Annex 9
Digitally-enabled monitoring tools

A-S-I: general. In-use real-time monitoring can be a useful tool to better inform policymakers, fill knowledge gaps and support the enforcement of environmental policies.

Context: all transport modes, all environmental impacts

Time frame: short/medium term

A9.1 Introduction

This factsheet focuses on the possibilities enabled by digitalisation in the field of real-time monitoring of the transport sector. In-use monitoring is an appealing option for policymakers, allowing us to fill knowledge gaps and better inform the development of new legislative initiatives, while supporting the enforcement of existing ones. Ultimately, this is expected to have a positive impact on the effectiveness of the process. Monitoring is only one of the possible ways in which digitalisation could support policymakers. For example, Factsheet 7 discusses innovative policy instruments made possible by digital technologies. The digitalisation of administrative processes and documents currently ongoing in various EU Member States will not be discussed here, despite their significant benefits for the citizens and institutions involved.

Given the broad scope of this factsheet, its structure is different from the previous ones, and it showcases several examples covering different sectors. Indeed, digitalisation enables the development of several diverse monitoring tools across multiple transport modes and for different environmental impacts. The next sections will discuss a representative selection of these, including both fixed and mobile technologies:

- remote sensing, plume chasing and onboard monitoring for pollutant emissions in road transport;
- onboard monitoring of fuel consumption and CO_2 emissions in road vehicles;
- remote sensing of marine oil spills from vessels;
- remote sensing of pollutant emissions in maritime transport.

Digitally enabled monitoring tools are not only relevant for policymakers but can also make easily available to the general public empirical data about their local environment, the factors contributing to it and on the impact of their modal choices, as also discussed in Factsheet 7. For this reason, the factsheet also discusses an example of a tool for empowering citizens and increasing their awareness of the environmental impacts of transport.

A9.2 Digitally-enabled tools for the monitoring and enforcement of air pollutant emissions from road vehicles

A9.2.1 Context

Vehicles are expected to comply with pollutant emission limits both at type approval and throughout their normal useful lifetime and under normal real-world operating conditions (EU, 2017c). Real-world emissions of road vehicles are a complex function of many variables. These include the age of the vehicle and its standard of maintenance, the proper functioning of the exhaust after-treatment system (ATS), the tyre pressure, the driving style, the weather conditions, the road gradient and the altitude.

Exhaust ATS can be subject to malfunctioning or they can be deliberately tampered with to reduce the total cost of owning a vehicle or to improve its performance (Giechaskiel, Forloni, et al., 2022). An internet review in 2017 identified 87 separate sites supplying Europe with tampering devices for Euro IV, V, and VI vehicles (Godwin, 2017). The phenomenon is believed to be more common for heavy-duty vehicles (HDVs) equipped with a selective catalytic reduction unit, which requires a diesel exhaust fluid (commercially known as AdBlue in Europe) to operate. This is estimated to costs operators up to approximately EUR 2,000 per heavy-duty vehicle on a yearly basis (at an annual mileage of 150,000km). If major servicing and repair is needed, the costs can be even higher (Frandsen, 2018; Janssen, and Hagberg, 2020). AdBlue emulators are devices that send a signal to the engine emission control, confirming that the exhaust ATS is working properly even if no fluid has been injected into the system. Such systems are becoming progressively more sophisticated and difficult to identify, especially because they can be easily deactivated by the user for an inspection.

Currently, ATS are verified on a regular basis during mandatory periodical technical inspections. Notably, however, the systems controlling some of the most relevant pollutants (e.g. nitrogen oxides (NOx) and solid particle number >23nm (SPN_{23}) for diesel engines) are currently not verified. The scope of the periodical technical inspections and the techniques used for the verification of ATS performance are currently under revision by the European Commission (EC, 2021x). To guarantee the effectiveness of air pollutant emission standards and of area restrictions based on the emission characteristics of the vehicles, it is important that the real-world emissions of road vehicles are monitored in real time. This will allow both better enforcement of the current policies but also the collection of an extensive set of data on the performance of the vehicle fleet. This can be used to develop new legislative initiatives and to fill knowledge gaps such as how to account for the deterioration in catalytic ATS.

A9.2.2 Environmental impacts

The magnitude of the problems caused by malfunctioning or manipulated after-treatment devices (e.g. deNOx units or particulate filters) is largely unknown and a comprehensive EU statistic is currently lacking. The number of malfunctioning or manipulated vehicles circulating in the EU-27 is not straightforward to determine. This is due in part to the absence of systematic monitoring but also to the cross-national dimension of the problem. Indeed, long haulage HDVs systematically drive in several Member States in addition to the one where they are registered and for which most of the statistics are available.

It is not uncommon for modern light- and heavy-duty diesel vehicles with a malfunctioning or manipulated deNOx after-treatment unit to have exhaust emissions that are 40 times higher than vehicles with a properly functioning unit. However, in some cases this difference could exceed two orders of magnitude (Janssen et al., 2020; Pöhler, 2020; Giechaskiel, Forloni et al., 2022; Selleri et al., 2022).

A similar situation holds for malfunctioning or deliberately manipulated particle number filters. Melas et al. (2021, 2022) report that studies have estimated that 10% of high emitting light-duty vehicles can contribute to 85% of the entire fleet's emission of particle numbers. Approximate estimates show that assuming that just 1% of diesel particulate filters are severely damaged or have been removed would increase the SPN emissions of a filter-equipped diesel vehicle fleet more than 10 times.

Switzerland carries out continuous testing of HDVs driving through the country. For 2017, it reported that 0.7% of 15,500 vehicles inspected showed evidence of tampering (Frandsen, 2018). In Norway it is estimated that 10-20% of trucks are equipped with emulators, while acknowledging the difficulty in providing sound estimates (Frandsen, 2018).

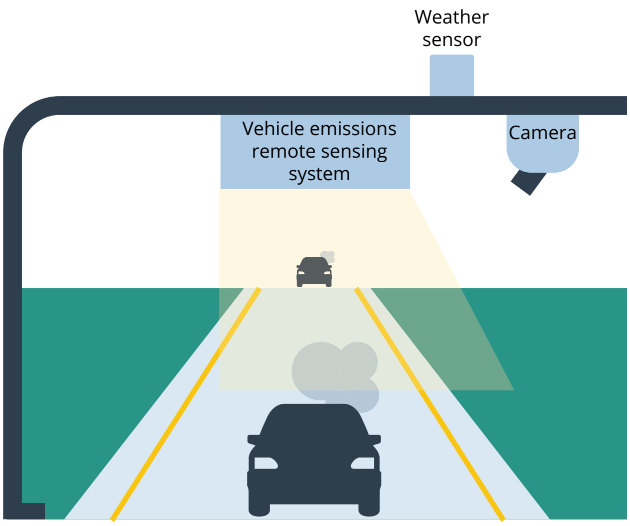
A9.2.3 Examples of monitoring tools

Various methods are available to determine the real-world air pollutant emissions from road vehicles. In the following, remote sensing, plume chasing and onboard monitoring are briefly described. A description of portable emissions measurement systems (PEMS), the reference instruments for the in-use verification of real-world vehicle emissions can be found elsewhere (Bonnel et al., 2022).

Remote sensing

Remote sensing is a well-known technology that has been applied in the United States since 1989 (Bishop et al., 1989) but has developed significantly in recent times due to the evolution of digital technologies and sensors. A remote sensing installation typically consists of a source and detector module, a sensor for speed and acceleration, a weather station for monitoring ambient conditions, and an automatic number plate recognition system for identifying vehicles and their characteristics, as shown in Figure A9.1. With this technology it is possible to monitor, at fixed positions, a large number of vehicles in a short time and in an unobtrusive way (Yang et al., 2022). The large amount of information collected by such installations is then transmitted over the internet and processed by a back-office system.

Figure A9.1 Example of a remote sensing installation for road vehicles



Source: Borken-Kleefeld and Dallmann (2018).

Remote sensing instruments generally use absorption spectroscopy to measure several pollutants such as carbon monoxide (CO), unburned hydrocarbons, NOx (including nitrogen oxide, nitrogen dioxide), N_2O, sulphur dioxide and ammonia. Particulate emissions can also be measured by complementary systems, for example dedicated instruments such as opacimeters, or by gas sampling and filter analysis. Usually, the measure is expressed as a ratio between the concentration of the pollutant and the CO_2 concentration, since that quantity remains fairly constant even at high dilution ratios (Dallmann, 2018). To translate this into the more commonly used emission factors per kilometre, the measurements need to be combined with additional information. For example, Davison et al. (2020) develop an approach based on vehicle specific power (power demand on the engine during driving).

These installations can record pollutant emissions for many vehicles but only at the moment they drive past the remote sensing location. This is at variance with what happens in other systems such as those using onboard sensors, PEMS or plume chasing approaches in which a vehicle is continuously monitored for a whole trip or a part of it.

Remote sensing installations have already been used in several situations, with interesting results.

A remote sensing campaign in Warsaw during autumn 2020 shows that imported second-hand vehicles, which make up more than 30% of the vehicles in the city, have NOx and particulate matter (PM) emission rates that are more than two and three times as high as those from domestic vehicles (i.e. vehicles only registered in Poland). This is due to their older emission technologies. The study concludes that a clean transport zone that bans older vehicles could improve air quality in Warsaw (Lee, et al., 2022).

In Hong Kong the remote sensing enforcement programme, which has been operating since September 2014, aims to detect high-emitting petrol and liquefied petroleum gas vehicles. It is combined with a subsidy for fitting exhaust reduction equipment for certain vehicles. The owners of the high-emitting vehicles identified are notified and must repair and have their vehicles tested within a specified period of time. If they fail to do so or fail the test, they are delicensed and not allowed to drive their vehicle on the road. Huang et al. (2022) conclude that the combination of the replacement programme and enforcement has been effective, while pointing out that the remote sensing system does not yet monitor all lanes in multilane roads and does not yet cover diesel vehicles.

Hooftman et al. (2020) report on a remote sensing campaign in the Flemish region in Belgium in 2019. Some 10% of the 'high-emission events' arising from diesel cars are found to be responsible for 80% of the cumulative PM_{10} (PM with a diameter of 10µm or less) emissions of Euro 5 and 6 diesel cars. For petrol cars, about 7% of high-emission events cause approximately 40% of the observed NOx emissions. It is estimated that 9.5% and 4.8% of Euro V and VI trucks, respectively, are driving with either damaged or intentionally manipulated exhaust ATS. This is reckoned to result in 24% and 67% additional NOx emissions, respectively. On motorways, the NOx emissions of the most recent Euro VI trucks are found to be very low.

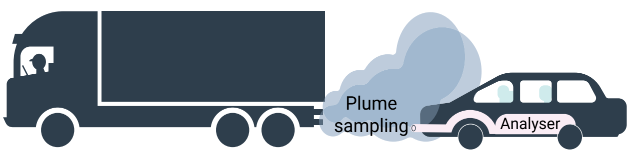
Research is also ongoing on identifying potentially problematic vehicles with remote sensing data, for example within the CARES project (Rushton et al., 2021; Qiu, and Borken-Kleefeld, 2022; Yang et al., 2022). Remote sensing is also at the core of the NEMO project (2021), aimed at facilitating the enforcement of low-emission zones and the monitoring of noise pollution levels in cities.

Plume chasing

In plume chasing, an instrumented vehicle is used to sample gas directly from the exhaust plume of the vehicles inspected, as shown in Figure A9.2. This can be done without informing the vehicle's driver and at a random location during a normal driving situation. This is different from inspection at fixed remote sensing locations, making the approach very suitable for identifying vehicles that are not only malfunctioning but have also been deliberately tampered with.

From a technical point of view the measurement concept is similar to that of remote sensing. It exploits the fact that the ratio between NOx and CO_2 is fairly constant, including at high dilutions. The method appears tolerant of different driving patterns and distances from the chased vehicle.

Figure A9.2 Example of the plume chasing approach for road vehicles



Source: CARES project (Sjödin, 2011).

The measurements are not sensitive to weather, such as rain, moderate wind or fog, and the rate of false-positive detection is generally low (Janssen et al., 2020), confirming the potential of plume chasing for enforcement purposes for the Danish Road Traffic Authority, although the system could benefit from further refinement. The data collected are processed in real time using dedicated software that helps the inspector to immediately identify problematic vehicles. The data collected can be subsequently downloaded and further analysed.

Plume chasing is already systematically used for inspections, and reports mention that up to 25% of the vehicles inspected could have had their devices tampered with (Pöhler et al., 2019; Vojtisek-Lom et al., 2020), although more conservative estimates exist.

An HDV plume chasing campaign in Denmark showed that around 2% of Euro V and Euro VI trucks were high emitters, with malfunctioning or tampering confirmed through subsequent dedicated technical inspection. Of the overall sample tested, only 55% of the vehicles were registered in Denmark (Pöhler, 2020).

Two similar experimental HDV campaigns on German and Austrian motorways showed a higher share of high-emitting vehicles. However, in these cases, the HDVs identified as high emitters were not subsequently inspected to confirm the presence of a faulty or manipulated device (Pöhler et al., 2019). A summary of the results of recent plume chasing campaigns is reported in Table A9.1.

Table A9.1 Results of plume chasing campaigns for heavy-duty vehicles in Denmark, Germany and Austria

Campaign details	Share of high-emitting vehicles		Comment	Source
	Euro V	Euro VI		
Denmark (2020)	2.1%	2.2%	Confirmed by inspection	(Pöhler, 2020)
Germany (2016)				
German trucks	0%	6.9%	Potentially manipulated	(Pöhler et al., 2019)
Non-German trucks	26%	19%		
Austria (2018)	35%	25%		

In the United States, the Air Enforcement Division of the Environmental Protection Agency estimated that more than 550,000 diesel pickup trucks were tampered with in the last decade, constituting approximately 15% of the national fleet. As a result, it is expected that these vehicles will emit more than 570 kilotonnes of excess NOx and 5,000 tonnes of excess PM over their lifetime. Due to their high emissions, these trucks have an air quality impact equivalent of more than 9 million additional circulating diesel vehicles (compliant, non-tampered with) (US EPA, 2020).

Onboard monitoring systems

Modern vehicles are nowadays equipped with multiple onboard sensors which allow real-time detection of several parameters and checking that the vehicle is functioning properly . There is a growing interest in the possibility of using such sensors and the information already available on board the vehicle not only for diagnostics but also to monitor its emissions for environmental purposes (California Air Resources Board, 2018; Zhang et al., 2020; CLOVE, 2021; Winther, 2021; Selleri, Gioria et al., 2022; Selleri et al., 2022). This approach is sometimes referred to as onboard monitoring (OBM).

A potentially interesting application that is less complex to implement is that for diesel vehicles. Indeed, in both modern light (Euro 6) and heavy (Euro V and Euro VI) duty diesel vehicles, onboard NOx sensors are widely already available to control the status and the proper functioning of deNOx ATS such as selective catalytic reduction units. These could be used, for example, to monitor NOx exhaust emissions.

To obtain a real-time measure of vehicle emissions, accurate measurements of both the vehicle exhaust flow rate and the concentration of pollutants are needed. In a recent Joint Research Centre study on two light-duty commercial diesel vehicles, in the specific case of NOx, both quantities were acquired from currently available onboard sensors and compared to reference laboratory and PEMS instruments, with fair agreement. This allowed accurate estimation of NOx emissions in both laboratory and real-world driving tests. Sensors were able to detect both high and low NOx concentrations, indicating that a malfunctioning after-treatment unit could be easily identified (Selleri et al.,2022). Similar results were obtained in previous studies performed on an HDV (Mendoza-Villafuerte et al., 2017; Selleri, Gioria et al., 2022).

In principle, such data could be stored in the vehicle and periodically downloaded (e.g. during periodical technical inspections) or directly transmitted over the air. In the latter case, the information could conceivably allow real-time detection of malfunctioning and rapid intervention. In addition, the data from the onboard system could be used to monitor the trend in the average emissions of the fleet during its whole lifetime, building evidence on the different ageing phenomena affecting the vehicles and their ATS. All this could ultimately facilitate the design of emission limits and their systematic enforcement.

To carry out real-time monitoring of pollutants from vehicles through onboard sensors some technical hurdles still need to be surmounted and are actively being researched. Indeed, currently available sensors are not designed for real-time monitoring but rather for diagnostic purposes. They can take up to 15-20 minutes to reach the operating temperature, meaning that, in their present form, they cannot be used to monitor short trips. In addition, although the quantification of NOx emissions has been demonstrated under research conditions, additional sensors and efforts will be needed to cover other pollutants and to reduce their cross-sensitivity (Selleri, et al., 2022).

The real-time monitoring of NOx through OBM is a consistent part of the new proposal for a Euro 7 regulation, recently put forward by the European Commission (EC, 2022h).

A9.3 Onboard devices for monitoring fuel consumption of road vehicles

Regulation (EU) 2019/631 (EU, 2019a) sets CO_2 emission standards for new passenger cars and new light commercial vehicles. CO_2 emissions subject to targets are determined in laboratory testing. Up until 2020, the officially reported CO_2 emissions of cars and vans were based on measurements using the New European Driving Cycle (NEDC). Research, however, showed that real-world fuel consumption and CO_2 emissions are significantly higher than the NEDC levels, and that this gap increased over time, from 8% in 2001 to 39% by 2017. Hence, the average real-world CO_2 emissions in 2017 were 39% higher than the test value (Dornoff et al., 2020). For this reason, a new testing procedure, the World Harmonised Light Vehicle Test Procedure (WLTP), was introduced to better represent real-world driving conditions. In 2018 countries started to report CO_2 emissions based on the WLTP. From 2021 onwards, compliance assessment is fully based on the WLTP data. However, WLTP-tested and real-world emission levels reported by drivers show that there is still a gap (Dornoff et al., 2020), although it is smaller than with the NEDC.

To prevent the gap between real-world and tested emissions increasing, Regulation (EU) 2019/631 includes the provision that as of 1 January 2021 onboard fuel and/or energy consumption monitoring (OBFCM) devices are mandatory for new types of passenger cars and most light commercial vehicles. As of 1 January 2022, this is mandatory for all new cars and light commercial vehicles. Table A9.2 reports the information collected (EU, 2021b).

The following entities are responsible for reporting the information collected to the European Commission: (1) manufacturers, based on either direct data transfers from the vehicles to the manufacturer or on data collected by their authorised dealers or authorised repairers; (2) Member States, with data collected by bodies or establishments responsible for roadworthiness testing (e.g. periodical technical inspections). The entities responsible for the data collection have to ensure that secure means of communication are used for the collection of the VINs and respect the General Data Protection Regulation specifications (EU, 2021b).

Based on the anonymised OBFCM data the European Commission plans to publish annually the average real-world CO_2 emissions, and the gap between those and type-approval CO_2 emissions, by manufacturer, vehicle category and fuel type. This will provide information on the trends in real-world emissions to vehicle owners and potential vehicle buyers. Using data for 2021-2026 the Commission will evaluate the future development of the gap between real-world and type-approval emissions. To prevent an increase in the size of the gap it will assess in 2027 how this might be counteracted by further regulation. The OBCFM data will also be used to determine the average real-world utility factors of plug-in hybrid electric vehicles. These parameters are used to calculate the official CO_2 emission values of these vehicles at type approval and are a complex function of the vehicle electric range (Melas et al., 2022; Selleri, Melas, Ferrarese et al., 2022; Selleri, Melas, Franzetti et al., 2022; Tansini et al., 2022).

The Regulation on CO_2 standards for new HDVs, Regulation (EU) 2019/1242 (EU, 2019b), also mandates the introduction of OBFCM devices for the monitoring and recording of fuel and energy consumption, payload and mileage in HDVs. The technical and legal framework for the OBFCM devices for HDVs is currently under discussion.

Table A9.2 Information collected in the scope of real-world CO_2 monitoring

Vehicle type	Information collected
All vehicles	Reporting period (year of data collection)
	Manufacturer's name (as provided in the certificate of conformity)
	Vehicle identification number (VIN)
	Total fuel consumed (lifetime) (litres)
	Total distance travelled (lifetime) (km)
Plug-in hybrid vehicles	Distance travelled (lifetime) in charge-depleting operation with engine off (km)
	Distance travelled (lifetime) in charge-depleting operation with engine running (km)
	Distance travelled (lifetime) in driver-selectable charge-increasing operation (km)
	Fuel consumed (lifetime) in charge-depleting operation (litres)
	Fuel consumed (lifetime) in driver-selectable charge-increasing operation (litres)
	Total grid energy into the battery (lifetime) (kWh)

Source: Source: EC (2021e).

A9.4 WeCount project: involving citizens in local transport and environmental policies

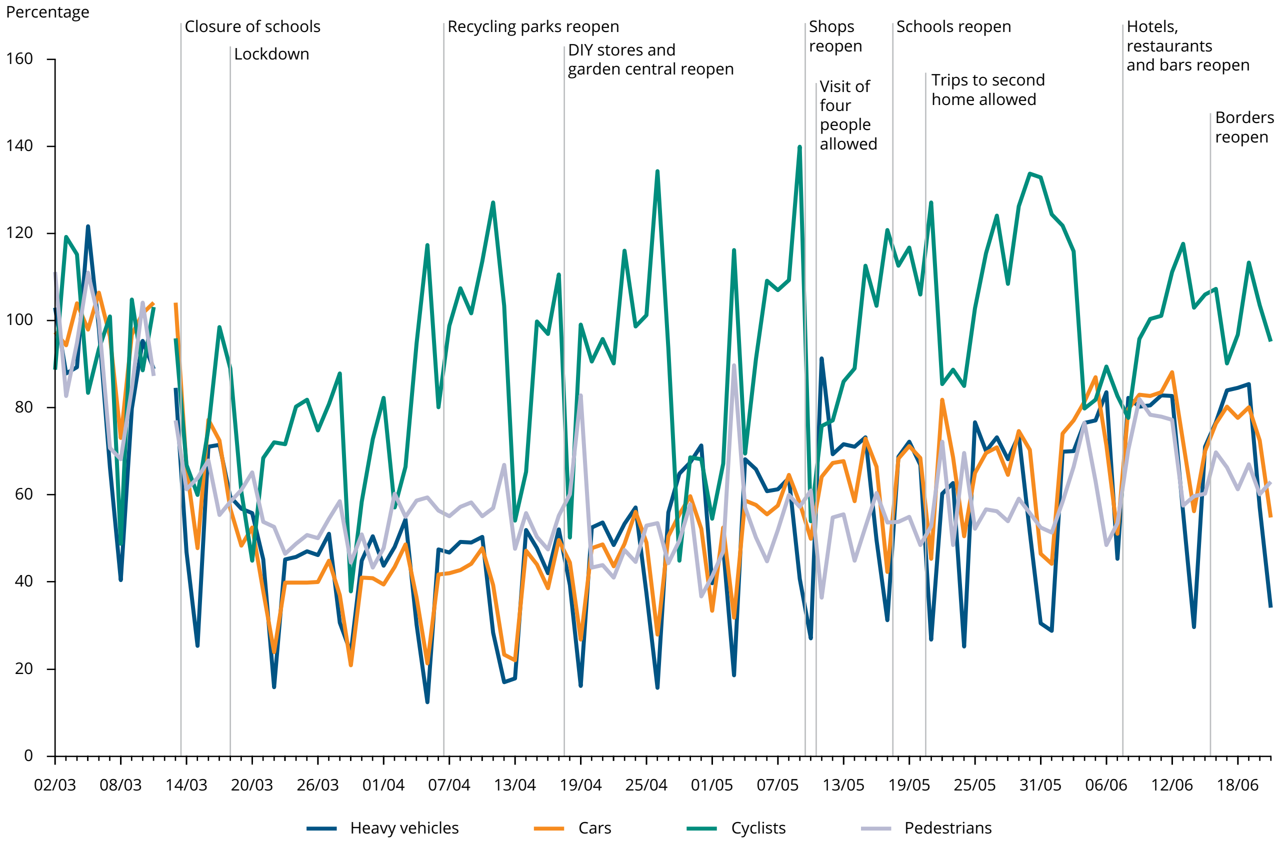
Traffic counts, i.e. the quantification of vehicular, bicycle or pedestrian traffic, are important instruments to support local environmental policies and develop a better understanding of local mobility patterns. These counts are normally realised automatically by installing electronic traffic recording devices. However, nowadays classic traffic counts are limited in time, geographical coverage and scope, e.g. the transport modes to which they apply. In addition, they are often expensive and the data collected may not be readily available.

To overcome these limitations, the WeCount project (TML et al., 2022) collaboratively developed and deployed an innovative, low-cost automated traffic counting sensor and multi-stakeholder engagement mechanisms in five European cities: Leuven (Belgium), Madrid and Barcelona (Spain), Cardiff (United Kingdom), Dublin (Ireland) and Ljubljana (Slovenia). It was funded by Horizon 2020 and it is an example of public participation in scientific research (citizen science). The traffic counting sensor, called 'Telraam', is a combination of a Raspberry Pi microcomputer, sensors and a low-resolution camera. It is mounted on the inside of an upper-floor window with a view over the street. Compared to classic devices it covers a wider range of modes: cars, heavy goods vehicles, public transport vehicles, cyclists and pedestrians. Figure A9.3 presents traffic monitoring per mode by devices in Leuven during the first 14 weeks of the COVID-19 pandemic, highlighting the impact on traffic of changes in the pandemic containment measures.

In all participating cities, WeCount showed that the availability of local mobility data promoted a number of initiatives such as speed bumps, lower speed limits and changes to traffic circulation.

Although the quantification of environmental impacts was not the main focus of the project, the increased knowledge of the local traffic situation can be a driver for new initiatives that can also have positive environmental impacts.

Figure A9.3 Traffic registered by Telraam in the first 14 weeks of the COVID-19 pandemic, Leuven, Belgium



Source: Pápics et al. (2020).

A9.5 Remote sensing of marine oil spills

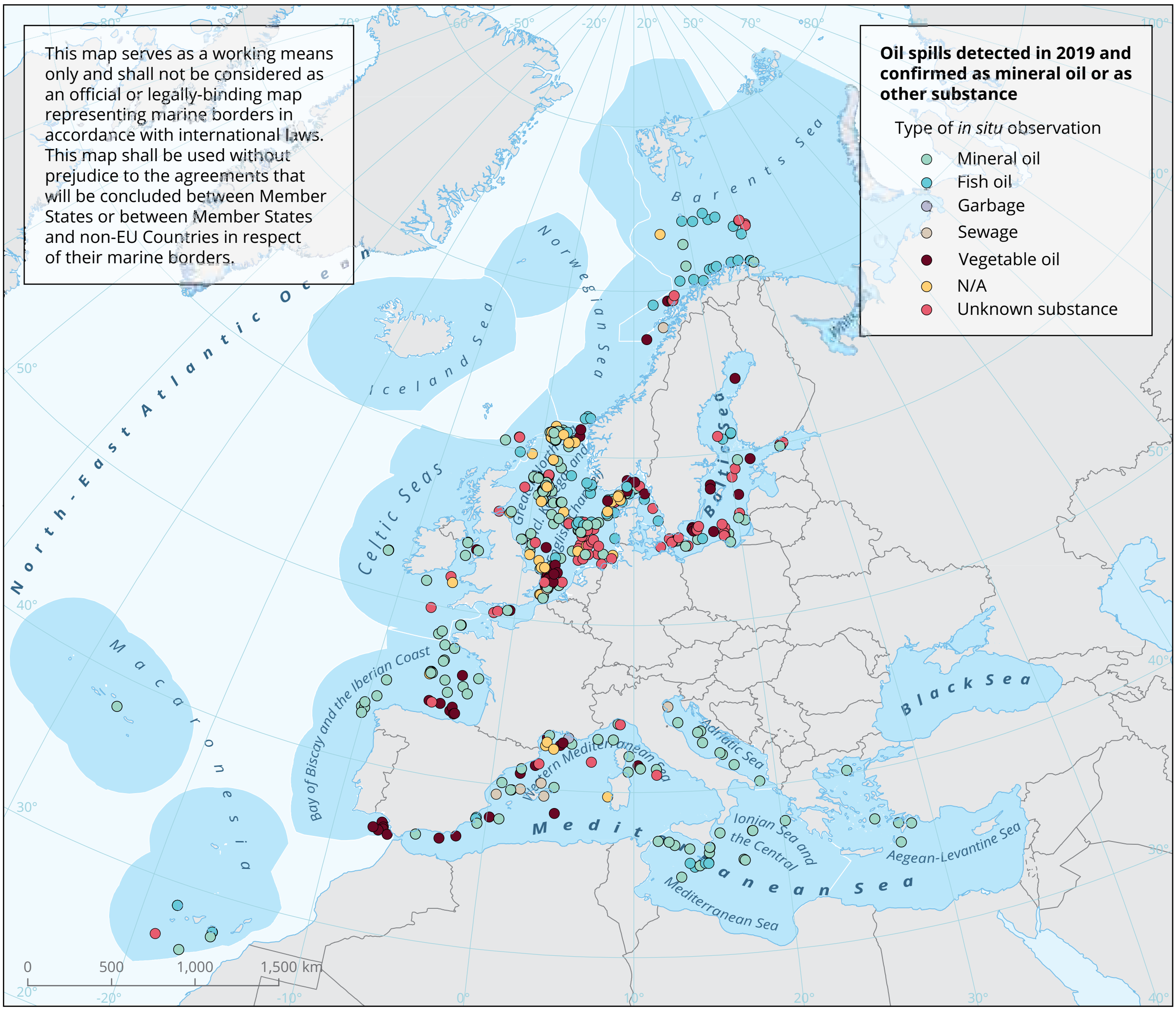
Digitally enabled monitoring solutions could also be applied to non-road transport modes, with similar benefits. For example, in the maritime sector, oil spills are one of the most concerning sources of pollution, as they are difficult to clean up and can remain for long periods in the marine environment. Almost two thirds of them are due to vessels, followed by offshore installations, fish farms, accidents and other causes. Oil spills can severely pollute marine and coastal habitats, causing damage to the natural environment and the economy (EMSA et al., 2021). It is therefore of relevance to have tools for the detection of the spills and for the enforcement of the policy measures taken to address them.

Since 2007 the European Maritime Safety Agency (EMSA) has operated CleanSeaNet, the European satellite-based oil spill monitoring and vessel detection service. The service provides monitoring on a regular basis. Satellite images from both synthetic aperture radar (SAR) and optical satellite missions are analysed with the aim of detecting oil pollution, identifying its possible source and gathering information on the spread of oil spills. An important challenge in detecting oil spills using SAR is the high share of false detections, or so-called 'oil look-alikes'. Research on improved interpretation approaches is ongoing (Cantorna et al., 2019; Bianchi et al., 2020; Rousso et al., 2022). In the event of potential oil spill being detected the coastal states involved receive an alert within 20 minutes. EMSA's web interface allows it to acquire further information on the spill, ships identified and vessel traffic information (EMSA et al., 2021). This system complements monitoring by aerial surveillance (for example in the Baltic Sea area by the Helsinki Commission contracting partners (Helcom, 2020)). It allows coverage of a larger area and optimising the effectiveness of the surveillance flights.

According to the *European maritime transport environmental report 2021* (EMSA et al., 2021) CleanSeaNet monitors more than 3 million km^2 per day. In the period 2010-2019 there were three large oil spill accidents (>700 tonnes) in EU waters and five medium-sized accidents (7-700 tonnes). In addition, many smaller oil spills (under 7 tonnes) took place. In 2019 more than 7,700 satellite images were produced, leading to the identification of over 7,900 possible oil spills. 5% of the *in situ* verifications in 2019 took place within 3 hours of the satellite observation. In 42% of these cases pollution by mineral oil and other substances (such as fish oil or vegetable oil) was subsequently confirmed.

In the Baltic Sea, the combination of aerial surveillance of the Helsinki Commission countries and satellite surveillance has led to a substantial fall in the number of confirmed oil spills: from 472 in 2000 to 72 in 2019, and this is despite the higher shipping density. The estimated volume of the oil spills has fallen throughout the period (Map A9.1). In 2019, 89% were smaller than 0.1m^3 (100 litres) and 97% were smaller than 1m^3 (Helcom, 2020).

Map A9.1 Oil spills detected in 2019 confirmed by CleanSeaNet users as mineral oil and/or other substances



Reference data: ©ESRI

Source: EMSA and EEA (2021).

A9.6 Remote sensing of emissions in maritime transport

Monitoring of air pollutant emissions is relevant for the maritime sector too. Ships emit various air pollutants, including SOx, NOx, PM, CO, non-methane volatile organic compounds and ozone-depleting substances. These ship-generated emissions can sometimes be significant in areas of heavy maritime traffic and can also travel long distances (EMSA et al., 2021).

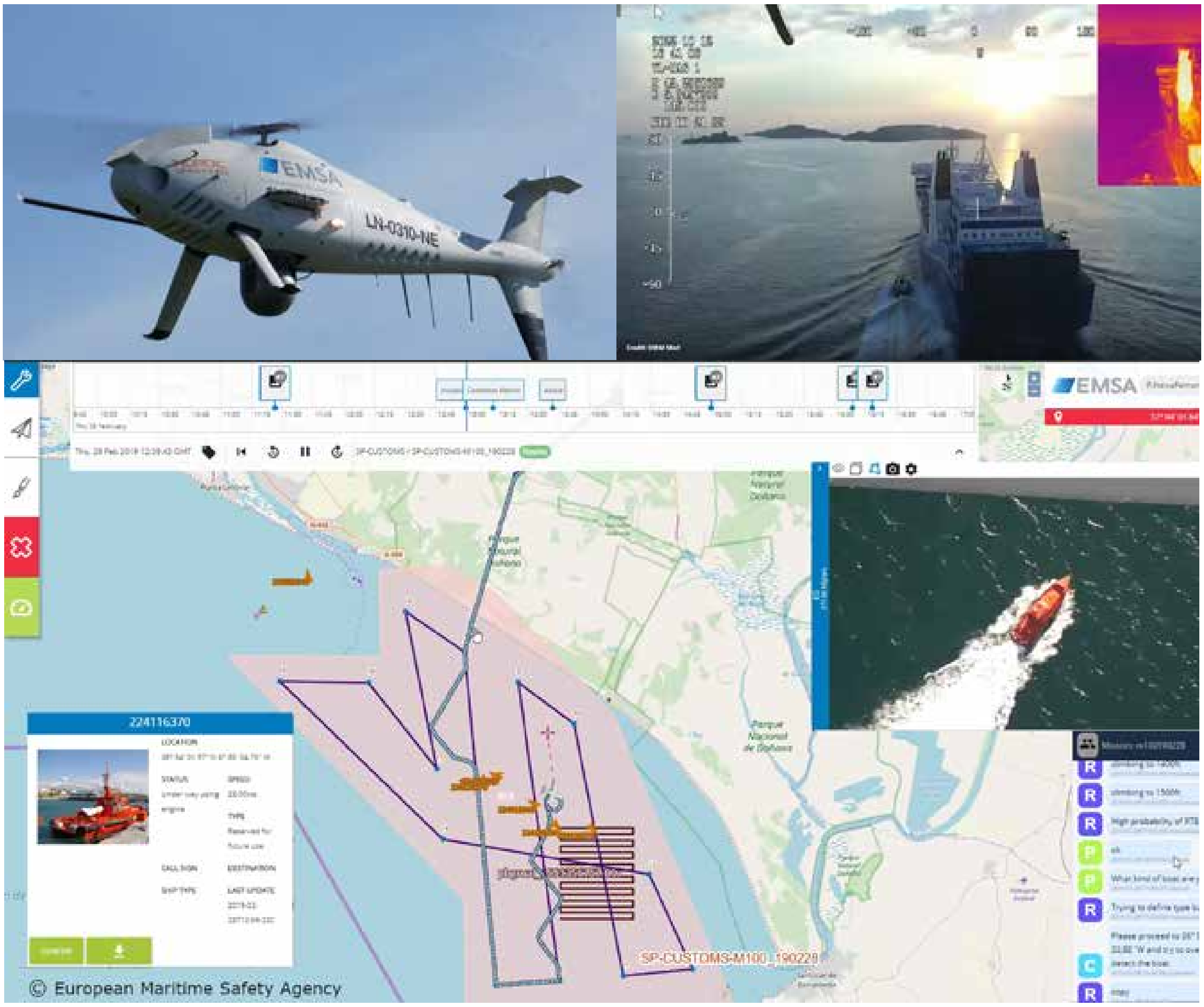
In 2019 international maritime transport was responsible for almost 85% of SOx emissions by transport in the EU-27 (EEA data reported by Eurostat (2021a)). In order to reduce the resulting environmental impacts the Baltic Sea, the North Sea and the English channel are designated as SOx emission control areas (SECAs) pursuant to Annex VI of MARPOL (International Convention for the Prevention of Pollution from Ships (IMO 2022)). In these areas EU Member States must ensure that the sulphur content of fuels used by ships does not exceed 0.1%. This level has been in force since 2015. Higher sulphur contents are allowed only on condition that exhaust systems are installed on board. While the SOx emissions from maritime transport in European seas remained fairly stable between 2014 and 2019, they fell substantially in the North Sea and Baltic Sea SECAs but not in the Mediterranean Sea, which accounts for the largest share of SOx emissions and where no SECA applied at the time (EMSA et al., 2021). Since 2020, EU Member States must ensure that the sulphur content of fuel does not exceed 0.5% for ships in all EU waters outside the SECAs. The same requirement also holds at world level, as decided in 2016 by the International Maritime Organization (IMO, 2022).

EMSA contributes to the enforcement of the sulphur regulations by providing remotely piloted aircraft systems (RPAS) that measure the SOx and CO_2 emissions from individual vessels and based on the relationship between the two, the sulphur content can be determined and compared with the legal limits. These systems are based on similar principles of the remote sensing and plume chasing ones already described (Section A9.2.3). In addition, information about the ship's identity is recorded. This service is provided for free to interested countries, in addition to their own enforcement methods. Through EMSA's RPAS data centre historical and real-time data can be accessed, and new tasks or points of interest can be defined. There is the possibility of real-time interaction with the pilot and sensor operator (EMSA, 2017).

On a mission in the Strait of Gibraltar in 2021, 10% of the ships monitored were found to be potentially above the legal limits (Maritime Executive, 2021). In the first half of 2022, campaigns started in the Baltic Sea and Denmark (Maritime Executive, 2022; Safety4Sea, 2022). The system can also be deployed for NOx emission monitoring in the North Sea and Baltic Sea nitrogen emission control area, which was put in place in 2021.

Remote sensing of maritime emissions is also used in research. An example is the Fugitive Methane Emissions from Ships (FUMES) project, started in March 2022. The project focuses on methane emissions from ships fuelled by liquefied natural gas (LNG). It will monitor emissions using in-stack continuous monitoring, drones and helicopters, with the aim of better understanding the potential of LNG-powered ships to reduce greenhouse gas emissions in maritime transport (ICCT, 2022).

Image A9.1 Example of remotely piloted aircraft system for measuring SOx emissions



Source: EMSA.

A9.7 Policy corner

Digitally enabled solutions for monitoring are useful for supporting the design and enforcement of environmental policies in transport. These could address knowledge gaps, ensure a more thorough enforcement of existing legislation and obtain data at the local scale. Accountability and identifying responsibility in cases of violation is a delicate topic that will require a clear and robust framework. Privacy concerns are a point of contention and should be adequately addressed.

By means of research and development funding the performance and cost-effectiveness of these systems could be improved, ensuring that the social benefits exceed the costs. The latter include, for example, the system costs, or the costs incurred by the inaccuracies remaining in the monitoring systems, leading to either false positives or negatives.

A9.8 Bottom line

Monitoring has the potential to support the design of environmental policies and their subsequent implementation, contributing to their effectiveness. A good incentive for improving and developing monitoring systems is the growing public awareness of the problems caused by environmental pollution. The magnitude of the environmental benefits depends not only on the quality of the monitoring systems but also on the quality of the policies and on the environmental problem that is addressed. When they are used for enforcement purposes, the impact also depends on the quality of the next steps in the enforcement process: the extent to which violations that are identified lead to sanctions and the size of these sanctions.