change, or noise, with a seamless interface to any local smart city solution.

"In 2020, we dedicated a lot of time to developing the database and the algorithms for calibration as part of the iFLINK project", says Castell. "In 2021, we will set up large sensor networks with different air quality sensors in the participating municipalities. In Oslo, we will set up an even larger network as part of both iFLINK and the European project SensEURcity (see text box). We are cooperating with Ruter and Urban Infrastructure who are kindly allowing us to mount our sensors on bus stops and city bike stands and providing them with electricity. The data we collect will help to test the infrastructure and improve the algorithms in the database."

The data platform that has been developed in the iFLINK project is already being used in several new research projects with focus on use of low-cost sensor networks, such as the NordicPATH project (see text box).

Opening for citizen engagement

For 2021, NILU is planning to use the new infrastructure to test different ways for citizens to engage in the measurement activities and in utilising the data. As part of the NordicPATH project, a highly engaged municipality and user community in Kristiansand have already started measuring air quality with low-cost sensors in different areas that are not covered by official monitoring stations. The measurement data are already being pushed into the new database.

As part of the EU ACTION project (see text box), school classes in Oslo will build PM sensors and push the measurement data via API to NILU's platform. The platform will also be an integral part of activities in Oslo, Kristiansand, and Bergen within a new project, URBANITY (see text box), which is a continuation of the work that began with iFLINK. This project is funded by the Research Council of Norway and will start in September 2021. The project will focus on engaging citizens in monitoring of air quality by using NILU's iFLINK platform.

iFLINK

The aim of the iFLINK project (Innovative management of air and environment in Norwegian municipalities) is to develop a cost-effective open infrastructure for machine-to-machine communication, also called "Internet of Things", to be able to manage local environment-related data from low-cost sensor platforms. NILU is project owner, with Oslo municipality being the project lead. Other project partners include Telia, Telenor, OsloMet and Vicotee AS. The project also receives funding from the Research Council of Norway.

SensEURcity

In this project, two departments under the EU's Directorate-General (the Joint Research Centre and the Environment department) will evaluate the use of low-cost sensor systems for air quality and compare them with traditional air quality monitoring methods. Partners are VITO (coordination, Belgium), Flanders Environment Agency (Belgium), Institute for Medical Research and Occupational Health (Croatia), and NILU (Norway).

ACTION

The EU Horizon 2020 project ACTION transforms the way we do citizen science (CS) from a mostly scientist-led process to a more participatory, inclusive, citizen-led one. It acknowledges the diversity of the CS landscape and the challenges CS teams must meet as their project evolves. NILU is leading an initiative where high school students build and code their own PM sensors and design their own air quality research projects. https://actionproject.eu/

NordicPATH

NordicPATH's overall objective is to establish a new model for citizen participation and collaborative planning in the Nordic countries. The project is focused on urban air quality and the interlinked challenge of climate change. NordicPATH is funded by NordForsk and led by NILU; partners include IVL (Sweden), University of Gothenburg (Sweden), Maptionnaire (Finland), and University of Aalborg (Denmark). https://nordicpath.nilu.no/

URBANITY

URBANITY aims to empower citizens to take a leading role in the production of high-resolution data, evidence, and knowledge around air quality and greenhouse gas emissions, and to design new mobility solutions in their own neighbourhoods. It is funded by the Research Council of Norway with Oslo municipality as project owner. The scientific part is led by NILU. Other partners are OsloMet, TØI, the municipalities of Oslo, Bergen, Kristiansand, and Lillestrøm, Ruter AS, Telenor, and Vicotee AS.

Photo: Colourbox

HAPADS: A mobile air quality monitoring platform

Imagine this: You're driving your lorry down the street, and you get a warning about high levels of NO_2 in the air of the cab. Immediately, the vehicle's built-in air conditioning system switches to self-contained ventilation, filtering out the unhealthy gas and preventing entrainment of more NO_2.

Christine Forsetlund Solbakken
Head of Communications

"This could be reality in a few years", says Tuan-Vu Cao, researcher at NILU and co-manager of the project HAPADS: "Highly Accurate and Autonomous Programmable Platform for Providing Air Pollution Data Services to Drivers and the Public".

In this project, scientists from Gdańsk University of Technology, AGH University of Science and Technology, Wrocław University of Science and Technology, LESS Industries, UiT the Arctic University of Norway, and NILU collaborate. Their aim is to develop a new and highly accurate autonomous mobile air quality monitoring platform for nitrogen dioxide (NO_2) and particulate matter (PM_{10}, $PM_{2.5}$, PM_1).

Several automobile manufacturers already offer air quality monitoring, but these monitors are integrated into the air conditioning systems and are not available separately. HAPADS will provide a retrofittable solution for both in-cabin air quality monitoring and accurate real-time outdoor pollution measurement through sensors deployed on the vehicle.

HAPADS mobile sensors utilise Edge Intelligence that will allow local data processing and enhance sensor performance:

- Reduced volume of data to transfer through wireless network
- Enhanced data quality
- Shorter response times
- Real-time decision-making

The innovation in HAPADS is not restricted to the air quality monitoring platform itself, as HAPADS will develop novel sensing technologies. These technologies will avoid the problems faced by the low-cost sensors currently available on the market, which use electrochemical cells for gases and nephelometers for particulate matter.

Another bonus of using small, mobile air quality sensors is that the data they provide will improve the spatial resolution and help identify pollution hotspots. In short, HAPADS will contribute with air quality data at higher temporal and spatial resolution.

"Our goal is to enable end-users such as drivers, transport companies, municipalities, and the general public to make information-driven decisions to mitigate air pollution exposure", says Cao.

HAPADS is funded under EEA and Norway Grants, 2020-2023.

Read more: https://hapads.eu/

Tuan-Vu Cao Photo: Finn Bjørklid, NILU

Evaporation of volatile chemicals from soft, fun toys

The bags containing toys and air samplers were filled with pure, VOC-free air and sealed. Then they were left at room temperature in the laboratory for 24 hours before the air samplers were taken out and analysed. Photo: Ingunn Trones, NILU.

Have you heard of "squishies"? They're those soft, brightly coloured foam toys that have taken over Norwegian toy stores and children's rooms in recent years. Children play with them, collect them, and cuddle with them. But is that safe?

Christine Forsetlund Solbakken
Head of Communications

"Not necessarily," says Pernilla Bohlin-Nizzetto, senior scientist at NILUs Environmental Chemistry Department.

Soft, perfumed toys

On behalf of the Norwegian Environment Agency, Bohlin-Nizetto and senior scientist Norbert Schmidbauer at NILU's Department of Monitoring and Instrumentation Technology have studied a selection of toys for children under three, including "squishies".

The objective was to find out whether the toys contain and release volatile organic compounds (VOCs) to indoor air in amounts that might be harmful.

Some VOCs can irritate eyes and airways, among their other effects. Prolonged exposure can damage the liver, the kidneys and the nervous system, and increase the risk of cancer. VOCs have also been linked to asthma, or exacerbation of asthma.

"Squishies" are toys made of soft, colourful polyurethane foam and are often perfumed. The foam the toys are made of contains VOCs, among other substances. The purpose of this study was to determine which VOCs are released, and in what amounts. At the same time, the researchers from NILU wanted to find out if other toys made of plastic or rubber contain and release VOCs.

Toys in the laboratory

Bohlin-Nizzeto and Schmidbauer examined the toys in two stages. First, all the toys the Environment Agency had purchased at various brick-and-mortar and online toy stores in Norway were collected in the laboratory at NILU. Each toy was unpacked from its wrapping and placed individually in an air-tight ziplock bag along with a Tenax TA passive air sampler. The bag was filled with pure, VOC-free air and sealed.

"We left the bags at room temperature for 24 hours before taking out and analysing the air samplers," says Bohlin-Nizzetto.

What they found was not encouraging.

"We found between 12 and 30 different VOCs per toy, at concentrations well above the detection limit, and the chemicals were clearly identifiable," says Bohlin-Nizetto. "Taking all the toys together, we found nearly 150 different VOCs."

She goes on to explain that the levels of all the VOCs emitted by some toys were extremely high. If the toy that emitted most had been placed in a child's room, it would have been a greater source of VOCs than walls, flooring, or furniture.

How is indoor air affected?

After these initial analyses, and in cooperation with the Environmental Agency, the researchers selected the twelve toys with the highest VOC emissions and subdivided them according to the type of compound released.

Bohlin-Nizetto and Schmiedbauer wanted to find out how the chemicals emitted from the toys affect the air inside a home. To simulate that

This image shows one of the toys included in the study in an airtight ziplock bag. The metal tube is the Tenax TA air sampler. Photo: Ingunn Trones, NILU.

environment as realistically as possible, they borrowed an unoccupied 40-square-metre apartment containing a child's room of about 6 square metres.

"Since nobody lived there, the apartment was free of skin care and cleaning products, and also lacked clothing that could influence our measurements," says Norbert Schmidbauer. "That meant we could be fairly certain that our samplers would capture whatever came from the toys."

They put the first group of toys in the apartment, placing them at the head of the bed in the child's room. Then they put Tenax TA samplers in three different locations within the apartment: one was placed in the bed, alongside the toys, to measure emissions in the immediate vicinity of where the child's head would be. The second sampler was positioned at the opposite end of the same room, and the third sampler was placed in the living room.

"We left the first group of toys in the bed for ten hours," says Schmidbauer. "Then we removed both the toys and the samplers, aired the room out for 24 hours, and set out the second group of toys and samplers. We repeated this until we had measured emissions from all four groups of toys. The results from this second stage of the experiment showed that the toys with high levels of cyclohexanones and cyclic siloxanes also affected the indoor air. When these toys were placed in the child's room, the levels of VOCs in the indoor air increased so much that further examination of potential health risks is warranted."

Conversely, the toys with high levels of aromatic VOCs and the plasticiser TXIB (a potential irritant) did not affect the VOC levels in the apartment's indoor air.

"One explanation might be that the aromatic VOCs had already evaporated during the time that passed between stage 1 in November and stage 2 in February," says Bohlin-Nizzetto. "We noticed that the toys smelled less when we unpacked them in the apartment than they had when they were new."

Air those toys!

This single study in isolation does not allow the researchers from NILU to conclude that "squishies" are harmful to the health of children who play with them or sleep alongside them. But they are concerned by their results, and want additional research on this topic. Meanwhile, they advise against unpacking new, strongly scented toys and placing them directly into a child's bed or room. Since the VOC emissions appear to decline over time, they recommend putting new toys in a well-ventilated place to "air out" first.

The Norwegian Environment Agency will continue examining whether the VOCs the toys emit could pose a risk to children's health. The Agency will also assess the need for additional follow-up within the EU.

On behalf of the Norwegian Environment Agency, Pernilla Bohlin-Nizetto and senior scientist Norbert Schmidbauer have studied a selection of toys for children under three, to find out whether the toys contain and release volatile organic compounds (VOCs) to indoor air. Photo: Christine F. Solbakken, NILU.

The PFOS concentration in fieldfare from the old landfill Grønmo is more than ten times higher than the average in other fieldfare eggs the scientists analysed. Photo: EldbjørgHeimstad, NILU

Oslo's wildlife reveals what pollutants we live with

Red foxes, rats, earthworms, fieldfares, sparrowhawks and tawny owls. All these creatures live in and around the city of Oslo, where they are surrounded by – and affected by – everything humans own, eat, and do.

Christine Forsetlund Solbakken
Head of Communications

Every year since 2012, NILU – Norwegian Institute for Air Research, the Norwegian Institute for Nature Research (NINA), and the Norwegian Institute for Water Research (NIVA) have been collecting a variety of samples from several different animals living in and around Oslo, and analysing their content of pollutants, on behalf of the Norwegian Environment Agency.

Want to know more about urban wildlife

The researchers are looking for various pollutants – everything from heavy metals such as lead, to chemicals such as flame retardants and perfluoroalkylated substances (PFAS). The analyses reveal which pollutants end up in the animals' tissues as a direct result of how we humans influence nature and the environment in the cities we live in.

"We actually know less about pollutants in terrestrial animals than about pollutants in marine ecosystems," says research director and environmental chemist Eldbjørg Heimstad. "That's why the Norwegian Environment Agency started this monitoring programme with a focus on animals in cities."

The researchers' findings provide vital information for the Environment Agency. The data are used not just within Norway, but also for international pollutant regulations such as REACH and the Stockholm Convention.

The sins of our fathers

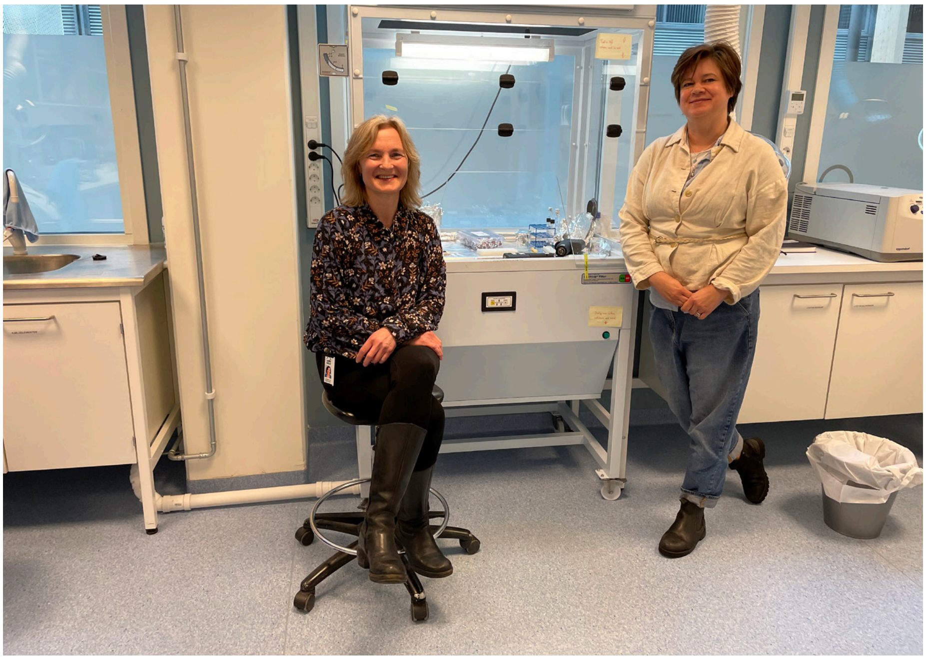
Oslo is the largest city in Norway, encompassing both densely populated areas, industrialised zones, and forests. This means that scientists must take samples from soil, air, and animals in both industrial and residential zones, in parks, sporting and recreational areas, water treatment plants, and abandoned landfills to get a complete overview of the situation.

Researchers analyse the samples for hundreds of pollutants, which are then sorted into groups: metals, PCBs, PBDEs, chlorinated paraffins, PFAS, pesticides, etc. For each class of substances, pollutant levels are compared across species and locations.

In addition, the researchers assess which groups of substances predominate in the various samples and species, and try to determine where the pollution comes from.

Senior researcher Dorte Herzke says that both the types and the levels of pollutants they find vary greatly from place to place.

"For example, we found the highest concentration of PFAS in the form of PFOS in fieldfare eggs from Grønmo, in earthworms from Alnabru, and in rat liver in general. We have observed this for several years running: the PFOS concentration in fieldfare from Grønmo, for example, is more than ten times higher than the average in other fieldfare eggs. Since Grønmo is an old landfill, and Alnabru is an industrial area, these levels aren't terribly surprising. These 'sins of our fathers' still affect the environment around us."



Research Director Eldbjørg Heimstad (left) and Senior Scientist Dorte Herzke find a large number of different environmental toxins in samples taken from animals living in and around Oslo. Photo: Linda Hanssen, NILU

Where do the pollutants come from?

In the case of all those rats with excessive PFOS concentrations, identifying a single source is more difficult. The most plausible explanation is that multiple places in the city are polluted by PFAS. But can we assume that the animals take up the pollutants at the sites where they are captured?

"The biologists at NINA have explained that the animals are most likely to get the substances locally," says Herzke. "Birds can travel long distances, but they metabolise what they eat very quickly – especially the smaller birds. Thus, the chances are that the pollutants we find in their eggs are ingested close to the nesting sites."

But it isn't always easy to figure out exactly what has happened. When scientists find rat poison in foxes, they can't tell whether the fox has fed on poisoned rat bait, or on rats that have eaten poison and become sick and easier to catch.

The latter is what researchers call secondary poisoning; it can also be suspected when lead is found in predatory birds and mammals. Did the predators consume the lead directly, or did they get it by eating prey or carrion containing lead shot?

Sunscreen and soap drift away

Heimstad goes on to highlight differences between the air samples they have taken and the other samples. They find completely different levels of some pollutants in the air samples than in the samples from animals, soil, and water.

"Take siloxanes, for example," she says. "That is a group of pollutants that are widely used in personal care products, such as shampoo, sunscreen, soap, and moisturiser. Siloxanes are very volatile, that is, they evaporate easily. When you shower, they're washed down the drain, so we find them in air samples from VEAS, Norway's largest wastewater treatment plant. They also appear in air samples taken in Oslo's popular Palace Park."

Thus, the air can tell us something about the substances we city-dwellers surround ourselves with. The researchers also find many other substances that are less volatile, that are resistant to breakdown, and that both humans and animals are exposed to mainly through the food we eat.

In most samples from animals, the researchers find that the well-known pollutants PFAS and PCB predominate.

Unique monitoring

At present, no other country runs a similar monitoring programme. Individual studies have been done, but the exceptional feature of this Norwegian programme is that the testing is done repeatedly, and with the same design, over many years. This provides unique insight into developments over time, while offering opportunities to follow up on interesting findings and expand the programme if necessary.

"Investigating local pollution is important," says Heimstad. "Not only does it reveal old sins; it also exposes new ones. Over the next four years, we will expand the sampling programme to cover additional substances, more locations (such as Marka, the forested zone around Oslo), and new species. Roe deer, bees, bumblebees, snails, nursery web spiders and rowan trees are on the list.

The animals in Norway's capital live side by side with its human inhabitants – everything humans make, emit, and throw away. This is what leads to the locally high levels of pollutants, because only a fraction of the substances that environmental scientists find in Oslo's animals occur naturally.

"We study animals and the environment," says Herzke. "We can't say for sure what our findings imply for humans, but they can probably serve as an indicator of what we can expect to find in people. Maybe we should be more mindful of that? And of the fact that we have a responsibility to know what chemicals we release, and an obligation to minimise the amounts released to the local environment we share with Oslo's wildlife?"

Read the latest report about the monitoring programme MILBY:
Environmental pollutants in the terrestrial and urban environment 2019: https://www.nilu.no/pub/1846964/

Workers erecting the mast itself and mounting instruments on it are well secured at all times Photo: Chris Lunder, NILU

New mast offers new measurement possibilities at the Birkenes Observatory

Birkenes, Norway's oldest atmospheric observatory, is in Aust-Agder. NILU has been measuring long-range transported air pollution there since the 1970s – but a new era began 11 September 2020, when the first measurements were obtained from the brand-new 75-metre mast. This means that the Birkenes Observatory is now part of the ICOS atmospheric monitoring network.

Christine Forsetlund Solbakken
Head of Communications

"The Integrated Carbon Observation System (ICOS) is a European research infrastructure focused on understanding the carbon cycle, including carbon dioxide and other greenhouse gases," says Stephen Matthew Platt, a researcher at NILU's Atmosphere and Climate Department.

"Several requirements must be met before atmospheric observations can be included in the ICOS measurement network. Among other things, it must be possible to take air samples at least 100 metres above ground, and at several levels farther down. Since the Birkenes Observatory is at the top of a hill about 40 metres high, the new 75-metre mast means that we now meet this requirement."

Not a task for those afraid of heights

The work of getting the mast set up is nearly competed. The engineers from Norconsult have erected the mast itself, and NILU employees have just finished mounting all the necessary equipment.

"This is not a task for people who are afraid heights," says Kjersti Tørnkvist, head of NILU's Monitoring and Instrumentation Technology Department. "The three scientists and engineers who have been working way high up have been well secured at all times. Before starting, they took a course in fall prevention, and they've adhered to strict safety protocols.

One of the first things NILU's scientists and engineers did when the mast was erected was to set up and isolate an air intake vent. It conducts air from heights of 75, 50, and 10 metres down to an instrument that measures the concentrations of carbon dioxide, methane, and carbon monoxide. They also mounted meteorological instruments on beams that extend from the mast at 75 and 10 metres above the ground.

Air measurement above the treetops

"The reason we have to measure so high up is to capture what we call background air," explains senior researcher Cathrine Lund Myhre. "Background air shows the levels of various particles and gases that are in the atmosphere, but that don't come from nearby sources. Background levels can only be measured in places where other activities don't contribute to local pollution. In addition, we want to minimise any direct effect the vegetation around the observatory might exert through photosynthesis and CO_2 uptake, so we need get up over the treetops. That also makes it possible to study exchange between the atmosphere and the vegetation."

"This gives the Birkenes Observatory the status of ICOS measuring station class 2," adds Platt. "The methane and CO_2 measurements from Birkenes are as precise as those we do at the Zeppelin Observatory in Svalbard, but we don't measure as many atmospheric components at Birkenes. So at present, it's only Zeppelin that has class 1 status in the System."

The data from Birkenes will be used in a wide range of contexts. In addition to being freely available on the ICOS carbon portal, they will be reported annually to the Norwegian Environment Agency as part of Norway's climate monitoring programme.

"This is essentially the data that gets used for research," explains Lund Myhre. "Here at NILU, we use ICOS data in our research to understand emissions and sources of CO_2 and methane. The data from Birkenes are important for estimating Europe's total emissions and trying to distinguish between anthropogenic emissions and those from natural sources."

The long-term objective is that the mast at Birkenes will be used to measure more than just meteorological variables, CO_2 and methane. Lund Myhre envisions that it will eventually be possible to set up research on other atmospheric components as well.

Reliable operations for years to come

The mast was constructed with the necessary protection against lightning and falling ice. In addition, special HSE procedures were developed to ensure the safety of everyone who works at or up in the mast.

"These procedures apply to scientists and engineers," says Tørnkvist, "but also to the local station manager at Birkenes. He is there every day to change sample filters and do routine checks on the instruments."

The mast at Birkenes will be the tallest of the instrument masts NILU manages. The institute already has a 15-metre mast up at the Zeppelin Observatory on Zeppelin Mountain in Svalbard, as well as a 25-metre mast at the monitoring station in Hurdal. The latter is operated in close cooperation with the Norwegian Institute for Bioeconomy Research (NIBIO).

According to Tørnkvist, the mast at Hurdal is actually in the process of being replaced by a new 40-metre mast – but the Birkenes mast will still be taller by a good margin.

All data from Birkenes and NILU's other observatories are freely accessible via the EBAS database, available to anyone who wishes to use them in their research or other activities.

"The mast at Birkenes has funding from the Research Council of Norway," says Lund Myhre. "Given that it is part of the national research infrastructure ICOS-Norway, we eventually hope to have research projects linked directly to the mast. That would ensure activity and longevity for both the mast and the observatory itself.

The brand-new and 75-metre mast at the Birkenes-observatory. Photo: Chris Lunder, NILU

Photo: Colourbox

DRAQCL: Deciding the trustworthiness of inconsistent observations

Monitoring air quality is no mean feat. Malfunctioning instruments, human error, certain weather conditions and a harsh environment can contaminate air quality measurements with so-called outliers.

Christine Forsetlund Solbakken
Head of Communications

Outlier or anomaly detection is the identification of rare items, measurements or observations occurring in datasets.

If such outliers are not detected, and instead considered normal measurements and allowed to remain in the dataset, they can affect the final result.

Humans versus machines

Detecting outliers is a key quality control task performed manually by air quality experts. Flagging air quality (AQ) observations as valid or non-valid and providing the cause of aberrant values is complex and time-consuming. It is also not scalable to large datasets.

"Pollutants show particularly rich patterns of variations in space and time on multiple scales", explains scientist Jean-Marie Lepioufle at NILU's Department of Software and Hardware Development. "These variations are driven by complex processes of chemical reactions, atmospheric transport, emissions and depositions."

Lepioufle has worked with machine learning for several years. He explains that neither statistical nor machine learning methods are automatically adaptable to evolving city environments. Thus, human expertise is a necessity when air quality observations are non-consistent, missing or of bad quality.

Incorrect data still has a value

Still, even for quality control experts, it is difficult to affirm an air quality value as 100% valid or 100% non-valid. Moreover, a value that is not completely correct might still provide some relevant information. Luckily, scientists are used to handling input of weighted data into their scientific pipeline, for instance to evaluate the importance of observations for data fusion purposes.

To accommodate this, Lepioufle came up with the idea for the DRAQCL project: "Deployable and Re-usable AQ Quality Control protocols". Its goal is to predict the "weight" or trustworthiness of each observation from an AQ monitoring station, e.g. predictive distribution or error prediction.

To do this, Lepioufle and his colleagues need to solve two main challenges. The first is that the regular protocol proper to machine learning – training a prediction model using target data and input data – is irrelevant here. It assumes everything to be certain (without any uncertainty), and it is not.

"Target data is not the 'ground truth' and is most of the time not available", he explains. "Input has errors. Algorithms at the foundation of prediction models can generate artefacts. And last but not least, our imperfect knowledge of a physical phenomenon makes us unable to build the correct prediction model."

The second challenge is that scientists, engineers, and technicians test different AQ prediction models with different algorithms and datasets. This makes further testing and reproduction of studies difficult. It is also difficult to construct a beta product that can be tested without access to highly specialized IT infrastructure.

Refining techniques in new projects

After a year's work, the NILU-funded DRAQCL project has advanced some way towards solving these issues: They have implemented a baseline error prediction model for AQ monitoring stations, and developed a light infrastructure for better deployability and reproducibility.

Lepioufle and his colleagues will keep working on improving these methods and models in the ongoing project HAPADS (see article on page 17) and also in the ambitious project AirQMan funded by the Research Council of Norway.

"Our aim is to generalize this method to fit any environmental observations", Lepioufle says, "and to be able to state what causes the outliers: Is the error internal, e.g., caused by an instrument? Or is it external, for instance road work causing a peak in PM concentration? Determining that would be really helpful for our AQ experts."

Read more about AirQMan:
Low Latency Air Quality Management:
https://www.mn.uio.no/ifi/english/research/projects/airqman/

Non-target and suspect characterisation of organic chemicals of emerging concern in air and biota

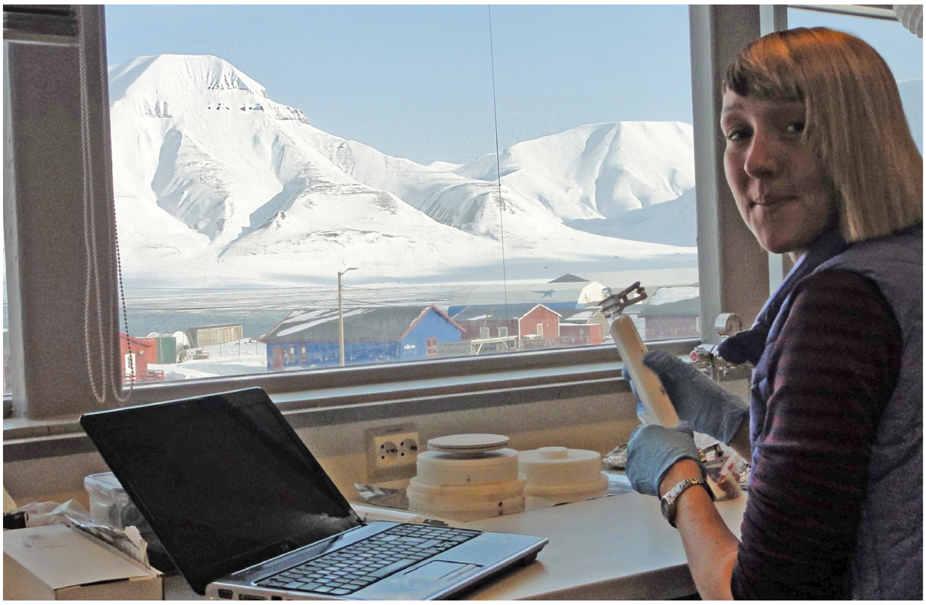
On Friday 25 September 2020, Laura Röhler defended her PhD thesis at the Norwegian University of Environmental and Life Sciences (NMBU). With her two examiners located in Russia and Sweden, the defence was held on Zoom. The research was carried out at the Department of Environmental Chemistry at NILU.

In her thesis "Non-target and suspect characterisation of organic chemicals of emerging concern in air and biota" Laura Röhler wanted to find new methods to scan for large number of compounds in environmental samples of air and biota, and to identify potential new chemicals of emerging concern (CECs).

Laura also developed and evaluated new sample preparation methods that do not use destructive or selective purification processes, to keep as many interesting compounds as possible in the clean extract.

The evaluation of the new clean-up method showed that it provides sample extracts of similar cleanness and quality compared to the traditional method using concentrated sulfuric acid, but also with a wider range of compounds (i.e., also acid-labile compounds).

Other aims of the research were to develop data processing workflows for the detection, identification and prioritisation of potential new CECs as well as a wide-scope instrumental method employing two-dimensional gas chromatography combined with low-resolution mass spectrometry.



Laura Röhler working in the laboratory at the University Centre in Svalbard (UNIS) in Longyearbyen, Svalbard. View of Adventfjorden against Hiorthfjellet. Photo: Laura Röhler.

The combination of these broad detection methods, the new purification methods and new computing workflows revealed several potential CECs in the environmental samples, some for the very first time.

Some of the CECs were detected in air in both southern Norway and the Arctic, demonstrating their ability to be transported over long distances in the atmosphere.

Furthermore, it was found that some of the CECs detected in biota may have a bioaccumulation potential. This means that they can end up at the top of the food chain.

Laura's findings highlight the importance of non-specific characterisation of organic compounds to detect new CECs in the environment at an early stage. Further research is necessary to evaluate the environmental fate of these CECs for possible regulatory actions.

Röhler, L. (2020). *Non-target and suspect characterisation of organic chemicals of emerging concern in air and biota = Ikke-spesifikk karakterisering av organiske forbindelser av økende miljørelevans i luft og biota* (Philosophiae doctor (PhD) thesis, 2020:42). Norwegian University of Life Sciences, Faculty of Chemistry, Biotechnology and Food Sciences, Ås, Norway.

NILU's efforts for gender equality and against discrimination (excerpt)

NILU's efforts to achieve gender equality and counter discrimination are firmly grounded in the Institute's overall strategy and business plan, its vision and values. After discussion with union representatives, NILU has formulated overarching policies on personnel, salaries, and seniors, as well as guidelines for whistleblowing.

Kristin Butveit,
HR Manager

Principles and objectives

NILU's personnel policy affirms that NILU's employees are of equal value, regardless of age, disability, religion/creed, native language, cultural attributes, and sexual orientation. Individual characteristics are respected and valued.

Status

Using the available management tools, Institute leadership works actively in cooperation with union representatives to achieve these objectives through personnel processes such as recruitment (internal and external), determination of pay and working conditions, and competence-building.

Statistics

As of 31 December 2020, NILU had 162 employees.

Gender balance Percentage of all employees		Temporary employees Percentage of all employees		Parental leave Average weeks		Actual part-time Percentage of all employees	
Women	Men	Women	Men	Women	Men	Women	Men
52 %	48 %	4 %	1 %	31,3	9,4	10 %	8 %

Complete information is available on NILU's website: www.nilu.no

Key figures

Extract from the annual statement (all figures in MNOK):

INCOME STATEMENT	2020	2019
Project revenue	156,0	154,8
Basic grant	35,0	32,2
National tasks and assignments	12,0	12,0
STIM-EU	5,4	5,9
Operating revenue	**208,3**	204,9
Wages and social expenses	-142,4	-143,4
Direct project expenses	-20,0	-23,4
Other expenses	-38,9	-41,3
Operating profit	**7,0**	**-3,3**
Net financial items	-2,9	-1,7
Tax	-1,4	0,6
Profit for the year	**2,7**	**-4,4**

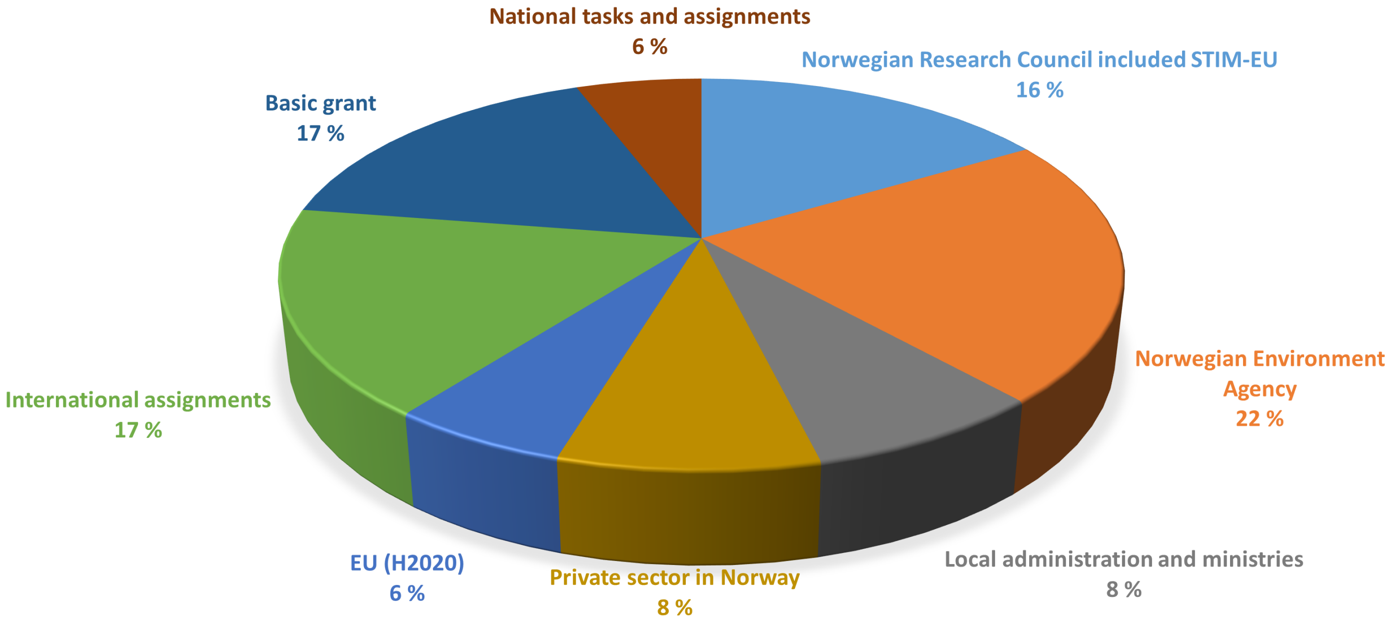
BALANCE SHEET	31.12.20	31.12.19
Fixed assets	89,5	97,2
Current assets	100,9	82,9
Total assets	**190,4**	**180,1**
Total equity	119,0	116,3
Short-term liabilities	71,4	63,8
Total equity and liabilities	**190,4**	**180,1**

NUMBER OF MAN-YEARS	2020	2019
Total	147	155
– whereof research man-year	72	101
– whereof man-years of other personnel	75	54
Turnover per research man-year	**2 893**	**2 038**

NUMBER OF EMPLOYEES	31.12.20	31.12.19
Total from over 20 different nations	162	161
– whereof women	85	81
– whereof men	77	80
Number of employees holding a doctorate	**70**	**68**

PUBLICATIONS AND DISSEMINATION	2020	2019
Scientific articles and chapters	105	104
Lectures and posters	97	254
NILU reports	30	26
EMEP/CCC reports	4	4
External reports	18	22
References in the media	526	320
Followers on Facebook	1295	1217

Project portofolio – percentage 2020



NILU – Norwegian Institute for Air Research

NILU – Norwegian Institute for Air Research is an independent, nonprofit institution established in 1969. Through its research NILU increases the understanding of climate change, of the composition of the atmosphere, of air quality and of hazardous substances. Based on its research, NILU markets integrated services and products within analyzing, monitoring and consulting. NILU is concerned with increasing public awareness about climate change and environmental pollution.

NILU's values: Integrity - Competence - Benefit to society
NILU's vision: Research for a clean atmosphere

www.nilu.no

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