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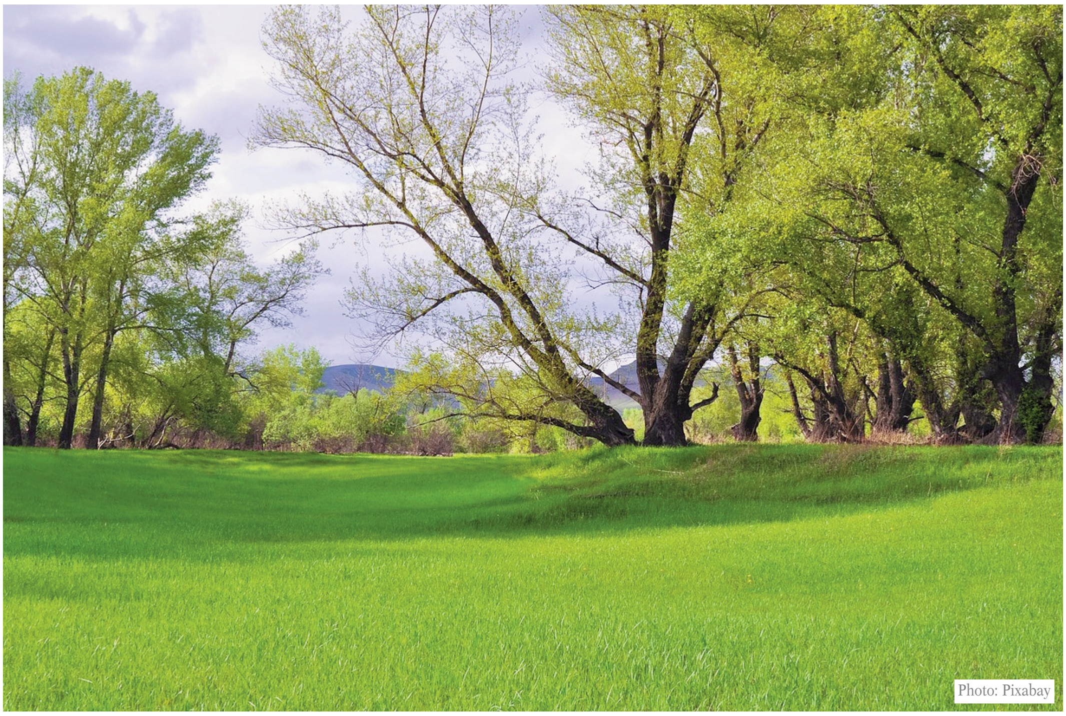
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Metrology for a sustainable environment

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THE OIML BULLETIN IS THE JOURNAL OF THE ORGANISATION INTERNATIONALE DE MÉTROLOGIE LÉGALE

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■ Editorial

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METAS

Deuxième Vice-président du CIML

La métrologie au service d'un environnement durable

Le travail des métrologues du monde entier peut contribuer à atteindre les objectifs de l'Agenda 2030 pour le Développement Durable (ODD), adopté par tous les États membres des Nations unies en 2015. Les dirigeants mondiaux ont affirmé dans le préambule de l'Agenda 2030 leur détermination « ...à protéger la planète de la dégradation, notamment par une consommation et une production durables, une gestion viable de ses ressources naturelles et une action urgente sur le changement climatique, afin qu'elle puisse subvenir aux besoins des générations présentes et futures ». Les articles de cette édition du Bulletin de l'OIML démontrent comment le travail des métrologues peut fournir une expertise pertinente, et comment ce travail peut contribuer de manière substantielle à la réalisation des objectifs des ODD en utilisant des exemples concrets.

Le concept d'« économie circulaire » a gagné en importance en tant qu'approche permettant de relever efficacement certains des défis les plus pressants en matière de développement durable. En outre, il est très prometteur car il agit comme un catalyseur potentiel pour accélérer la mise en œuvre de l'Agenda 2030. Le concept d'économie circulaire, c'est-à-dire une économie dans laquelle les produits et les matériaux sont maintenus en usage et deviennent une ressource pour d'autres, permet de boucler la boucle des écosystèmes industriels et de minimiser les déchets. L'une des contributions de cette édition illustre à l'aide de trois exemples comment la métrologie peut être un vecteur de ces changements importants.

En outre, trois articles présentent les effets négatifs de la pollution sur le changement climatique, ses effets néfastes sur la santé, et l'importance de mesurer avec précision la concentration des émissions. L'une de ces contributions explique la nécessité d'une nouvelle métrologie, la concentration en nombre de particules et le développement de nouveaux contrôles techniques périodiques des gaz d'échappement des véhicules ; elle résume également la législation en vigueur dans divers pays. Le deuxième article montre comment la métrologie joue un rôle crucial dans l'amélioration de la qualité des données utilisées pour la surveillance de l'environnement et comment les Recommandations de l'OIML contribuent à la cohérence des données entre les pays. Le troisième article informe sur les recherches entreprises sur la technologie de mesure spatio-temporelle des émissions de gaz à effet de serre.

Enfin, trois autres articles fournissent un examen complet de l'utilisation des technologies numériques et intelligentes en métrologie, qui peuvent accélérer et maximiser les effets positifs sur les ODD. Le premier article traite de l'importance croissante de la science des données en métrologie. Les auteurs expliquent notamment comment le traitement et la transmission des résultats de mesure sont importants pour relever les défis croissants de la transition énergétique et du changement climatique. Un autre article décrit comment les technologies axées sur les données peuvent renforcer l'infrastructure de la qualité, et informe sur le rôle du groupe de travail de l'OIML sur la numérisation dans le contexte de cette mission. Le dernier article souligne le rôle central de la métrologie légale pour les compteurs intelligents dans la réduction de la consommation d'énergie et l'amélioration de l'efficacité énergétique.

Tous les excellents articles de cette édition illustrent de manière très engageante et claire comment le travail de la communauté de la métrologie légale dans le domaine du développement durable et du changement climatique est un catalyseur pour la réalisation des ODD. J'espère que vous apprécierez cette édition du Bulletin. ■

Dr Bobjoseph Mathew

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Head of Legal Metrology

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CIML Second Vice-President

Metrology for a sustainable environment

The work of metrologists around the world can help achieve the Goals of the 2030 Agenda for Sustainable Development (SDG), adopted by all the United Nations Member States in 2015. World Leaders affirmed in the preamble to the 2030 Agenda their determination "...to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations". The articles in this edition of the OIML Bulletin demonstrate how the work of legal metrologists can provide relevant expertise, and how this work can contribute substantially to the achievement of the SDG goals using concrete examples.

The concept of "circular economy" has gained increasing importance as an approach that efficiently tackles some of the most pressing sustainable development challenges. Additionally, it provides much promise by acting as a potential catalyst to accelerate the implementation of the 2030 Agenda. The concept of a circular economy, i.e. an economy in which products and materials are kept in use and become a resource for others, closes the loop in industrial ecosystems and minimises waste. One of the contributions in this edition illustrates with three examples how metrology can be an enabler for such important changes.

In addition, there are three articles presenting the negative effects of pollution on climate change, its adverse health effects, and the importance of accurately measuring the concentration of emissions. One of these contributions explains the need for new metric, particle number concentration and the development of new periodic technical inspections of vehicle gas exhaust; it also summarises the current legislation in various countries. The second article illustrates how metrology plays a crucial role in improving the quality of data used for environmental monitoring and how OIML Recommendations contribute to data consistency across countries. The third article informs on the research undertaken on spatiotemporal measurement technology of greenhouse gas emissions.

Finally, three further articles provide a comprehensive review of the use of digital and smart technologies in metrology, which can accelerate and maximise the positive effects on the SDGs. The first article discusses the increasing importance of data science in metrology. In particular, the authors explain how the processing and the transmission of measurement results are important to address the growing challenges of energy transition and climate change. Another article describes how data-driven technologies can strengthen the quality infrastructure, and informs on the role of the OIML Digitalisation Task Group in this endeavour. The final article highlights the pivotal role of legal metrology for smart metering in reducing energy consumption and improving energy efficiency.

All the excellent articles in this edition illustrate in a very engaging and clear way how the work of the legal metrology community in the area of sustainable development and climate change is an enabler for the achievements of the SDGs. I hope you enjoy this edition of the Bulletin. ■

CIRCULAR ECONOMY

Circular economy and metrology

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Abstract

Many national governments and several business organisations worldwide promote the circular economy as a substitute to today's linear system. In a circular economy a product at the end of its shelf life will become a resource for others, thus closing loops in industrial ecosystems and minimising waste. Metrology can be an enabler of such changes, e.g. by tackling analytical challenges to collect, assess, sort, or recycle waste. In general, multi-disciplinary approaches and new measures are necessary to overcome such challenges. Three examples are shown ranging from assessing the amount of content from technological critical elements in electronic waste, the recovery of phosphorous from wastewater, sewage sludge or sewage sludge ash to the absence of peat in growing media. Applied metrological solutions range from advanced analytical methods to certified reference materials, which enable industry to make a swift transition and provide the legislator with the means to monitor and assess regulatory measures.

1 Introduction

The circular economy has emerged as a substitute to today's linear system, which now appears to be reaching its physical limitations. The linear system based on "extraction-production-disposal" maximises the flow of resources [1]. According to [2] the world generated 2.01 billion tonnes of municipal solid waste in 2018. For the estimated population growth to 9 billion people in 2050 global waste will reach 3.40 billion tonnes. In particular, 75 % of all plastics ever produced have become waste, and volumes are rising quickly. The global production of plastics was over 450 million metric tons in 2018 and, if present growth rates continue, will triple by 2050 [3]. Other products of major anthropological and environment concerns are e.g. cement and electronics.

In contrast to the linear system, a circular economy will turn a product at the end of its shelf life into a resource for others, thus closing loops in industrial ecosystems and minimising waste (see Figure 1). The concept of a circular economy is not a new one. Already

Figure 1: In a circular economy, cycles are created by sharing, reusing, repairing, remanufacturing, refurbishing, and recycling [5].

40 years ago, the European Commission (EC) described the concept in a report [4]. In 2014, under the European Union (EU) Horizon 2020 programme the EC launched the first calls for circular economy proposals. Today, many national governments and several business organisations worldwide promote the concept of circular economy. To do so, governments work closely with industry, support innovative environmental technologies, and take regulatory measures in individual cases.

2 A topic for metrology?

Examples of instances where a change from a linear system to a circular industry was economically beneficial include Xerox (selling modular goods as services), Caterpillar (remanufacturing used diesel engines), USM (modular furniture), Adidas (renting shoes) and AB InBev (drinks in returnable glass bottles). It is expected that more industries will develop circular material flow if there is a resulting economic advantage. Metrology can be an enabler of such changes, e.g. by tackling analytical challenges to collect, assess, sort or recycle waste. In general, multi-disciplinary approaches and new measures are necessary to overcome such challenges. In cases where the change is not economically beneficial regulatory measures, such as prohibition, limits or taxations, are necessary. These cases resemble analytical questions already addressed for other legal limits or prohibited goods. In the following paragraph, three examples show where metrology can be an enabler for the change to the circular economy.

3 Case studies

3.1 Technological critical elements (TCEs) in electronic waste

In everyday life, tools using innovative technologies, such as electronics, renewable energy, transport, agriculture, health, and the military are widespread. These technologies have in common an absolute dependence on so-called technology-critical elements (TCEs). TCEs comprise the rare earth elements (REEs), the platinum group elements (PGEs), and others such as Gallium (Ga), Germanium (Ge), Indium (In), Niobium (Nb), Antimony (Sb), Tantalum (Ta), Tellurium (Te), and Thallium (Tl) [6]. Most of these elements occur in nature only in traces and their extraction is very complex, requires a lot of energy, and is extremely harmful to the environment. However, the available amounts of TCEs are limited.

The EU has classified the raw material supply of TCEs as critical. Since these elements do not occur naturally in Europe and the EC wants to reduce dependencies on the main producers of these elements, their extraction from e-waste is the preferred route to obtain them. In addition, the recovery of these elements from electronic scrap provides the opportunity to reduce environmental damage caused during extraction of the TCE containing ores. Up to now recycling rates for TCEs are still low [7]. This is partly due to the very inhomogeneous e-scrap with low yields of the rare TCEs but also due to a variety of different metals present in this “raw material”, which makes efficient extraction processes very complex. Meanwhile the amount of waste continues to increase. In 2019, Europe produced 12 million tons of electronic waste, which corresponds to 16.2 kg per capita, the highest in the world [8]. This waste is referred to as “urban mine waste” as it contains valuable TCEs in potentially high quantities. In the urban mine, the Gold (Au) mass fraction is estimated at 200 g/t in cell phones, whereas it is only around 5 g/t in primary ore [9, 10]. Therefore, because of the criticality and the implications of TCEs for impact on the economy, the environment, and human well-being, there is a pressing need to develop analytical techniques to conduct ecological and human health risk assessments [11].

The EC has identified TCE recycling as a priority of the “circular economy” agenda. However, methods to precisely measure TCE content in electronic waste, along with a lack of certified reference materials, limits the interest and capability of recycling industries to tackle this challenge. To overcome it, an international consortium launched the EMPIR “MetroCycleEU” project last year (see Figure 2). Reliable metrology is indispensable and is a key factor for this task because here too, accuracy, objectivity and quality of measurements are crucial. In order to master these challenges, several European metrology institutes are working together to establish both accurate and precise yet easy-to-use methods for TCE content determination in electrical scrap and to produce certified reference materials in this field. The knowledge gained in this way should increase the efficiency and accuracy of TCE recycling. The project goal is to develop validated SI-traceable reference methods and materials to determine the amounts of 14 different TCEs in urban waste at parts-per-million levels [12]. Reaching this goal should facilitate the take-up of this technology.

3.2 Phosphorus in wastewater, sewage sludge, or sewage sludge ash

A consultative paper drafted by the EU in 2013 states:

"Phosphorus is an essential building block of life. It is an irreplaceable part of modern agriculture, as there is no substitute for its use in animal feed and fertiliser. The current situation, involving waste and losses at every step of the phosphorus life cycle, contributes to concerns about future supplies and water and soil pollution, both in the EU and worldwide. With efficient production and use, as well as recycling and minimisation of waste, major strides could be made towards the sustainable use of phosphorus, thereby setting the world on a path towards resource efficiency and ensuring that reserves are still available for the generations to come" [13].

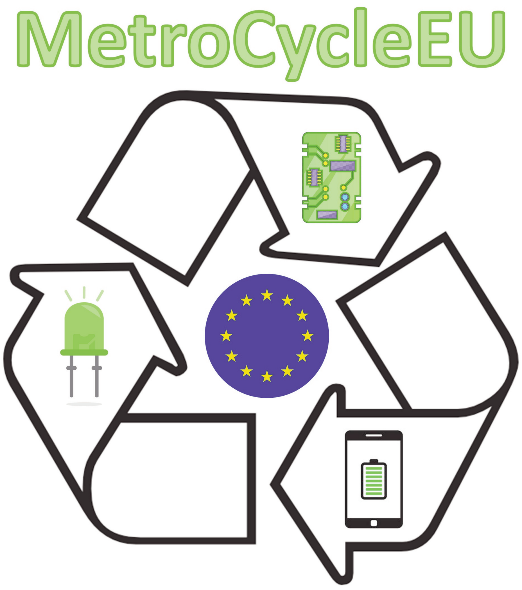

Figure 2: The "MetroCycleEU" project (www.metrocycle.eu) will develop Metrology for Technology Critical Elements.

The subject is still of huge importance. Considering the circumstances in Switzerland, where 783 wastewater treatment plants recover about 5 700 tonnes of phosphorus each year [14], which would cover the domestic agriculture needs of the country for the valuable mineral, demonstrates this fact. In addition, phosphorus recycling would minimise the use of phosphate ores, hence also avoiding huge areas of contaminated mining fields and contamination of used process water. Even more, recycled phosphorous shows a much lower content of heavy metals, such as cadmium and uranium. Yet, the risks of concentrating heavy metals in the recycled phosphorus and the introduction of other contaminants over several recycling cycles remain.

The Swiss Waste Ordinance requires the recovery of phosphorous from wastewater, sewage sludge, or sewage sludge ash by 2026. German regulations foresee the same from 2029 onwards. To reach this goal, several new processes for the future energy and material recovery of sewage sludge have been evaluated [15]. For example, the "Phos4life" process is based on the existing process of sewage sludge drying with a subsequent pyrolysis. During the pyrolysis, the sewage sludge is thermochemically utilised. The process produces electricity, waste heat and a phosphate-containing valuable material (see Figure 3). The electricity will feed into the grid as renewable electricity, the waste heat can be utilised in a local district heating network, and the phosphate containing material can be reused by a fertiliser manufacturer [15, 16]. This type of process guarantees an almost complete recovery of phosphorous, and the remaining mineral part of the sewage sludge is burned in a cement plant. An additional benefit is the reduction in the landfill volume, which offers further convincing ecological advantages.

Figure 3: Phosphorous-containing fertilisers.

Thus, in short time, it will be feasible to recover phosphorus from sewage sludge in a reasonable yield and to market it as a technically pure, commercially available product. To assure a high quality of the recycled phosphorus, certified phosphorous reference materials have to be established with a well-described level of contaminants, as well as the development of robust, but easy to use analytical methods to determine these contaminants in the raw material as well as in the finished fertilizer.

3.3 Peat in growing media

The preservation and restoration of peatlands are among the key factors for climate change mitigation. Natural peat bogs cover only 3 % of the earth's surface [17] but they store around 25 % of the global soil organic carbon [18, 19]. The degradation of peatlands through drainage and through peat mining leads to aerobic mineralisation of the stored organic matter and causes the emission of important quantities of greenhouse gases. As such, it has been estimated that the destruction of peat bogs is responsible for around 5 % of the global anthropogenic carbon dioxide emissions (~ 2 billion tons of CO_2) [20]. Besides being an important source of greenhouse gases, peat mining destroys the sensitive ecosystems of peatlands. Raised peat bogs grow over several thousand years and therefore take centuries to recover from peat extraction.

Of the 63 billion m^3 of peat extracted annually in Europe, around half is used for growing media in horticulture [21]. In order to decrease their greenhouse gas emissions, several European countries have therefore declared the aim to reduce or, in the future, ban the use of peat in growing media. On the one hand these ambitions require further research on peat substitute products for growing media; on the other hand a ban of peat in horticulture requires the development of a method for identifying, and ideally quantifying, the peat content in growing media. The main challenge in developing the above-mentioned method consists in the heterogeneity of the peat material. Peat bogs in different climatic zones are home to different vegetation while the type of peatland (fan bog, low peat, raised bog) leads to different levels of degradation and can vary in time within one peat bog. Previous studies have listed a number of potential directions for peat detection [22, 23]; however, it has not yet been possible to define a method that can confidently identify peat material in growing media. In our lab, we tested two methods for peat detection: the analysis of biomarkers such as n-alkanes, and the optical identification of peat.

3.3.1 Biomarker method

Plants produce long chain n-alkanes and due to their resistance to degradation, they are preserved in soils over long periods. Sphagnum species, the main peat-forming plants, develop n-alkanes with specific chain lengths (mainly C31 and C33) [24, 25, 26]. The aim of this method is to identify the chain length of n-alkanes in a growing media sample to obtain information about the sphagnum content and thus about the presence of peat [22]. In addition, we identified the quantity of hopanoids in the samples. Hopanoids are large molecules produced by microorganisms that are abundant in peat bogs [27, 28]. N-Alkanes and hopanoids are extracted from dried and homogenised samples with organic solvents (dichloromethane: hexane, 1:1). Extracts are separated by polarity over a chromatographic column and subsequently measured by gas chromatography-mass spectrometry (GC-MS). We compared different parameters such as the concentration of hopanoids, the ratio of odd to even chain lengths of n-alkanes, and the relative concentrations of n-alkanes with specific chain lengths (C29, C31 and C33) in peat and peat-free samples.

None of the tested parameters in peat samples clearly differs from their values in peat-free samples. However, the combined parameters distinguish these two groups of samples. A principal component analysis of seven parameters shows a clear difference between peat and peat-free growing media (see Figure 4). These preliminary results suggest that the concentrations of n-alkanes with specific chain lengths and hopanoids in peat are characteristic and differ from the tested peat-free samples. However, it is probable that mixed samples of peat in growing media remain challenging to identify.

3.3.2 Optical methods

Furthermore, we tested the identification of peat by microscopy. In a peat-containing growing media, the tissue of peat-forming plants should be identifiable under a microscope. The most evident peat-markers are sphagnum species [23] as they occur in most peat bogs worldwide. We were able to detect the tissue of sphagnum in most of the peat samples studied. The main issue of this method is, however, that in strongly decomposed peat samples, the sphagnum tissues are no longer identifiable. Therefore, we are testing a new method focusing on the identification of microorganisms. Some microorganisms that are preserved over long periods of time in sediments are specific to peatlands and can therefore be used as a marker for peat.

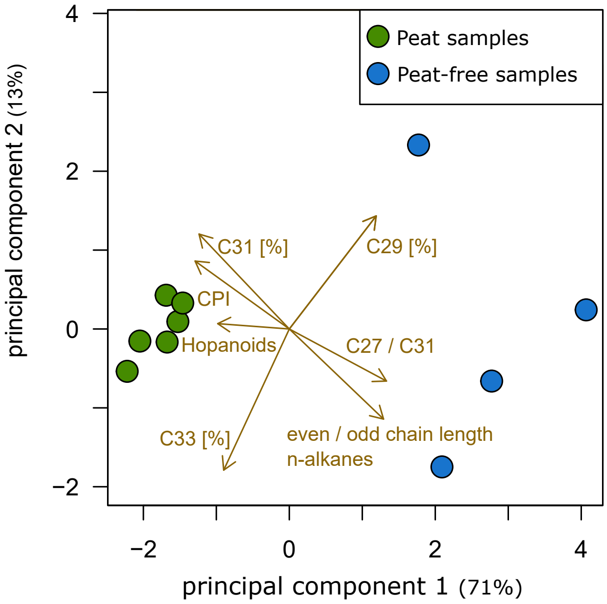

Figure 4: Principal components of n-alkanes and hopanoids in peat and peat-free growing media. Analysed parameters are:
Hopanoids (total concentration),
C31 (relative concentration of C31 n-alkane: C31/(C23+C29+C31+C33)),
CPI (carbon preference index),
C33 (C33/(C23+C29+C31+C33)),
C29 (C29/(C23+C29+C31+C33)),
C27/C31,
even/odd chain length n-alkanes (C24+C26+C28+C30+C32+C34+C36)/(C23+C25+C27+C29+C31+C33).

4 Summary and conclusions

The three examples described:

- assessing the amount content from technological critical elements in electronic waste,
- the recovery of phosphorous from wastewater, sewage sludge or sewage sludge ash, and
- the absence of peat in growing media

show that metrology is a key enabler for a swift transition from today's linear system to a circular economy. Both industry as well as regulators are in need of multi-disciplinary metrological solutions to undertake and monitor this transition. Metrological solutions range from advanced analytical methods to certified reference materials. It is expected that more industries will develop circular material flows in the near future, triggered by either economic benefits or regulatory measures. Thus, metrology institutes around the world need to engage with key stakeholders and develop new capabilities to address their needs. ∎

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PARTICLE CONCENTRATION

New periodic technical inspection of diesel engines based on particle number concentration measurements

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Abstract

Combustion particles must be monitored closely because of their role in climate change and their adverse health effects. Modern combustion engines emit small particles with negligible mass, but still at high number concentrations. The conventional metric, particle mass (PM) concentration fails to measure correctly the particle load in the exhaust gas. There is a need for a new metric, particle number (PN) concentration, and novel portable PN-measuring instruments suitable for tests directly at the vehicle tailpipe. European countries have recently started to develop new PN-based technical inspection procedures for vehicles. However, the lack of standardization/harmonization causes confusion among end-users and has to be urgently addressed.

1 Introduction

Airborne particles cause serious, acute and chronic human health effects [1]–[4], associated with several hundred thousand premature deaths in the EU each year. For historical reasons, atmospheric particulate pollutants have been regulated for human health purposes by the mass concentration of discrete size fractions: PM_{10} and $PM_{2.5}$ (particles with diameter below 10 µm and 2.5 µm, respectively). This metric, however, cannot account for ultrafine particles (<100 nm), the mass of which is negligible. Yet, it is these ultrafine particles (predominantly combustion particles, also known as soot) from diesel and gasoline vehicles, which are associated with the highest health risks. Moreover, combustion particles from automobile engines consist mainly of black carbon (BC) and have been identified as an important climate-forcing agent [1], [5].

There is therefore a strong need to control traffic-related particle emissions more efficiently. Equipping diesel engines with diesel particle filters (DPFs) was a major step forward, but DPFs cannot ensure low emissions over the whole service life of the vehicle. It has recently become clear that the DPF lifetime is unpredictable and that vehicles equipped with "cracked" DPFs emit as much particulate matter as those without one. Moreover, gasoline direct injection (GDI) engines can also emit high number concentrations of particles. Conventional methods for vehicle emission control, such as opacity (smoke) meters and on-board diagnostic (OBD) systems fail to detect high particulate emissions caused by defective DPFs or GDI engine malfunctions. As a result, vehicles with emissions exceeding several times the national target limits evade regulations and are still allowed to circulate on the roads. It has been shown that a rather small fraction, ≈10 % of the vehicles, is responsible for more than 80 % of the total fleet emissions [6].

Countries such as Switzerland, Germany, the Netherlands and Belgium have recently introduced national legislation for periodic technical inspection (PTI) of vehicle emissions based on the measurement of PN concentration. Other EU countries are expected to follow in due course. PN concentration is without a doubt the metric of preference for measuring ultrafine particulate emissions, however, it is a relatively new metric and a number of steps need to be taken in order to standardize both laboratory-based and field measurements:

- A new class of low-cost, (trans)portable PN-measuring devices suitable for field tests directly at the vehicle tailpipe is needed for the new periodic technical inspection of vehicle gas exhaust. This instrument class, hereafter referred to as PN-PTI instruments, will replace the conventional opacity meters (and OBD measurements). It is estimated that in Germany alone more than 30 000 PN-PTI instruments will be gradually introduced on the market as of 2023. In Switzerland, Belgium and the Netherlands more than 4 000 instruments in total will be introduced as of 2022. Metrological and technical specifications must be defined and harmonised across Europe for the type-approval of the PN-PTI instruments to eliminate inconsistencies between the existing regulations and their application in practice.

- There are two types of technical inspection under the EU Roadworthiness Package: on-the-spot roadside inspections and periodic checks, where owners have to take the vehicle to a specialist center. Under EU law, unannounced roadside inspections of commercial vehicles can be carried out in any EU country, whether or not the vehicle is registered in the EU. These checks include emissions among other tests. The measurement protocol for the new periodic technical inspection needs therefore to be harmonized in Europe to ensure fair and effective implementation of regulations across the continent.
- National Metrology Institutes (NMIs) need to standardize and validate their primary and secondary standards at high particle number concentrations, i.e. up to several hundred thousand particles per cm^3, to meet the demands of PN-PTI regulations and industry.

This article summarizes the current legislation in Switzerland, Germany, the Netherlands, and Belgium.

2 National legislations

2.1 Regulations in Switzerland

2.1.1 Follow-up inspection of diesel vehicles

A vehicle registered in Switzerland must be inspected regularly. During the official follow-up checks, tests are also carried out to ensure that the exhaust-relevant equipment does not have any defects. Since the opacity and filter measurement methods prescribed so far are not sensitive enough to detect every defect in the particle filters, in the future a more accurate measurement procedure based on PN concentration measurements will be used for vehicles with a mandatory diesel particulate filter. This ensures that defective particulate filters in exhaust gas purification systems are detected quickly and reliably. The Federal Department of the Environment, Transport, Energy and Communications (DETEC) has amended the *Ordinance on the Maintenance and Re-inspection of Motor Vehicles concerning Exhaust and Smoke Emissions* (SR 741.437) accordingly. The amendment will come into force on 1 January 2023 [7]. The PN limit values are 2.5×10^5 cm^{-3} at 2 000 revolutions min^{-1} and no load, or 1×10^5 cm^{-3} at low idle conditions. The measurement must be performed using a particle counter approved under Swiss Regulation SR 941.242 [8]. This regulation, first adopted in 2013, was originally developed for PN testers for non-road mobile machinery in Switzerland and subsequently revised three times.

The first PN-PTI instrument approved by METAS was the Nanoparticle Emission Tester Model 3795 (NPET, TSI Inc., USA) in 2015. Recently, three instruments, the HEPaC (University of Applied Sciences Northwestern Switzerland, Switzerland), the CAP3070 (Capelec, France) and the DiTEST Counter (AVL, Austria) were also approved according to Swiss Regulation SR 941.242. More type-approvals are currently under way.

2.1.2 Technical requirements according to Swiss Regulation SR 941.242

The technical requirements for PN-PTI instruments are described in Annex 4 of the *Ordinance of the FDJP on Exhaust Gas Analysers* (SR 941.242; in German also known by the acronym VAMV). Interested readers are referred to the original documents published in German, French and Italian [8]. Here, only a selection of the technical specifications will be listed to support the discussion in Section 3.

Measuring range

The measuring range for the nanoparticle number concentration is at least between 5×10^4 cm^{-3} and 5×10^6 cm^{-3}.

Nominal operating conditions

Climatic, mechanical and electromagnetic ambient conditions:

– Range for ambient pressure from 860 hPa to 1060 hPa;
– Mechanical environment class M2 [9];
– Electromagnetic environment class E2 [9].

Error limits

Depending on the particle size and particle composition, the measuring instrument must exhibit an efficiency E over the entire measurement range within the limits specified in Table 1.

Table 1: Counting efficiency of measuring instruments for nanoparticles

Geometric mean mobility diameter	Limits of efficiency, E
23 nm nanoparticles	$E < 50$ %
41 nm nanoparticles	$E > 40$ %
80 nm nanoparticles	70 % $< E <$ 130 %
200 nm nanoparticles	$E < 300$ %
30 nm droplets of tetracontane (number concentration up to 10^5 cm^{-3})	$E < 5$ %

Counting efficiency is defined as the particle number concentration reported by the measuring instrument under test divided by the particle number concentration reported by the reference instrument.

Official measurement

The mean value is obtained from three measured values which are determined as follows:

15 seconds waiting time,
5 seconds measurement time 1 (value #1),
5 seconds pause,
5 seconds measurement time 2 (value #2),
5 seconds pause,
5 seconds measurement time 3 (value #3).

2.2 Regulations in the Netherlands and Belgium

2.2.1 Dutch regulations

The Netherlands took part in the VERT association and performed research (TNO) on the particle emission of vehicles equipped with DPFs. The research concluded that the DPF improves the air quality related to the particle number significantly. It also concluded that approximately 10 % of DPFs are broken or removed. That made the ministry of Transport and Water management decide that DPF checking during vehicle PTI is necessary. During the VERT project, NMi proposed to draft a Proposal (based on OIML R 99 *Instruments for measuring vehicle exhaust emissions*) for Particulate Number Counters. The VERT group drafted a Proposal for Particulate Number Counters in 2 parts (Part 1 *Metrological and technical requirements*, Part 2 *Metrological controls and performance tests*) [10]. The Proposal Particulate Number Counters Part 1 is implemented in Regeling voertuigen (Regulation vehicles) which regulates the PTI in The Netherlands including the measuring instruments needed for the PTI [11]. The Requirements for Particulate Number Counters were published in January 2019 and November 2020 and came into force on 1 January 2021. Type approval for Particulate Number Counters started immediately after this. The obligation to check the DPF during PTI was fixed at 1 July 2022 in order to allow sufficient time for manufacturers to obtain type approvals and subsequently produce sufficient PNCs for PTI stations to be able to purchase them.

At the time of writing this text (April 2022), 10 types of Particulate Number Counters have already received a Dutch national type approval certificate.

2.2.2 Belgian regulations

GOCA, the association of PTI centres in Belgium, also participated in the VERT association. Their research was focused on the detection of defective and manipulated DPFs. After an extensive 18-month study commissioned by the Flemish, Walloon and Brussels-Capital Region in Belgium, it was concluded that a new emission measurement that uses PN measurement instruments can reliably assess the quality of the DPF during the periodic technical inspection (PTI) of diesel vehicles. With the cooperation of the inspection centres, GOCA and its members evaluated 1006 diesel vehicles with a Euro 5 or higher Euro standard.

Vehicle exhaust particulate emissions increase with age and mileage. A significant increase in PN emissions increase was observed especially after six years and/or after 150 000 km. As the costs for replacing or repairing a DPF can be high, some end users decide to remove it completely. Thanks to the use of PN meters and their high sensitivity, manipulations of DPFs will be easily detectable in the future.

Contrary to PN counters, current opacimeters suffer from a poor detection limit. Practical tests showed that only 0.49 % of all vehicles were rejected because of an exceeded opacity standard in accordance with the current European PTI legislation (Directive 2014/45/EU [12]). None of the vehicles tested showed any problems via the EOBD MIL indicator. On the other hand, via a PN measurement, 8.7 % of these vehicles would be rejected with an assessment criterion of 2.5×10^5 cm^{-3}. The detection rate of a PN measurement is therefore considerably better than that of an opacity test. Thus, if a stationary PN test is to be used for vehicle inspection, an opacity test as imposed by the European Directive 2014/45/EU [12], seems unnecessary. Furthermore, 86 % of the diesel vehicles with a Euro 5b or higher standard have low particulate emissions, namely lower than 5×10^4 cm^{-3}, in contrast to a small number of vehicles that emit a lot more. For example, 1.9 % of the Euro 6 diesel vehicles in the test sample emitted more than 10^6 cm^{-3} particles. Such extremely high emission values were also observed when testing vehicles with removed DPF. The introduction of a PN inspection on diesel vehicles equipped with DPF, where the large polluters are detected and remedied, means that an enormous reduction in total PN emissions from diesel vehicles can be reached. With an assessment criterion of 2.50×10^5 cm^{-3}, a 90 % reduction in PN emissions can be achieved from the inspection of euro 5b and 6 diesel vehicles alone.

These conclusions were the outcome of the study, together with an implementation file including the technical requirements of the measuring devices as worked out by the VERT association, as well as the metrological verifications and tests, a proposal for a test procedure based on a low idle test, and an assessment criterion.

The three regions published the regulations in order to start with PN counting on diesel M1, N1 vehicles on 1 July 2022. (Flemish part: BVR of 14 January 2022 – Belgisch Staatsblad 24255 of 24.03.2022 [13]; Brussels-Capital Region: BHR of 17 February 2022 - Belgisch Staatsblad 24273 of 24.03.2022 [14] and Walloon region: AGW 12 March 2022 - Belgisch Staatsblad 35106 of 14.04.2022 [15]). These requirements for the PN-PTI counters are the same as in the Netherlands, thus a type approval by NMi is also accepted by the Belgian authorities.

2.2.3 Technical requirements

Measuring range

The measuring range must be at least 5 000 cm^{-3} and up to 5 000 000 cm^{-3}.

Resolution

Less than or equal to 1000 cm^{-3}.

Nominal operating conditions

– Ambient temperature range +5 to +40 °C;
– Relative humidity up to 95 % RH;
– Ambient pressure range 860 hPa to 1060 hPa;
– Mechanical environment class M2 [9];
– Electromagnetic environment class E2 [9].

Counting efficiency

Particle size	Detection efficiency
23 nm ± 5 %	20 – 60 %
50 nm ± 5 %	60 – 130 %
80 nm ± 5 %	70 – 130 %

30 nm droplets of tetracontane: removal efficiency > 95 %

Response time

The response time must be ≤ 15 s.

Registration frequency

The registration frequency must be at least 1 Hz.

Maximum permissible error

The maximum permissible error must be ±25 000 or ±25 % of real value (whichever is greater).

Official measurement

Limit 1 000 000 cm^{-3}.

15 seconds stabilization time, 15 seconds recording time, average over recording time.

Fast fail if value exceeds 2 times the limit (2 000 000 cm^{-3}).

2.3 Regulations in Germany

Due to the increasing need for the identification of manipulated exhaust system and the detection of defective after-treatment components for diesel passenger cars, measurements for particle number (PN) were introduced for the very first time in the German PTI system. They will replace the opacity measurement for diesel vehicles from emission class EUR 6/VI at the beginning of 2023. Therefore, the national PTI directive sets a limit value for EUR VI/6 diesel vehicles of about 250 000 cm^{-3} and defines a test procedure for checks in the field by the legal German vehicle inspection organization [16].

The PTI PN devices must be approved by national regulations in Germany. Two technical procedures have to be followed:

1. German PTI directive (“AU-Richtlinie”) [16];
2. PN counter specification PTB-A 12.16 [17].

Additionally, the devices must fulfil all the general requirements of the German MessEV [18], because they are measuring devices for legal purposes, and this also includes requirements of WELMEC Software Guide 7.2 [19].

2.3.1 Technical requirements

The main technical requirements are summarized below.

Measuring range

The measuring range for particle number concentration must be between 5 000 and 500 000 cm^{-3} for particle sizes of 23 nm up to 200 nm in terms of solid soot particles.

Measurement error limits

The prescribed error limits for particle number concentration are ± 75 % of the measured value with at least 10 000 cm^{-3}. This relatively high error limit was chosen because a very large number of measuring devices will be expected. The associated large number of calibrations per year can only be realized by a multi-stage traceability chain (see Figure 1). Within each step of the traceability chain, the measurement uncertainty of the particle number standard increases and so does the achievable measurement uncertainty of the calibration for the PN-PTI counters.

In the case of type examination, the PN devices must fulfil the following error limits:

- Immunity to interference: ± 75 % of measured valued with at least 10 000 cm^{-3}.

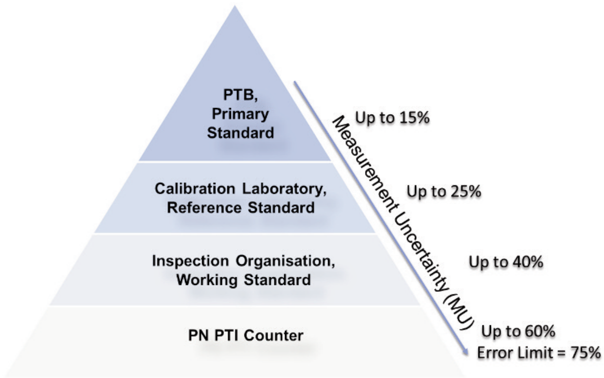

Figure 1: Possible traceability chain in Germany

- Measurement stability and accuracy with laboratory conditions except immunity to interference ± 25 % of measured value with at least 5 000 cm^{-3}.
- Measurements against a reference device with real exhaust gas emissions: ± 50 % of measured value with at least 5 000 cm^{-3}.

For particle counting efficiency at different monodisperse electrical mobility diameters, see Table 2.

The counting efficiency for PN-PTI devices during type examination at PTB is related to the requirements for Portable Emission Measurement Systems (PEMS) introduced in 2017 by the European Commission for Real Driving Emissions [20]. The counting efficiency is validated with monodisperse soot aerosols under laboratory conditions against reference particle number counters.

Operating conditions

PN-PTI devices must work between:

– Temperature: +5 °C to +40 °C
– Pressure: 860 hPa to 1060 hPa
– Mechanical environmental conditions:
  o M2 or M3, depending on the use, specified by the manufacturer [9]
– Electromagnetic environmental conditions:
  o E2 or E3, depending on the use, specified by the manufacturer [9]

Official measurement procedure for PTI

In 2021, a new procedure for PTI of diesel passenger cars (class EUR 6/VI) was published in the national PTI directive [16]. There is a warm up time for about 60 s in which an acceleration is carried out (activation of exhaust gas recirculation system) and then three consecutive measurements for every 30 s are measured by the PTI particle number counter. The mean of all three single intervals will be chosen as the reference value for pass or fail criteria within the stated measurement uncertainties.

In general, two criteria have to be demonstrated, a fast pass criterion is achieved if the particle number emission stays below 50 000 cm^{-3} in the first period after a warming up phase. In the second period, a passed limit value is achieved if concentration is below 250 000 cm^{-3} and a fail criterion when the limit value is above 250 000 cm^{-3}.

3 Towards a harmonization of the PN-PTI measurements in Europe

National Measurement Institutes (NMIs) in Europe and elsewhere have decided to standardize and validate their primary and secondary standards at high particle number concentrations, i.e. up to several hundred thousand particles per cm^3, to meet the demands of the new PTI scheme. With this aim, an international intercomparison (Euramet Pilot Study 1480) with NMIs from Europe and Asia will take place at PTB, Germany, at the end of 2022. Moreover, the Joint Research Centre of the EU is currently working on the harmonization of the PN-PTI regulations in Europe. As more countries introduce PN measurements for the periodic technical inspection of vehicles, standardization efforts will need to be intensified and geared towards ensuring international implementation of the regulations through wide consensus. To this end, the OIML TC 16/SC 1/p4 Project Group is able to play an important role.

4 Summary and conclusions

As opposed to opacity meters, PN-measuring instruments can efficiently detect even fine “cracks” in DPFs

Table 2: Particle counting efficiency at different monodisperse electrical mobility diameters

Particle size	23 nm	30 nm	50 nm	70 nm	100 nm	200 nm
Min. counting efficiency	20 %	30 %	60 %	70 %	70 %	50 %
Max. counting efficiency	60 %	120 %	130 %	130 %	130 %	200 %

and instrument manufacturers have already started to develop new portable and cost-efficient instruments for PTI procedures (PN-PTI instruments). Several countries such as Switzerland, Germany, the Netherlands and Belgium have recently introduced national legislation for periodic technical inspection (PTI) of vehicle emissions based on the measurement of particle number (PN) concentration. National legislations differ in key aspects, such as the required counting efficiency profile of the instruments or the measurement protocol used in the field. The lack of standardization and harmonization of regulations in Europe causes confusion among end-users. To ensure fair implementation of the regulations, the Joint Research Centre of the European Union is currently working on the harmonization of the regulations in Europe. The OIML TC 16/SC 1/p 4 Project Group will also aim to contribute to the international harmonization of PN-PTI requirements in the future. ■

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MEASUREMENT DATA

Data science meets legal metrology: inspiring trust in the processing and dissemination of measurement data

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Abstract

Data science is entering into metrology. An increasing number of applications in metrology and legal metrology incorporate substantial contributions from this relatively new field of science. Data science combines statistical concepts and algorithms with computer science techniques to extract knowledge from measurement data. Especially in areas where large volumes of data are collected, approaches of data science are useful in the reduction of data and the extraction of the information of interest to, for example, operate energy grids or to assess the concentration levels of air pollutants for compliance with regulatory limits. VSL's new Data Science and Modelling group is dedicated to the research and development of data science applications in metrology. The application of these more sophisticated techniques for the processing of data and the transmission of measurement results is essential to meet, for example, the challenges of the energy transition and climate change as shown by recent research projects. However, current regulations do not cover the usage of such novel techniques. Therefore supplementary regulations are needed to meet the climate targets.

Introduction

In many traditional areas of metrology small data sets are obtained to, for example, evaluate the standard deviation of a series of indications, or to obtain a model for describing the calibration data of a thermometer or a reproducibility effect in the calibration of an instrument (see annex H of [1]). There is, however, an increasing number of applications in metrology, such as in energy metering and in the manufacturing industry where much larger volumes of data are becoming available. These data are often collected to control and optimize the processes that generate them as well as, for example, for custody transfer. In this article, we introduce data science and its contribution to the energy transition. In particular, we outline how data science contributes to the management and evaluation of data from electricity and gas grids, and from air quality sensor networks. In these examples we also highlight the challenges that are brought to legal metrology by the usage of modern data science techniques. VSL's newly established Data Science and Modelling Group is a response to the increased need for mathematical, statistical and computational expertise in calibrations and in research and development.

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Data science and the energy transition

Data science is an interdisciplinary field focused on the extraction of valuable knowledge from sets of data. It uses techniques and theories from mathematics, statistics, computer science, information science and domain knowledge. A data scientist is thus someone who develops models, writes programming code, and combines it with statistical knowledge to create insights from the data. Advanced techniques with great potential come from the fields of machine learning (ML) and artificial intelligence (AI), which are closely related to data science. ML is dedicated to understanding and building methods that leverage data to improve performance on some selected tasks. AI instead is the study of systems that perceive their environment and take actions to maximize the chance of achieving the goal (these systems are also known as intelligent agents).

The fourth industrial revolution ("Industry 4.0") is about smart automation and increasing connectivity. Data science plays a key role in Industry 4.0. Since the advent of computers in the third industrial revolution, more and more data are generated and stored. Thus, it became easier to use these data to, for example, find interrelationships between different events and optimize the process to, for example, reduce undesired events and increase revenue. Process automation, already introduced during the third industrial revolution, is another key component of Industry 4.0. In fact, the overall target of Industry 4.0 is to combine automation and data science to develop a system that continuously and automatically monitors assets and processes in real time and takes decisions according to the data that it receives.

Data science is a key player also in the energy transition towards a more sustainable economy and environment. The introduction of energy from renewable sources presents new challenges where data science can contribute to a solution. Data may be used to, for example, forecast the amount of energy supplied to and withdrawn from grids, thereby contributing to the stability of operation of those grids as well as to accurate billing. Data science can also help in retrieving pieces of information that are necessary to policy makers, e.g. to reduce pollutant emissions and improve air quality. Data science thus offers tools that enable the energy transition. However, misuse of these techniques may lead to the incorrect actions being taken and to the introduction of mistrust.

Smart electricity grids

The regulation of active electrical energy meters has been internationally established in OIML R 46 [2]. The first essential requirement of these electricity meters is that they measure the electrical energy consumption correctly within the applicable maximum permissible errors (MPEs) [3,4]. However, these smart meters can also transmit information about energy consumption and generation, and instantaneous voltage, current and power levels at a high frequency (potentially up to every second) to the grid operator. In the framework of the energy transition this information is becoming of fundamental importance for the balance of the grid.

With the rapid increase of renewable sources of electricity such as solar panels at the generation side and large consumers such as electric vehicles at the consumption side the grid is becoming more congested, and rapid fluctuations at both the supply and demand side add an additional layer of complexity in operation and billing. In order to keep the grid running stably, advanced data science techniques and autonomous steering algorithms will become essential. Initial work optimizing the sensor network topology with a limited number of meters has already been carried out [5].

However, it is foreseeable that additional problems in the grid will arise in the near future, that more measurements will be needed, and that more regulatory recommendations will be necessary. This may involve both the smart meters performing the measurements, and the post-processing of their data used, for instance, to determine the stability of the electricity distribution network [6]. Therefore, it is necessary to establish groups of experts with domain knowledge both in metrology and in data science who can research the advantages and shortcomings of the different data science techniques when applied to the problem at hand. This will ultimately lead to the development of guidelines and regulations covering the new challenges brought about by the energy transition. The fact that the OIML recently established a Digitalisation Task Group [7] is a sign that the OIML, also, is aware of the impact that Industry 4.0 may have on legal metrology.

Hydrogen in gas grids

The injection of hydrogen into gas grids is another example where additional challenges are presented to transmission and distribution system operators (TSOs and DSOs). When blending hydrogen and natural gas, the blended gas has (depending on the relative volume of hydrogen injected) a substantial difference in calorific value and Wobbe index [8]. The resulting fluctuations are rather large and they affect metering performance, as well as the totalization of volume or energy delivered. There are growing concerns among TSOs and DSOs that the current measurement and computational infrastructure is inadequate for dealing with large variations in supply and demand, and in gas properties. Current models for the totalization of volume and energy (e.g. OIML R 140 [9] and ISO 15112 [10]) assume independence of the measurement results, and ignore the effects of the frequency of measurement. Furthermore, the total is approximated by a sum rather than computed by an integral, and temporal effects in data are neglected.

Hence, a comprehensive approach, based on realistic assumptions concerning the data collected and the conditions in the hydrogen supply line is lacking. The measurement uncertainty is therefore likely to be severely underrated. Models and techniques from data science will help in improving the models, thus ensuring that the results computed from these measurement systems meet the requirements of TSOs, DSOs and governments, and conform to international regulations, such as OIML R 137 [11] and OIML R 140 [9]. In the project "Metrology for the hydrogen supply chain", research is carried out into the magnitude of these effects and better models are being developed. The aim is to improve the evaluation of measurement uncertainty in fiscal metering by applying methods from, for example, data science, flow metering and the calculation of gas properties.

Sensor networks for air quality

Another example of a modern application involving metrology and data science, and having a legal aspect is given by geographically distributed sensor networks that are used for environmental monitoring. The data of such a network can be used to track how air temperature and the emissions of pollutants have been fluctuating in time and detect the presence of increasing or decreasing trends. These pieces of information might then be used by policy makers to take informed decisions regarding the type of measures to take to improve air quality and to meet the climate targets. An appropriate analysis of the measurement data that takes into account, for instance, the type of the sensors, their geographical distribution, calibration and uncertainty information of the individual sensors (possibly supplemented by information regarding the weather) can contribute to the extraction of new and more reliable insights. A correctly performed data analysis can thus assist policy makers in the decision process. However, an erroneous data processing may lead to insufficient conclusions that can result in erroneous decisions, which may have serious societal consequences.

The OIML has published a number of Recommendations related to measuring pollutants: OIML R 143 [12] and OIML R 144 [13] deal with the continuous measurement of SO_2, CO and NO_x in stationary source emissions, while OIML R 82 [14] is dedicated to *Gas chromatographic systems for measuring the pollution from pesticides and other toxic substances*, and OIML R 83 [15] to *Gas chromatograph/mass spectrometer systems for the analysis of organic pollutants in water*. Additionally, the performance assessment of single nodes of an air quality sensor network measuring gaseous pollutants in air is described in the Technical Specification CEN/TS 17660-1:2021 [16] recently published by CEN. However, a specification that addresses the analysis of the data of the sensor network as a whole does not seem to exist. Since emission measurements are achieved by a combination of sensor network measurements and mathematical modelling, a written standard addressing the data analysis for such networks with regulatory impact would be desirable, in particular when considering the increasing attention in monitoring the air quality and in regulating pollutant emissions. Currently such issues are dealt at the national level, although a harmonized international standard would be beneficial.

Data science and measurement uncertainty

The evaluation of measurement uncertainty is an essential part of legal metrology work. Measurement results are often used to assess compliance with regulatory limits, and the decision rules applied often take the measured value and the associated expanded uncertainty as inputs [17]. The evaluation of measurement uncertainty is described in the *Guide to the expression of uncertainty in measurement* suite of documents (OIML G 1-1xx GUM) [1][18][19][20]. The use of statistical methods is most prominently visible in type A evaluations of measurement uncertainty, and OIML G 1-100 [1] describes the calculation of the mean, variance (standard deviation), and covariance from series of observations.

In principle, the GUM allows for a much wider application of statistical methods in the evaluation of measurement uncertainty. The first reflection that a much wider family of models can be contemplated to describe measurement data is in OIML G-1-GUM 6 [20], which describes the development and use of measurement models [21]. The models described intend to give an impression of the possibilities, rather than very specific guidance on what to use. The use of frequentist and Bayesian statistical methods in metrology for evaluating the uncertainty of input quantities is well covered in the literature [22][23][24][25][26]. Bayesian methods, for instance, are particularly helpful in cases where there is substantive prior knowledge (i.e. knowledge about parameters before the measurement) to be combined with measurement data. An interesting example where the choice of the type A method makes a substantial difference is in the evaluation of the uncertainty of the temperature of a water bath (OIML G-1-GUM 6, 11.7.3 [20]). Modelling the readings using a time series analysis provides a standard uncertainty that is about three times larger than the naive evaluation using OIML G 1-100, 4.2 [1], which treats the observations as mutually independent. In this respect, OIML G-1-GUM 6 forms a bridge between the GUM framework for measurement uncertainty and data science and provides a mechanism to include advanced models and techniques from data science, machine learning, and artificial intelligence in the GUM framework.

Conclusions

New, more advanced data science techniques developed in fields such as machine learning and artificial intelligence are entering metrology. Especially in areas where large amounts of data are generated and collected, these approaches are valuable tools to extract knowledge and optimize operations. Here we have presented a non-exhaustive list of examples where data science could play a crucial role and speed up the energy transition towards a more sustainable economy and environment. In recent research projects on electrical grids [5], electricity meters [3] and the factory of the future [27] the need to use data science techniques proved to become more and more pronounced. Consequently, VSL established a new group dedicated to the research, development and application of data science techniques, as well as to creating best practices for the processing and dissemination of measurement data. Considering the legal and societal consequences that measurement data have in areas such as electricity grids, supply chains and air pollution monitoring, improved or supplementary regulations profiting from the application of these more advanced techniques are needed. ■

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DIGITAL TRANSFORMATION

Digital Transformation in the Quality Infrastructure - Challenges and Opportunities

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Introduction

Digital Transformation has introduced several new technologies and novel approaches for products and services. For instance, the existence and use of a large quantity of data sources is underpinning new digital services, and novel approaches for data analysis are based on artificial intelligence and machine learning. Sometimes, the corresponding data sets are not only large in volume, but are also highly complex and poorly structured; they are also volatile and of unknown veracity. Such data sets are also called Big Data and are part of the foundation for many of today's digital technologies [1].

Another fundamental aspect of Digital Transformation is the increasing use of interconnected, versatile, and often inexpensive sensors. These so-called sensor networks can be found in the "Internet of Things" (IoT) as well as in the "Factory of the Future" and autonomous systems [2]. For instance, because of the complexity of its tasks, an autonomous vehicle cannot rely on a single sensor and built-in pre-defined, deterministic algorithms. Instead, a sensor network is used to provide measured data, and machine learning / artificial intelligence is employed to derive decisions and actions based on the measured data. Moreover, digital technologies enable fundamentally new approaches in production, such as additive manufacturing. Based on three-dimensional models and digital control interfaces, this new way of production is finding its way into a wide range of applications – from consumer-created custom builds to high-end production in industry. The major advantage of additive manufacturing, also called "3D printing", is the possibility to produce single products of high complexity without deep knowledge of production technology.

These and further examples of the consequences and outcomes of digital transformation can be found in almost all areas today. In the health sector, the use of artificial intelligence is becoming a standard approach because of its performance and flexibility. Sustainable use of resources in industry and logistics is also made possible by digital technologies such as distributed ledger (blockchain) and cloud infrastructures to securely share data and information. Monitoring of climate change is based on large-scale sensor networks with machine learning for data analysis.

With the increasing integration of digital technologies into industry and society, new requirements and expectations arise for the quality infrastructure in general and for metrology in particular, see Figure 1. It is expected by customers of metrological services that these are offered in modern digital ways. That is, communication should be digital-first with platform interfaces and digital certificates instead of paper-driven processes and printed reports. The information in these platforms and contained in the digital reports should be machine-readable, i.e., read and processed by software. The information about a product should be made available

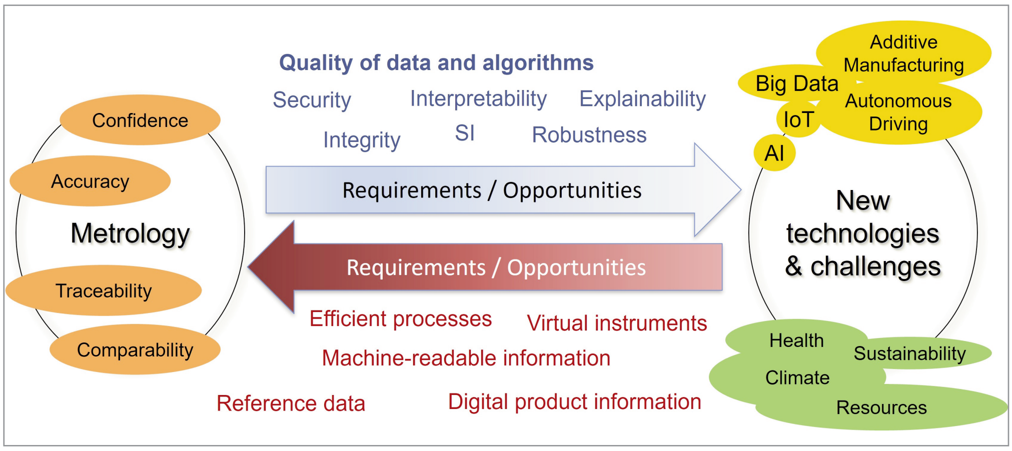

Figure 1: Mutual requirements and opportunities in the interplay of metrology and digital transformation

digitally – including its state of certification. Metrology should be able to handle virtual instruments and digital twins, which are based on simulation and may contain data-driven elements. Metrology service providers should also consider offering reference data for the assessment and certification of artificial intelligence.

Thus, there are many challenges to be addressed by the quality infrastructure. However, embracing these technologies and considering them as opportunities can strengthen the role and acceptance of the quality infrastructure and its bodies. Digital technologies make it more difficult for end-users and customers to control quality and adherence to standards and regulation. A reliable quality infrastructure for digital technologies can help to gain trust and confidence. Moreover, novel services can be provided by the quality infrastructure bodies, which are less demanding than, for instance, metrological services based on high-end measuring systems. This provides new opportunities for smaller and emerging institutes and economies.

For metrology to be integrated into digital technologies, novel digital services and products, the major benefits of metrology must be understood and communicated clearly. Metrology is providing confidence in measured data based on highly accurate measurements traceable to the SI and comparable across the globe. This in turn can become the basis for integrity and "explainability" of (big) data and artificial intelligence. The traceable calibration of measuring instruments can support interoperability and interpretability of sensor networks. Finally, the implementation of metrological principles in data formats and metadata standards can improve interoperability and machine-readability of data. Legal metrology extends these competences by considering security of "moving" and "resting" data, i.e., digital communication and data storage. This becomes even more important today than ever before. At the same time, though, the use of digital technologies must be embraced by legal metrology service providers and bodies to meet the expectations of customers and regulators.

These challenges cannot be solved by the bodies of the scientific and quality infrastructure individually. Furthermore, several of the opportunities of digital technologies can only become beneficial when several institutes and bodies interact and work together. Therefore, several international bodies of the scientific and quality infrastructure recently signed the "Joint Statement of Intent" (JSI) (see https://www.oiml.org/en/about/joint-declarations). This statement formulates the willingness to cooperate and coordinate in the wider digital transformation, starting with joint work on the development, implementation, and promotion of an SI Digital Framework, which was originally developed by the CIPM. The newly founded OIML Digitalisation Task Group (DTG) is the place at the OIML where this Statement is translated into concrete recommendations and actions for OIML. The DTG is also the group within the OIML which will actively seek to collaborate with other institutions of the international QI.

German initiative "QI-Digital"

The JSI is based on the idea that different bodies of the international scientific and Quality Infrastructure need to collaborate to ensure a successful and effective implementation of their services and aims in the digital era. The realisation of the JSI will require concrete collaborations and joint projects in which different bodies and institutions work on a joint solution, services, and technology.

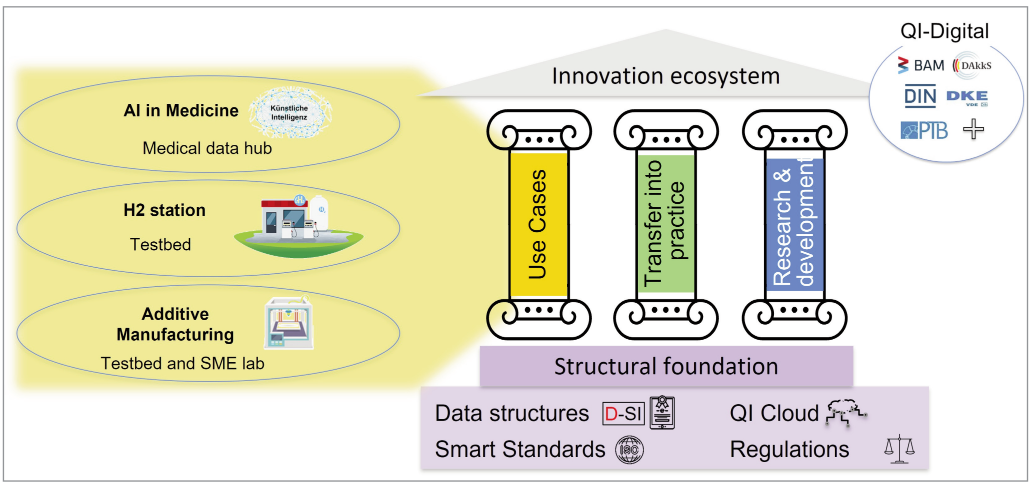

Figure 2: Concept and project structure of the "QI-Digital" initiative with the structural foundation as the fundamental basis for the quality infrastructure in the digital era

This was the intention of the "QI-Digital" initiative which was started in 2021 by five major institutes of the German quality infrastructure [3]. In QI-Digital the German national metrology institute, PTB, is collaborating with its sister institute the Federal Institute for Materials Research and Testing, BAM, the German standardisation body DIN / DKE as well as with the German accreditation body DAkkS. The main idea of the initiative is to further develop the quality infrastructure, its processes, and services such that it can efficiently and effectively address and make use of digital technologies.

The fundamental basis of a digital quality infrastructure is the "structural foundation", which contains the digital technologies required for the digital transformation of the QI, see Figure 2. This includes the definition of common data and metadata standards, a cloud infrastructure for digitalisation of processes and communication, as well as machine-readable standards. In some areas it may turn out that the regulations must also be adapted to enable the use of digital technologies, and for an effective treatment of products and services in the digital era.

The requirements for the quality infrastructure in the digital era can be understood by considering the lifecycle of a product, see Figure 3. In each step, the digital information associated with the product must be updated and potentially amended. That is, the digital product information (e.g., as a digital product pass) contains the most relevant QI-related data for the end users, manufacturers, authorities, and regulators. For instance, the product information may contain the relevant certificate information, documentation, log files and references to other data sources. At the end of the product lifecycle this information can also be used for an effective recycling of the material.

Machine-readable, smart standards and certificates can be directly integrated into such a digital product information system. For instance, the certificate of conformity can be provided, and its relevant information can be read by a software and integrated into other IT platforms, e.g. a computer system managed by the user. The standards which were used for the conformity assessment can also be referenced not only by name, but with a machine-readable reference to the corresponding part of the standard. A piece of software can thus assess the adherence of the product to standards and regulation automatically. All this could be combined using a QI cloud infrastructure which in turn would enable streamlining existing processes in the QI [4].

The challenge of digital transformation in the QI

The JSI is the expression and mutual agreement of the international bodies of the scientific and quality infrastructure to collaborate, and it is thus the first important step. However, the realization of a digitally interconnected QI also requires:

- definition of common (meta-)data standards and commonly accepted and machine-readable terminologies (e.g. expressed as ontologies and with so-called "linked data");
- machine-readable information from standards, certification, accreditation and regulations;
- application of digital twins for the assessment of products and services;
- continuous quality and conformity assessment for an effective handling of software updates and artificial intelligence; and
- digital interfaces to the platforms and data bases.

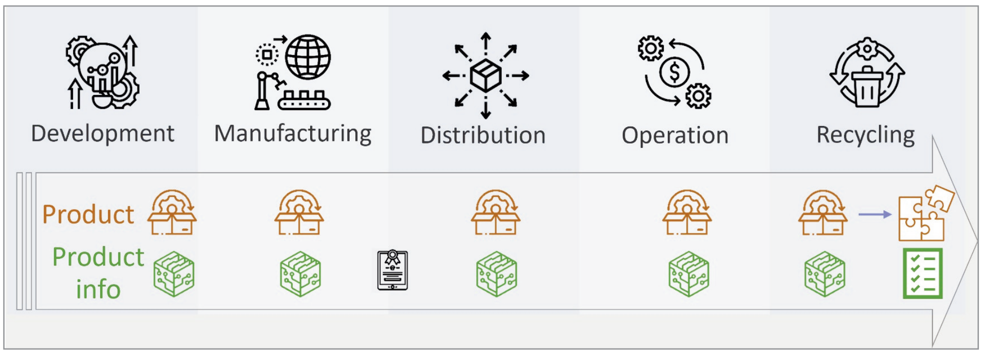

Figure 3: Product lifecycle – from development to recycling. In each part of its lifecycle, the product's digital information must be updated and amended

This is a huge challenge and can only be achieved in a joint effort of the QI bodies – nationally and internationally. For instance in standardization, developments towards machine-actionable, i.e. smart standards have already been started [5]. When Guides, Recommendations and other documents are digitally transformed in the legal metrology community, these developments need to be taken into account to ensure interoperability. In the longer term, these and other digital developments will lead to a document-free quality infrastructure with several new possibilities for products and services [6].

The role of the OIML DTG

The OIML *Digitalisation Task Group* (DTG) had its kick-off meeting in March 2022 [7]. From the start, the DTG members very actively discussed and planned its tasks and priorities. The DTG's work will realize the JSI by translating it to the core OIML activities: OIML Publications, the OIML-CS[1], and CEEMS[2]. Therefore, the DTG will seek input and collaboration opportunities within the OIML and establish interconnections with other QI bodies and activities, such as in regional organization (e.g. CECIP) and other international groups (e.g. ISO/IEC). In its activities, the DTG closely collaborates with and is supported by the BIML.

The first activities of the DTG will be in supporting the CEEMS Advisory Group (CEEMS AG) "Online Technologies" in the preparation of a guidance document, and in initiating the sharing of knowledge and experience with TCs/SCs regarding machine-readable documents and making OIML Publications "smart". ■

1 OIML Certification System

2 Countries and Economies with Emerging Metrology Systems

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ENVIRONMENT

Deep integration of metrology into environment monitoring for reducing pollution and carbon emissions in China

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1 Abstract

Metrology regulations play an important role in improving the quality of data used for environmental monitoring, ensuring the impartiality of environmental law enforcement, and providing scientific information in environmental decision-making. The International Recommendations published by the OIML and international comparisons organized by the BIPM should be promoted to ensure the consistency of environmental monitoring data all over the world.

However, metrology regulations are continuously challenged by rapidly evolving technologies. In China, the metrological technical regulations in environmental monitoring have changed significantly over the past 30 years. The National Institute of Metrology (NIM), China and the China National Environmental Monitoring Centre (CNEMC) are working together on legal technical regulations and scientific metrology research, and a joint Technical Committee on Metrology for Environmental Monitoring has been established. Metrology standards for O_3, $PM_{2.5}$ and volatile organic compound measurements have also been developed under this cooperation. Further strengthening cooperation between metrology and environmental monitoring would provide better scientific support for reducing pollution and carbon emissions in the future.

Keywords: Legal metrology, environmental monitoring, deep integration, reducing pollution and carbon emissions

2 Introduction

Metrology plays an important role in improving the quality of data used for environmental monitoring, ensuring the impartiality of environmental law enforcement and providing scientific information for environmental decision-making. With the increasing importance of the quality of the data used in policymaking, governments around the world pay more attention to the role of environmental metrology. However, environmental metrology is difficult due to the continuous changes in environmental samples. Besides, the legal metrology system is continuously challenged by rapidly evolving technologies, especially in the fields of on-site and online environmental monitoring. Only through in-depth cooperation can metrology and environmental monitoring jointly address these challenges.

Quantitative analysis of environmental pollutants is difficult due to their spatial-temporal changes as well as numerous interference factors. In cross-country environmental investigation, the analytical work should be based on the same technical specifications. The International Recommendations published by the OIML and the international comparisons organized by the BIPM have undoubtedly contributed greatly to the comparability of environmental monitoring data across countries. Without the support of well-recognized International Recommendations and international comparisons, there would inevitably be contradictions in monitoring methods and data between various countries, resulting in a huge waste of human and financial resources. Therefore, a well established traceability system should be built and the equivalence of local metrology regulations with the OIML's International Recommendations should be promoted to ensure the comparability of environmental monitoring data all over the world.

In China, the metrological technical regulations in environmental monitoring have changed significantly over the past 30 years. The focus of environmental monitoring has changed from point source pollution to non-point source pollution, from local pollution emission to regional pollutant migration, and from a manual method to an automatic method. Accordingly, the calibration requirements have changed from "beaker or pipette" into an online calibration instrument. Besides, the scope of metrology has extended to measurement data management, not merely the calibration standard management role that it had in the past. The function and tasks of legal metrology have expanded from domestic environmental monitoring data comparability to international mutual recognition. To support the transformation of legal metrology, the NIM and the CNEMC worked together on scientific metrology research and legal technical regulations, both of which will provide scientific evidence and counseling for reducing pollution and carbon emissions in China.

3 Three stages of the cooperation between metrology and environmental monitoring in China

3.1 Stage 1: Before the 1990s, manual measurements and point source monitoring

Before the 1990s, environmental monitoring in China was mainly focused on acid precipitation and industrial point source emission. Investigations were carried out on manual measurements of SO_2 and NO_x in pollution sources. Industrial waste water, emission and residue, namely the "three wastes", were the primary monitoring targets. In this stage, typical measurement methods were photometry for solution samples and flow rate measurement for samplers. Therefore, verification and calibration of pipettes, spectrophotometers and flow meters were the major demands in legal metrology. Consequently, NIM had published a series of national verification regulations, such as "Verification Regulation of Ultraviolet, Visible, Near-Infrared Spectrophotometers", "Verification Regulation of Pipette", "Verification Regulation of Rain Gauge and Measuring Cylinder", and "Verification Regulation of Weirs and Flumes for Flow Measurement".

Particulate matter pollution in this period was mainly caused by industrial point sources and retained in local areas. Corresponding metrological demands included reference materials of high concentration pollutants, verification and calibration for offline manual sampling, and monitoring instruments. In order to meet the demands of particulate matter monitoring in the mining industry, NIM had established "Verification Regulations of Dust Samplers", "Verification Regulation of Measuring Apparatus for Dust Content in Stack", and "Verification Regulation of Digital Dust Measuring Meter of Light Scattering Method" in the late 1980s, all of which provided solid supports for industrial point sources monitoring.

3.2 Stage 2: 1990-1999, assessment of environmental quality, manual and automatic monitoring

In the 1990s, along with the urban cluster development, the spatial migration of air pollution expanded from local to regional areas. China entered the stage of city-centric environmental monitoring. During this period, a nationwide environmental monitoring network, consisting of national, provincial, municipal and prefectural levels, was established. Novel measurement techniques, such as chromatography and spectroscopy were wildly deployed both manually and automatically. The demands of environmental metrology turned to the reference materials with the quantities conforming to environmental quality standards, as well as verification and calibration for samplers and monitors.

As a response, new reference materials were developed and verification regulations were established or modified. Research into the primary certified reference materials of SO_2, NO and NO_2 for chromatography or spectroscopy, and modifications of "Verification Regulation of Gas Chromatographs", "Verification Regulation of Liquid Chromatographs", and "Verification Regulation of Ion Chromatographs" provided better adaption for environmental monitoring. In accordance with the China national standard GB 3095-96 "Ambient Air Quality Standard", "Verification Regulation of Total Suspended Particulate Sampler" was established. The verification regulations of dust samplers and soot samplers were modified to reflect the changes in instrumental performance and administrative requirements.

3.3 Stage 3: 2000-2022, collaborative governance of complex air pollutants ($PM_{2.5}$, PM_{10}, O_3, Ozone precursors)

With the improvement of the nationwide monitoring network, regional monitoring of environmental quality and ecology became the primary task at this stage. Concentrations of traditional air pollutants, such as SO_2 and NO_x, have decreased greatly in many cities. Significant progress in dust and PM_{10} control has also been achieved. For emission control, the limits for vehicle emissions and ultra-low emission limits for stationary sources have been put into effect. In this period, great emphasis has been put on the metrological evaluation of performance of sensitivity, limit of detection, zero drift, etc.

Emerging pollutants have created an urgent need for new metrological standards. The pollution of fine particulate matter ($PM_{2.5}$) reached a peak level in 2013 and attracted serious concerns from society. In cooperation with China's environmental protection standards on $PM_{2.5}$ monitoring, NIM as the initiator led the joint working groups to establish the national gravimetric sampling method standard for particulate matters and the calibration specification of $PM_{2.5}$ monitors. In addition, NIM has developed the reference materials for the performance evaluation of the $PM_{2.5}/PM_{10}$ separators and has established the metrological standard of $PM_{2.5}$ mass concentration. In response to the particle number requirements in emissions limits of vehicles, NIM has developed a particle number calibration system based on a standard

Faraday cup aerosol electrometer (FCAE) and the calibration facilities for condensation particle counters (CPC) and optical particle counters (OPC). After 2018, while the density of $PM_{2.5}$ decreased, O_3 emerged as a significant photochemical pollutant. As a response, the national environmental monitoring network launched the monitoring for volatile organic compounds (VOCs) with high photochemical reactivity. NIM therefore developed several primary reference materials for VOC mixtures, such as 42 components (Methods TO-14A for the determination of toxic organic compounds in ambient air) and 57 components (critical ozone precursors). NIM has also participated in many VOCs international comparisons, so as to provide international equivalents for China's environmental monitoring data.

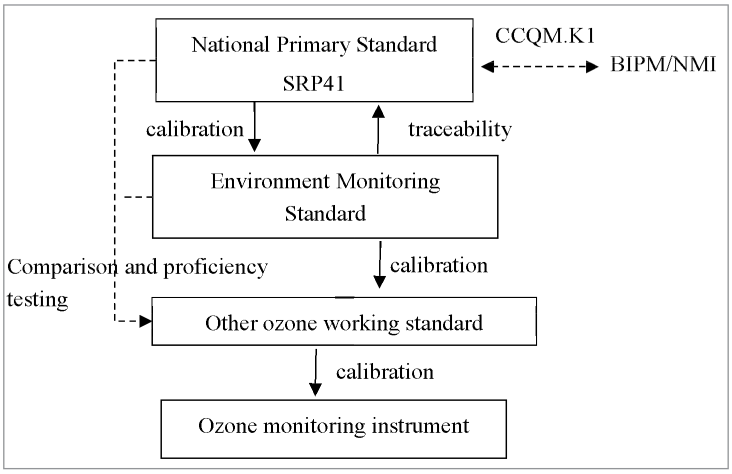

Figure 1: Ozone measurement standard and traceability system

4 Current achievements and trends in cooperation

4.1 Joint foundation of the Metrological Technical Committee of Ecological and Environmental Regulatory

In China, metrological technical committees provide key technical consulting services for legal metrology. For better interdisciplinary cooperation on legal metrology, NIM and CNEMC worked together to organize the Metrological Technical Committee of Environmental Monitoring Regulatory (MTC 41). As the first MTC established in the environmental monitoring division, MTC 41 is a milestone in building the traceability system of environmental monitoring and ensuring the accuracy and consistency of the monitoring data. By adopting corresponding OIML suggestions, international equivalences on the key definitions such as limit of detection, limit of quantitation, and the requirements of apparatus such as GC-PID and GC-FID were achieved. MTC 41 now focuses on the instruments involved in environmental management, such as assessment and evaluation of environmental quality, environmental law enforcement, tax assessment on environmental protection, discharge license, drafting and evaluation of pollution control policies, etc., and carries out the establishment and modification of the relevant metrological technical specifications to support the advancement of traceability.

4.2 Establishment of the ozone traceability system

NIM has developed the ozone primary standard (SRP41), which has successfully participated in the CCQM K1 international comparison and which has obtained Calibration and Measurement Capability (CMC) international recognition (see Figure 1). CNEMC has also developed the ozone standard (SRP-59) for the national environmental monitoring network, which was annually compared with NIM's standard. This step ensured the equivalence between the primary ozone standard in NIM and the top ozone standard in CNEMC. The two departments further jointly organized a national ozone standard comparison to ensure the unification of the ozone measurement standard.

4.3 Establishment of the traceability system of particulate matters

The traceability system of particulate matter consists of two parts: mass concentration and particle number concentration. NIM has established a measurement standard for public service as the national primary standard on $PM_{2.5}$ mass concentration, including the calibration facility and reference materials for $PM_{2.5}$ separators, gravimetric measurement standard and the calibration facility for mass concentration monitors, which covers the whole steps of sampling and measurement. See Figure 2. The traceability system of separator and mass concentration in the environmental monitoring division has been established collaboratively with CNEMC based on NIM's measurement standard. Thus the accuracy, consistency, and authority of the $PM_{2.5}$ mass concentration results in the national monitoring network were guaranteed.

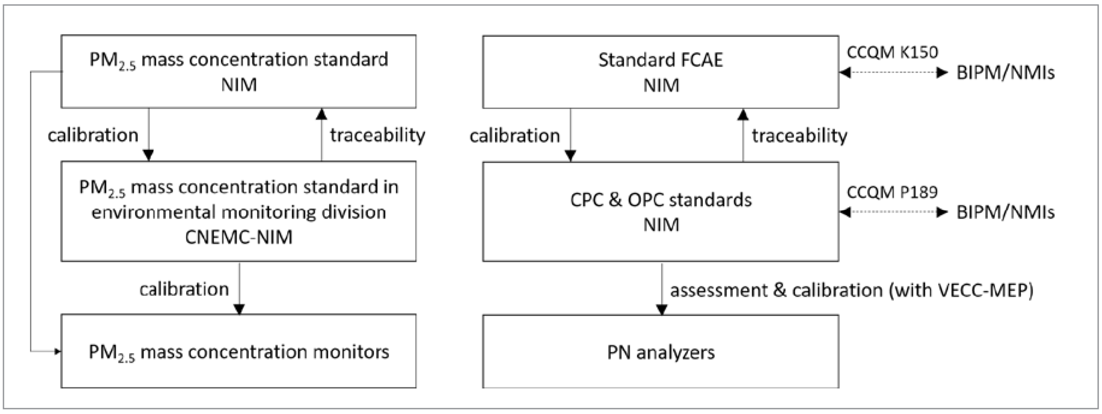

Figure 2: Traceability system of particulate matters

For particle number concentration, NIM participated in the CCQM K150 and P189 comparisons to validate the measurement capabilities on FCAE and CPC, and the CMC is now accepted and published in the BIPM KCDB. On this basis, NIM established the measurement standards for CPC and OPC, and cooperated with the Vehicle Emission Control Center (VECC) of the Ministry of Ecology and Environment of China on the performance assessment and calibration of particle number analyzers, to fulfill the legal requirements of CHINA VI limits.

4.4 Study on the effect of humidity on real atmospheric VOCs measurement

Environmental gas reference standards are usually dry gas of high concentration to ensure stability. However, real environmental samples are low concentration and high humidity. The measurement errors caused by the dilution of gas standards and the drying of environmental samples were seldom evaluated in the past. Therefore, it is necessary to evaluate the impacts of the above factors from the perspective of measurement. NIM has developed ozone precursors gas standards (57 components of mixture), and took part in the Asia Pacific Metrology Programme (APMP) comparison of APMP.S14 to verify the preparation capacity of such substances. On this basis, NIM and CNEMC have jointly developed a standard gas humidification and dilution system, which can dynamically generate standard gas with specific concentrations and simulate atmospheric humidity. The system can further achieve a 2000:1 dilution ratio in one step, with humidity simulation ranging from 0 % R.H. to 80 % R.H. See Figure 3.

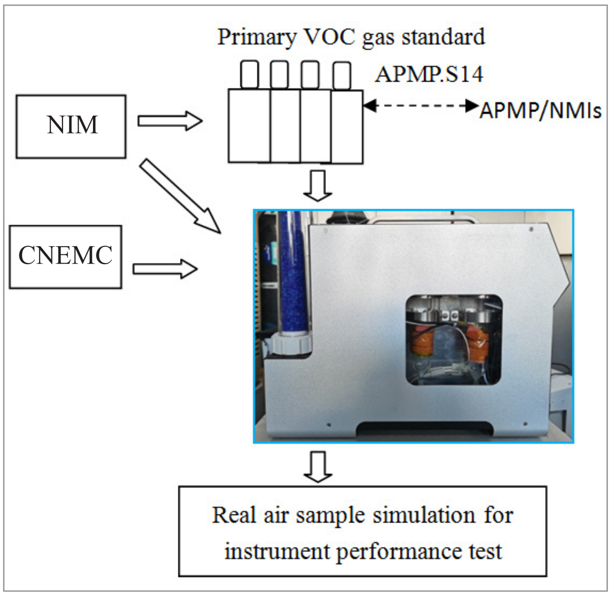

Figure 3: Dynamic dilution and humidifying system

For real ambient air, the measurement results show that rapid humidity fluctuations have a great impact on both atmospheric sampling systems and preconcentration processing systems. The deviation between hydrophilic components and high boiling point components will lead to the deviation of data from the target quality. These results will be used to draft the document "Measurement and Calibration Specifications for Ozone Precursors", which will be used to standardize the dehumidification performance and humidification calibration of the instrument in the scope of statutory measurement.

4.5 Synergy between pollution and carbon emissions control

The World Meteorological Organization has made active moves in transnational observation cooperation and government suggestions. But there is still a lot of work to be carried out on the effectiveness of the evaluation and mutual recognition of data under the framework of national measurement laws and regulations that needs to be achieved by international organizations such as the BIPM and the OIML. The OIML's International Recommendations in these emerging areas will contribute to the equivalence and mutual recognition of national measurement laws and regulations, especially for developing countries whose laws and regulations are still improving. The cooperation between NIM and CNEMC on the reduction of traditional air pollutants and greenhouse gas emissions simultaneously is also on the agenda. The two departments intend to:

- jointly develop a long-term stable, accurate and internationally-equivalent standard scale for domestic greenhouse gas monitoring;
- jointly formulate the standardized project for the preparation and maintenance of greenhouse gas standards;
- define the concentration range of the main greenhouse gases and the use of standard gases to meet the monitoring needs of regional background, pilot cities and pilot enterprises;
- accelerate the construction of China's greenhouse gas quantity value traceability and transfer system to ensure the quantity value is continuously transferred from the gas standard to the on-site analyzer;
- simultaneously build the greenhouse gas comparison and verification capability, and quantitatively evaluate whether the data quality of the monitoring station meets the target quality;
- jointly carry out capability verification and clarify the rules and methods of standard gas comparison verification; and
- set up an on-site comparison system, clarify the system construction mode and operation process, and design the comparison implementation scheme.

For particulate matter pollution, the collaborative governance of complex air pollutants and regional collaborative governance leads to new demands arising for source apportionment and boosts the evolution and application of chemical analysis methods for particulate matters.

NIM and CNEMC will promote the investigation of chemical measurements of particulate matters and the construction of the metrological technical systems including water-soluble ions, inorganic metals, EC/OC and typical organic pollutants, to establish the calibration specifications of online chemical analyzers such as online water-soluble ion analyzers and aerosol mass spectrometers.

5 Conclusion

The OIML's International Recommendations and the BIPM's international comparisons significantly contribute to the mutual recognition of measurement results among different countries. Those works are important references in the endeavor to build a worldwide recognized traceability system, especially in developing countries. In emerging areas such as greenhouse gas observation, the OIML's International Recommendations will contribute to data consistency across countries. The National Institute of Metrology and the China National Environmental Monitoring Centre have worked together on legal technical regulations and scientific metrology research, such as organizing the metrological technical committee of environmental monitoring regulations, establishing the standards for O_3, $PM_{2.5}$ and volatile organic compounds measurements, etc. Further strengthening of the cooperation between metrology and environment monitoring would better provide scientific support and counseling for reducing pollution and carbon emissions in the future. ■

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GREENHOUSE GASES

Research on spatiotemporal precise measurement technology of greenhouse gas emissions

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Abstract

This paper presents the current status and development trend of international and domestic carbon data quality. Both the preparation of the national carbon emission inventory and the verification of industrial plant carbon emissions in the carbon trading market need the support of metrology. Internationally, national metrology institutes such as those in the United States (National Institute of Standards and Technology, NIST) and the United Kingdom (National Physical Laboratory, NPL) have carried out pilot projects for direct inversion of carbon emissions in many cities, and these projects are cross-validated with traditional inventory calculation methods. Both NIST and NPL have researched the precise measurement of industrial plant emissions. The National Institute of Metrology (NIM), China has established the technical capabilities for the spatio-temporal monitoring of urban carbon emissions and the ability to accurately measure industrial plant emissions.

Spatiotemporal precise measurement technology of greenhouse gas emissions combines the two measurement methods of "bottom-up" and "top-down" to accurately measure all or typical sources of known emissions such as industrial plants and transportation, and obtain a "bottom-up" initial emission inventory. Through the establishment of multi-level monitoring sites, accurate concentration and meteorological parameters are obtained, and the initial emission inventory is corrected by using the urban-scale atmospheric inversion model to obtain a more accurate emission inventory. Unknown emission sources and sinks can be found, and emission inventories can be obtained with a spatial resolution of 1 km × 1 km and a temporal resolution of 1 hour. Combining small-area inversion and differential absorption LiDAR (DIAL) technology, it can precisely locate emission sources and measure the emissions inside the main emission area.

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Keywords: CEMS calibration; small-area inversion; large-scale inversion; differential absorption lidar

1 Status and development trend of carbon data quality

In 2020, the President of the People's Republic of China proposed to "strive to reach the peak of carbon dioxide emissions by 2030 and to achieve carbon neutral by 2060". In 2021, the national carbon emissions trading was officially launched in China. In the process of achieving the national carbon dioxide emissions peak and carbon neutralization, carbon data is the basis for promoting carbon emission reduction, and it is also the focus of compiling a national greenhouse gas emission inventory, conducting carbon trading, and imposing carbon tariffs. The quality of carbon emissions data is important to accurately judge whether countries are meeting their commitments to reduce emissions, and it is also important to the fair development rights and international competitiveness of domestic enterprises.

1.1 Carbon inventory data

The reduction in the emission of greenhouse gases requires concerted efforts by all countries in the world. There have been several rounds of negotiations under the United Nations framework for reducing greenhouse gas emissions, clarifying the greenhouse gas emission reduction obligations of all countries, and striving to control the global temperature rise within 2 degrees Celsius by the end of this century. Carbon peak and carbon neutral is the goal of carbon emission reduction in many countries. Whether each country's carbon emissions reach their peak and return to zero requires internationally recognized carbon inventory data as a support.

The traditional carbon emission inventory calculation method is based on statistical accounting data, using statistical data such as energy consumption, combined with empirical emission factors, and according to the fixed formula to calculate the theoretical emissions. Similar to the situation in many countries, China still uses the IPCC (Intergovernmental Panel on Climate Change) "1996 Inventory Guidelines" [1] and adopts traditional methods to calculate carbon emissions. As a major emitter, China covers almost all types of emission sources. At present, the uncertainties of emission data for many industries are large.

In order to ensure the data quality of carbon inventories in all countries, the 49th Plenary Session of the IPCC in 2019 adopted the "IPCC 2006 National Greenhouse Gas Inventory Guidelines 2019 Revised Edition" [2] (referred to as "2019 Inventory Guidelines" below). It has made major revisions in the acquisition of statistical accounting data and uncertainty analysis of traditional inventory calculation methods, emphasizing the important role of industrial plant-level data in national inventories. As a first step it proposes that the greenhouse gas emission inventory method based on direct measurement inversion, and the inversion method be used as the verification and modification of the traditional inventory calculation method.

1.2 Carbon trading data

Carbon emission trading can effectively reduce the cost of emission reduction. The carbon trading market needs accurate measurement methods to ensure fair trading, and meet the international data quality requirements of "1 ton reported must be 1 ton emitted".

The measurement methods of industrial plant emissions are divided into the fuel-based calculation method and the direct measurement method. The fuel-based calculation method is based on parameters such as fuel consumption and fuel quality, and is calculated according to a fixed formula to obtain theoretical emissions. The direct measurement method uses advanced instruments and technologies to directly measure the carbon emissions in real-time and obtain the actual emissions.

As China's carbon trading market is in its infancy, the monitoring and accounting method adopts the fuel-based calculation method, and there are no measurement requirements for data quality. Because the fuel-based calculation methods involve various industrial sectors and the production processes are complex and diverse, if there are no strict measurement requirements, this will cause a large uncertainty in the emission data.

From experience in international carbon trading markets, developed countries have generally adopted both the fuel-based calculation method and the direct measurement method. The United States considers that the data accuracy of direct measurement is better than the fuel-based calculation method, therefore most large and medium-sized emission sources in the US carbon trading market use the direct measurement method. At the beginning of the EU carbon trading market, only the traditional fuel-based calculation method was used, but with the continuous recognition of the advantages of the direct measurement method, since 2013 industrial plants are required to choose the method independently according to the actual situation, but whichever method is used must meet the requirements of data uncertainty.

2 Demand for metrology

For carbon emission inventory, the method of obtaining carbon emissions based on direct measurement inversion is proposed in the "2019 Inventory Guidelines" and is used for the validation and modification of traditional inventories. This method is actually a calibration of traditional inventory calculation methods to evaluate and correct traditional emission inventory data, and to judge whether the carbon emission data of a country or a region meet the emission reduction expectations.

The greenhouse gas inversion method uses the atmospheric greenhouse gas concentration data and meteorological data measured by a small number of high-altitude monitoring stations in the city, and uses the atmospheric inversion model to calculate the emissions distribution in the city. Its spatial resolution is 1 km × 1 km, and the time resolution is 1 hour. Through this technology, not only more accurate but also a dynamic greenhouse gas emissions inventory of a region, city and nation can be obtained, and the main emission sources of greenhouse gas can be found in time to assist the management department to carry out precise governance and emission reduction. In order to support the early realization of China's carbon peak and carbon-neutralization, fulfilling the emission reduction agreement, it is urgent to establish a more accurate carbon emission inventory inversion measurement method concerning the "2019 Inventory Guidelines".

For the carbon trading market, measurement can ensure the accuracy of industrial plant carbon emission verification data, ensure the fairness of the carbon trading market, and protect the right of the enterprise to develop fairly. For the verification of industrial plant carbon emissions, direct emission measurement methods can be used to check the verification data to ensure the accuracy of the emissions data. However, due to the limitation of accurate emission measurement technology in many countries, direct emission measurement as a verification method for industrial plant carbon emission data is hindered.

Industrial plant emissions are divided into stack emissions and fugitive emissions. In China, large and medium-sized industrial plants have installed Continuous Emission Monitoring System (CEMS) on the stacks, which can be monitored by adding carbon dioxide and other greenhouse gas concentration analysis modules. There are no emissions monitoring requirements for fugitive emissions.

For the CEMS stack pollutants monitoring, system according to the requirements of HJ75-2017 "Specifications for continuous emissions monitoring of SO_2, NO_X, and particulate matter in the flue gas emitted from stationary sources" and other specifications [3–6], industrial plants need to independently or entrust third-party testing agencies to regularly calibrate and compare their CEMS to ensure the accuracy of the data. However, due to the technical limitations of the calibration and comparison methods in HJ75 and other specifications, the quality of CEMS data after calibration is poor. When using different comparison methods according to the technical specifications, the standard emission data obtained by different comparison methods are significantly different, which seriously affects the judgment of law enforcement officers. Likewise, if CEMS similar to the HJ75 standard calibration is used for carbon emission monitoring, the CEMS monitoring data cannot meet the accuracy requirements of carbon trading check or verification.

According to HJ75, in order to ensure the quality of pollutants CEMS data, it is necessary to use standard gas to calibrate the concentration measurement of CEMS every week, and to use comparison methods to compare the concentration and flowrate of CEMS every 3–6 months. For CEMS concentration measurement, although a standard gas or portable flue gas analyzer is regularly used for calibration and comparison, because the influence of water vapor on the measurement results is not considered in the calibration process of CEMS and portable flue gas analyzer, it will cause a CEMS concentration measurement error. This error makes a big difference for instruments with different measurement principles. For CEMS flow measurement, although the S-type pitot tube is regularly used for comparison, because the S-type pitot tube cannot identify the flow direction, the measured value of flow velocity cannot truly reflect the axial flow velocity in the stack when there is a strong transverse flow. Therefore, it will cause a large velocity and flowrate measurement error. Moreover, since many Chinese industrial plants install CEMS on a horizontal duct, the upstream and downstream straight pipe length is short and the transverse flow is large, for example, the pitch angle or yaw angle of the flow is more than 45 degrees. The strong transverse flow will cause a significant flow velocity measurement error, and the error can be as high as 50 % or more. Therefore, the measurement technology of stack emissions is urgently needed to support the quality of CEMS data.

For industrial plant fugitive emissions, due to the lack of effective monitoring methods the management requirements of the environmental protection department for fugitive emissions are limited to whether the measures are in place, such as the requirement to adopt closed coal bunkers. However, although industrial plants have adopted corresponding fugitive emission restriction measures, industrial plants still have fugitive emissions of different sizes.

For the evaluation of air pollutants and fugitive emissions in industrial plants, the Chinese national standard [7,8] specifies the criteria for compliance. The fugitive emission of an industrial plant is usually measured at the downwind side of the plant wall or near leakage places such as doors and windows, and it is determined whether the fugitive emissions exceed the standard according to the concentration limit. Since this method cannot measure the location and amount of fugitive emissions and the concentration limit is usually high, the supervision effect on industrial plants' fugitive emissions is not ideal. If the direct measurement method is used to calculate or verify the carbon emissions of industrial plants, the traditional standards for fugitive emissions of pollutants are no longer applicable. It is necessary to accurately measure the amount of fugitive emissions of industrial plants, not just to establish whether the measures are in place and whether the concentration reaches the standard.

Therefore, in order to achieve accurate validation and verification of industrial plants' greenhouse gas emissions, the stack CEMS calibration and the accurate measurement of fugitive emission are necessary to allow the full play of metrology, which will establish and develop the "weights and measures" for the Chinese carbon trading market, to ensure the traceability of carbon data and realize the international mutual recognition of carbon data.

3 International carbon metrology research and cooperation

In terms of atmospheric inversion technology, developed countries such as the US and the UK have carried out carbon inventory pilot projects based on direct measurement inversion methods in many cities, and have achieved mutual verification with traditional inventories to ensure the accuracy and reliability of carbon inventory data.

In the US, NIST has conducted pilot work in several cities using inversion techniques. NIST has funded the Indianapolis Experimental Program (INFLUX), Los Angeles Megalopolis Project (LA Megacity), and Northeast Corridor Pilot Project (Northeast Corridor

Test Bed) to develop new measurement and data analysis techniques to monitor city carbon emissions and determine their sources. Hourly monitoring data are generated by using the carbon concentration measurement network of each city, and city grid carbon flux data are obtained by atmospheric inversion, these data can reveal the details of city carbon emission patterns and can also be used to verify the effectiveness of the inversion method.

Since 2012, NIM and NIST have established long-term cooperation. Through the initial study from NIST and subsequent independent development, the ability to accurately monitor atmospheric spatiotemporal emissions based on the direct measurement inversion method has been independently realized, which can support the verification and revision of the Chinese national carbon inventory, as well as the pilot application of a new inventory measurement method.

In terms of industrial plant carbon emission measurement, NIST took the lead in establishing a smoke stack simulation to simulate and research the online comparison methods for stack flowrate, and carried out pilot verification work in a number of power plants, greatly improving the measurement accuracy of stack flowrate comparison methods. NPL has developed a differential absorption lidar system that enables rapid measurement and verification of industrial plants' stack and fugitive emissions, and NIST is also developing lidar measurement technology.

Through cooperation and independent research with several national metrology institutes, NIM has established a traceability system for stack flowrate. A water-containing standard gas generator has been developed to simulate real flue gas conditions, which is used to calibrate the portable flue gas analyzer and CEMS. Through small area inversion and differential absorption lidar technology, the monitoring and verification of industrial plant fugitive emissions are realized.

4 Carbon measurement research and demonstration of NIM

Determination of emission sources is a necessary prerequisite for precise carbon emission reduction. Only by accurately identifying the location of main emission sources and measuring the amount of emissions can we achieve fine governance. The spatiotemporal accurate emission measurement technology is divided into two steps: "bottom-up" initial inventory measurement and "top-down" atmospheric inversion. The former means that the emissions of known emission sources are measured or calculated accurately, a grid emission inventory with 1 km × 1 km is obtained, and this data is used as the initial value to support atmospheric inversion. The latter refers to the monitoring of gas concentration and meteorological parameters in the atmospheric environment. The initial inventory is taken as the initial value, and the meteorological and concentration inversion model is continuously optimized to obtain a high-precision dynamic emission inventory and an accurate emission temporal and spatial distribution, so as to identify unknown emission sources and sinks.

The location and amount of the main emission sources can be judged by using the emission spatiotemporal distribution data, and the main emission sources can be controlled. The spatial resolution of city scale inversion technology is narrowed down to 1 km × 1 km. Small area inversion technology and lidar measurement technology can be used to make fine measurements in key emission areas and determine the specific emission location. The spatial resolution of small area inversion technology is 50 m and that of lidar is 7 m.

4.1 Emission inventory measurement

For a region, industrial plants and transportation are the main sources of emissions. In order to obtain a more precise initial emission inventory, it is necessary to measure all or typical emission sources in these sectors, and calculate the emissions and distribution of known emission sources in the region according to the measured data.

4.1.1 Industrial plant emission inventory measurement

There may be thousands of industrial plants in a region. However, usually the emissions of the top 100–200 industrial plants account for more than 90 % of the total emissions of all industrial plants. Therefore, measuring the emissions of these industrial plants with large emissions can greatly improve the accuracy of inventory data.

For CEMS concentration measurement, NIM uses a steam generator to generate water vapor and mix it with standard gas to calibrate CEMS and a portable flue gas analyzer, so as to ensure the precision of CEMS concentration calibration and comparison monitoring, and solve the defects of dry standard gas calibration. For CEMS flowrate measurement, NIM establishes the traceability system of stack flowrate, and realizes the online comparison and calibration of the CEMS stack flowmeter by using a two-step calibration method from laboratory to field. The stack velocity calibration facility

Figure 1: The stack velocity calibration facility

Figure 2: The primary stack flowrate calibration facility

developed by NIM is shown in Figure 1, which is used for multi-angle and multi-working condition calibration of the non-nulling three-dimensional pitot tube. The stack velocity calibration facility can simulate the real flue gas conditions. The velocity range is 0.5–70 m/s, the velocity uncertainty of the device is 0.58 %, and the range of yaw angle and pitch angle is ± 65°.

The primary stack flowrate calibration facility developed by NIM is shown in Figure 2. Using air as the fluid, the facility can simulate the real flow field and verify the flow measurement accuracy of the on-site stack flowrate calibration facility based on the non-nulling three-dimensional pitot tube. The flowrate range of the primary facility is 900–190000 m^3/h, and the uncertainty of the facility flowrate is 0.43 %. The test section includes circular and rectangular pipes, and the maximum pipe diameter is 1.5 m. The on-site stack flowrate calibration facility developed by NIM uses the non-nulling three-dimensional pitot tube as the standard. The facility can automatically control the movement and measurement of the three-dimensional pitot tube, obtain the measurement data, and calculate the average velocity of the stack or duct cross-section according to the model. Combined with the cross-sectional area measurement module based on laser scanning, the standard flowrate of the stack or the duct is obtained. The measuring diameter range of the on-site facility is 0.5–15 m, the maximum flowrate exceeds 10 million m^3/h, and the uncertainty of flowrate measurement is 4.8 %.

For fugitive emissions of industrial plants, NIM measures the concentration of greenhouse gases and pollutants in the atmosphere at 4 or 5 points in the industrial plant area, combined with the measurement of meteorological parameters, and uses the small area inversion algorithm to obtain the emission location and amount of fugitive emissions within the industrial plant. NIM can also use the differential absorption LiDAR mobile monitoring system to measure the fugitive emissions of industrial plants flexibly.

4.1.2 Traffic emission inventory measurement

The traditional traffic emission inventory uses the number of vehicles multiplied by the vehicle emission factor to obtain the annual vehicle emission. However, on the one hand, the data accuracy of this rough estimation is poor, on the other hand, the emission inventory obtained does not have temporal and spatial distribution information, which is not conducive to targeted emission reduction. For the traffic emission inventory, NIM has developed a traffic flow measurement system based on traffic big data and the coupling of multi-dimensional data by integrating vehicle information, GPS, gate photography, and other multi-source static and dynamic traffic data. Combined with the dynamic emission factor library related to vehicle operation status, an accurate calculation of vehicle emission is carried out so as to build a real-time monitoring system of city high-resolution transport network traffic emission, as shown in Figure 3.

The system innovatively carries out high-precision dynamic monitoring of the emission of mobile sources in the transport network hourly and sectionally. And it resolves the problems of inadequate spatiotemporal resolution and insufficient emergency support of traditional emission calculation methods, so as to provide a scientific basis for the management to grasp the dynamic evolution trend and the law of motor vehicle emission in city transport networks in real-time. By setting up electronic fences, GIS track traceability analysis and other technologies to monitor and evaluate the key indicators, and complete the fine tracking and evaluation of the implementation effect of the existing city traffic control policies, so as to lay the foundation for realizing carbon peak and carbon neutralization in the transportation industry and establish a full life-cycle transportation carbon emission accounting and verification system.

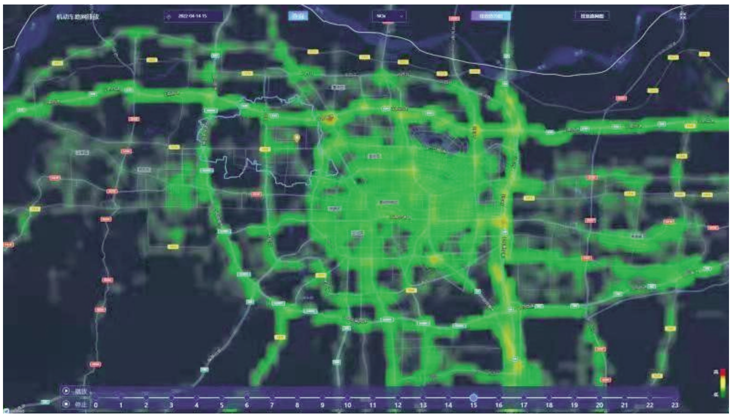

Figure 3: The real-time monitoring system of the city's high-resolution transport network traffic emission

4.2 Construction of monitoring sites

The construction of atmospheric greenhouse gas monitoring sites aims to obtain accurate emissions from inversion. Precise "top-down" atmospheric inversion depends on accurate monitoring data of concentration and meteorological parameters, so it is very important to build a scientific monitoring network. When selecting the location of greenhouse gas monitoring sites, it is necessary to comprehensively consider the local meteorological information, land use types, emission source characteristics, etc., and carry out the monitoring network location design and effect evaluation [8,9] in the target area by using the technologies of atmospheric transmission, particle diffusion, Bayesian inversion, and observation system simulation test, so as to ensure that the selected location can effectively reflect the current situation and transmission characteristics of greenhouse gas emission in city areas, maximize the monitoring role of each site, avoid redundant station construction, and reduce costs. At the same time, it is necessary to establish boundary or background observation sites according to the scope of the target area, the characteristics of regional dominant wind direction, the concentration contribution of emission sources in surrounding areas, and other factors, so as to exclude the contribution of external sources to local emissions [10,11]. The monitoring site selection scheme design for Zhengzhou was completed based on the above methods. Combined with the overall carbon emission status of Chinese cities, the technical guide for the layout of urban atmospheric greenhouse gas monitoring sites was jointly issued with the China National Environmental Monitoring Centre and the Institute of Atmospheric Physics of the Chinese Academy of Sciences.

At the same time, by adding mobile monitoring and medium precision monitoring sites, a multi-level concentration data and meteorological data monitoring network is established. During the construction of monitoring sites, a high-medium-near ground gradient is formed to realize a spatiotemporal precise monitoring system with high density and full regional coverage. At present, the high-altitude monitoring data are mainly based on various precision high-altitude monitoring sites. The medium and low-altitude monitoring data mainly come from mobile monitoring sites, low-cost monitoring sites, and near-ground monitoring vehicles, forming a height gradient, which provides basic data for city-scale inversion and small area inversion.

4.3 Atmospheric inversion

Industry, transportation, catering, and other monitoring data are "bottom-up" emission inventory. Based on the investigation, statistics, and combined with emission factors, obtaining regional greenhouse gas emission information not only requires a lot of manpower and financial resources, but also has drawbacks such as time lag and lack of temporal and spatial distribution information.

The air pollutant emission inversion system based on Bayesian statistics and Kalman filter can optimize the emission source information and obtain an objective, precise, and high-resolution real-time greenhouse gas emission inventory. The inversion can be summarized into two parts: the real world and the mathematical model. The emission of greenhouse gases in the real world is transmitted through the atmosphere and finally forms the concentration distribution. Greenhouse gas emission is the cause, and the final concentration distribution is the result. The inversion process is to deduce the emission through calculation from the result part, that is, the observation of greenhouse gas concentration. The emission inversion mainly includes three parts: atmospheric dynamic simulation, particle dispersion simulation, and the inversion optimization method.

Atmospheric dynamic simulation provides a meteorological driving field for the subsequent particle dispersion model. The mesoscale numerical weather prediction model WRF (Weather Research and Forecasting) is generally selected for city-scale simulation. The FNL (Final Operational Global Analysis) data provided by the National Center for Environmental Prediction (NECP) / National Center for Atmospheric Research (NCAR) is the common driving field of the WRF model [12]. Nested domains can ensure the precision of meteorological field simulation boundary and initial conditions, as well as the precise identification of the target region. In the regional climate model, the error accumulation will occur in the long-time integration process, resulting in the dynamic downscaling result gradually deviating from the large-scale background field. In order to solve this problem, Observation Data Assimilation (OBSGRID) and Four-Dimensional Data Assimilation (FDDA) can be added to the meteorological field simulation process to ensure that the model simulation results are close to the observation data. Based on the analysis results of the meteorological field model and the transmission model of the Lagrange random walk theory, the emission flux upstream of the concentration observation site is connected with the concentration change of the site by footprint to simulate the backward trajectory operation of a certain number of particles released by the monitoring site. Based on the backward trajectory, the model is used to calculate the distribution of greenhouse gases around the site, and the grid method is used to obtain the influence function of different grid points in the whole region (unit: ppm/(μmol·m^{-2}·s^{-1})), and finally obtain the contribution rate of the regional emission flux to the high-altitude monitoring station, with a spatial resolution of 1 km × 1 km [13].

The relationship between emission and concentration is established by using the distribution characteristics of the influence function obtained by the backward diffusion model and *a priori* emission information. At the same time, considering the difference between the simulated concentration and the observed value at the observation site, the difference between the emission posterior information and the prior information, the error covariance of the observation data and the error covariance with the prior emission, the loss function of the inversion optimization process is established, and the optimized inversion emission is obtained by iteratively calculating the optimal solution of the loss function [14]. Accurate and high-resolution carbon emission information provides data support for precise identification of high emission areas, precise emission reduction of greenhouse gases, and efficient pollution control.

4.4 Lock unknown emissions

Through initial inventory measurement, site construction, and atmospheric inversion, the emission distribution data with a spatial resolution of 1 km × 1 km, and a time resolution of 1 hour can be obtained. And the high emission area can be determined according to the emission temporal and spatial distribution. However, there may be many emission sources in the grid of 1 km × 1 km. In order to locate the emission sources more accurately, technologies such as small area inversion and differential absorption lidar need to be used to realize fine emission source locking.

Based on the city scale inversion technology, small area inversion is optimized and improved in a small area, and the local meteorological model is constructed in combination with the surface information such as buildings and trees in the area; Combined with the regional concentration monitoring data, the Bayesian inversion model and Geostatistics theory are applied to eliminate the impact of *a priori* emission inventory, and an emission source inversion and traceability model that does not rely on *a priori* emission inventory is established to realize the accurate traceability and quantitative analysis of greenhouse gases and pollutants in a small area. The measurement range of small area inversion is 5 km and the positioning accuracy is 50 m.

The movable differential absorption lidar system is the most advanced high-precision remote detection system for greenhouse gases and air pollutants in the world. Compared with traditional methods of air pollution monitoring, it can realize the accurate measurement of the three-dimensional spatial distribution of greenhouse gases. The movable differential absorption lidar system has a measurement range of 3 km and a positioning accuracy of 7 m.

5 Summary

According to the current situation and development trend of international and domestic carbon data quality, this paper expounds on the demand for carbon measurement. Both the preparation of the national carbon emission inventory and the verification of industrial plant carbon emissions in the carbon trading market need the support of measurement to ensure the authenticity of national implementation and the fairness of enterprise development.

There is an urgent need for China to establish a more accurate method/system for carbon emission inventory preparation based on direct measurement and a “metric” of the carbon market. Internationally, national metrology institutes such as the United States (NIST) and the United Kingdom (NPL) have carried out pilot projects of direct carbon emission inversion in many cities, which have achieved mutual verification with traditional inventory preparation methods. NIST has researched stack flowrate measurement, which has greatly improved the accuracy of industrial plant stack flowrate measurement. NPL has developed a differential absorption lidar system, which can realize the rapid verification of industrial plant fugitive emissions. Through cooperation and independent research with metrology institutes of various countries, NIM has obtained the technical ability of spatiotemporal monitoring of city carbon emissions and the ability of accurate measurement and monitoring of industrial plant emissions.

The spatiotemporal accurate monitoring and measurement technology of emissions integrate the two methods of "bottom-up" and "top-down". Firstly, all or typical emission sources of known emissions such as industrial plants and transportation shall be accurately measured to obtain the "bottom-up" initial emission inventory. Then, through the establishment of multi-level monitoring sites, the accurate concentration and meteorological parameters are obtained. The city-scale atmospheric inversion model is used to modify the initial emission inventory, obtain a more accurate emission inventory, and identify unknown emission sources and sinks. After obtaining the emission inventory with a spatial resolution of 1 km × 1 km, and a time resolution of 1 hour, we can judge the main emission area. Finally, combined with small area inversion and differential absorption lidar technology, the emission source is accurately locked and measured in the main emission area. This technology has achieved remarkable results in the Zhengzhou High-Tech Development District, realizing accurate measurements of spatiotemporal distribution of greenhouse gas emissions. ■

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SMART METERING

Legal metrology requirements for smart utility meters

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Abstract

Smart meters are the subject of many discussions. Nevertheless, there is no universally accepted definition of the term *smart meter*. In the context of legal metrology, the most relevant aspect is the interval metering function. When the unit price becomes time-variant, the performance of the interval metering function impacts the price to be paid and hence the confidence the parties concerned by the measurement have in the result of the measurement. Therefore, legal metrology requirements for the interval metering function are needed. Another aspect that is often discussed in the context of smart metering and data protection is the suitable technical implementation of the requirement to make the result of the measurement available to all concerned parties. This requirement is not specific to smart metering and neither is the requirement to store measurement results durably. However, the need for modern implementations is amplified by the large amount of data generated by interval meters. Where traditional meters generated one reading per year, interval meters for electricity generate one reading per 15 min – about 35 000 per year.

1 Introduction

The introduction of smart utility meters and the implications they have on many aspects of our lives has been, and still are, discussed in great detail in many different contexts. However, there is no commonly accepted definition of the term *smart meter*. The most basic of the definitions requires just a bidirectional, machine-readable interface. Another requires an interface, which may be unidirectional, to be connected to a remote readout system. Yet another definition requires the smart meter to perform interval metering, i.e. automatically store the measured values at regular intervals, typically every hour or every 15 minutes.

These two new aspects of utility meters have many implications, both practical and legal, only a few of which are relevant to legal metrology. For instance, the question of whether data protection regulation such as the European GDPR [1] is applicable or not and what this entails is very important, but is outside the scope of legal metrology. The aim of legal metrology is to allow all parties affected by a measurement inside the scope of legal metrology regulation to have confidence in the measurement (MID [2] Annex I, first sentence). From this, all other requirements are derived, for instance the accuracy requirements, but also the requirement to give access to the legally relevant result of the measurement.

In many countries, all activities of the state are based on and limited by law [3, Art. 5]. Therefore, it is essential to determine whether interval metering functions are regulated by the regulation that applies to the measuring instruments for the basic quantity and is already in force. For example, if the scope of a regulation is instruments measuring "active electrical energy", does this automatically include the interval metering function or is dedicated regulation needed? For states subject to the MID, this immediately leads to another question: is the regulation covering the interval metering function harmonised under the MID? The correctness of interval readings depends on the correctness of the measurement of the basic quantity. However, additional requirements, e.g. on the synchronisation, are needed to allow all parties affected by a measurement to have confidence in the measurement. The points related to interval metering are discussed in Section 2.

The MID calls the function of making the result of the measurement accessible to all parties "display", without defining it further. Section 3 discusses this point.

Durable storage of the measurement result is the subject of Section 4.

2 Interval metering

2.1 Applicable regulation

All parties affected by a measurement should be able to have confidence in the result of the measurement [2]. When interval readings are used for billing, this includes the interval metering function. Metrology legislation for utility meters usually covers the quantities energy and volume. In the European Union, legislation for utility meters measuring active electrical and thermal energy, as well as volumes of gas and water is harmonised in the MID. Interval meters automatically generate a reading per registration period. A registration period usually lasts 15 min or 1 h and is synchronised with the legal time such that one period each day ends at midnight. Interval readings are series of one reading of the total energy or volume register per registration period. Another possibility is to show their first derivative, averaged over the registration period. At first sight, the measurand seems to be an energy or a volume in the first case and power or volume flow rate in the second case. However, a more thorough analysis of the technical implementation shows that in both cases, the measured quantity is average power or average volume flow rate. The averages are taken over the actual registration period. Any energy or volume shown in the interval registers is the product of such an average multiplied by the rated registration period. Since the measured quantity is power or volume flow rate, the legislation for interval meters is not harmonised under the MID.

2.2 Technical requirements

Interval metering is based on three distinct basic quantities:

- the energy or volume;
- the device time; and
- the duration of the registration period.

All of these three basic quantities affect the billing-relevant measurement. The price to pay is only correct if all three basic quantities are measured correctly. For all affected parties to have confidence in the measurement, all three need to be subject to metrology legislation.

Interval meters shall have a totalising register of a cumulative quantity such as energy or volume and fulfil the respective traditional requirements for such utility meters. This simplifies the design and the testing, which can be based on traditional approaches and automated accordingly. Additionally, such a register can be used for plausibility checks by parties affected by the measurement, namely the consumer. The accuracy class for this traditional function shall be the same as for the interval metering function. Both the interval register and the total register shall respect the same MPEs. This is an indirect requirement for the resolution of the interval register: The measurement for the verification of the total register can be prolonged as much as necessary to reduce the impact of its limited resolution on the measurement uncertainty [5]. This is perfectly legitimate since the billing measurement lasts for a whole billing period, typically up to a year. For interval registers, this is not possible since the registration period is well-defined and short. It is not legitimate either since the unit price changes or can change from one billing period to the next, often by a factor of two or three. Only if the interval register respects the MPE per registration period, i.e. without taking averages over longer periods, may the measurement be used as the basis for the price to pay.

The device time shall be synchronised to the same reference that the utility uses to specify the applicable time-variable unit price. Usually, this is the legal time. The deviation of the device time with respect to legal time shall not exceed a given tolerance. A common tolerance is 3 % of the duration of the registration period. For instance, 3 % of 15 min equals 27 s. This tolerance seems very generous since modern technology allows for much more precise synchronisation. It is a compromise between synchronisation uncertainty – how well can the smart meter's internal clock be synchronised, synchronisation frequency – how often shall the smart meter's internal clock be synchronised, and impact on the price to pay – how much does the price change from one registration interval to the next.

When smart meters are not permanently connected to readout systems, synchronisation may only be practical once a year, when a meter reader passes with a portable readout terminal. Between two successive readouts, the meter's internal clock is free-running and larger deviations may accumulate. Smart meters with a permanent connection to readout systems will become increasingly common. When those are synchronised daily using state-of-the-art technology, their device time will not deviate more than 1 s from legal time in practice. When the legal basis is a performance requirement such as "the device time may not deviate from legal time excessively", it does not need to be changed when the state-of-the-art, as reflected in harmonised standards, changes.

The correctness of the device time cannot be easily checked during verification since the maintenance of synchronisation requires a power supply to be available. Prior to verification, the meter is disconnected and shipped to a verification lab, which involves a power loss for a long duration and could cause a loss of synchronisation. A practical solution is to show the device time on the display, to metrologically seal the adjustment of the device time by excessive amounts – e.g. by logging adjustments exceeding 3 % of the registration period in the metrologically sealed logbook – and to flag any data affected by lack of synchronisation. To avoid fraudulent adjustments in order to prolong some registration periods and to shorten others, the device time may be synchronised or adjusted only once per registration period. The logging reveals cases of unusual and potentially fraudulent adjustments.

The duration of the registration period shall respect specific tolerances. These translate into requirements for the short-term stability of the internal clock source, e.g. a quartz crystal. Often this tolerance is implicit since, if the short-term stability is insufficient, synchronisation will be lost quickly. As long as the synchronisation is satisfactory, the data may be used for billing. There is no independent reason for a short-term stability requirement. However, since the synchronisation cannot be checked during verification, the short-term stability is often checked. For meters designed to check the stability automatically, e.g. by logging all synchronisation processes, possibly with suitable data compression, such additional verification tests could be unnecessary.

WELMEC prepared Guide 11.2 on interval metering in 2010 [6]. WELMEC WG 11 Subgroup Electricity Drafting Group 2 is preparing an update taking into account the experience gained since. Even though interval metering is outside the scope of the MID, the Guide is based on the general requirements of the MID as much as possible, so that instruments implementing its requirement do not need to be fundamentally changed should the MID be extended to cover interval metering.

3 Display function

All parties affected by a measurement should be able to have confidence in the result of the measurement [2]. This is only possible when this trustworthy result of the measurement is also accessible to the parties concerned, otherwise they cannot compare it to a presumed measurement result claimed by another interested party. For instance, a utility will read the measurement result from a Ferraris type meter on 1 January each year, and enter it into their accounting system. It will print the results of the beginning and the end of the billing period on the bill, calculate the difference, and multiply it by the unit price to determine the price to be paid. A consumer can only have confidence in the correctness of the price to pay if they can have confidence in all the contributing elements. The measurement result as determined by the measuring instrument is subject to legal metrology and trustworthy. The copy of this measurement result as used on the bill may be wrong, but the user can easily compare it to the measurement result as shown on the measuring instrument. The unit price shown on the bill may be wrong, but legislation on price declaration usually requires it to be made available by other means and the consumer can again compare the two values. The calculation of the difference and the product may be wrong, but the consumer can again check it easily using primary school knowledge. Therefore, all parties affected by the measurement, even the party that does not own the instrument, can have confidence in the correctness of the total price because they can trace it back to trustworthy and impartial sources of information.

This confidence is key to an efficient society – otherwise, its productivity would be severely reduced by lengthy discussions and litigations about the correctness of, for instance, measurement results. A side effect of the transparency is that it will be very obvious if a measurement result reading was intentionally changed for billing. Fraud therefore becomes uninteresting to attempt.

All this defines performance requirements with a high level of abstraction:

1 The legally relevant measurement result shall be indicated.

2 The indication shall be clear and unambiguous. All parties shall be informed about the significance of the result. The indication shall be easy under normal conditions of use.

3 Any additional indication that could be mistaken for the legally relevant measurement result is not permissible. This includes remote readings when the only legally relevant measurement result is the measurement result shown on a display.

These performance requirements are, for instance, defined in the MID, Annex I, Point 10 [2].

Since these performance requirements are sufficient to achieve the transparency required, the principle of proportionality [4, Art. 5] prohibits the legislator from defining further requirements, namely detailed technical specifications. Recital 25 MID elaborates further on this and this also explains why the term *display* does not need to be defined explicitly in the MID – the teleological interpretation is straightforward, but an explicit definition might introduce unintended detailed technical specifications. Those are not permitted and violate the principles of the MID.

The practical question that is best dealt with in a standard as explained in Recitals 25 and 26 MID, is "which technical specifications satisfy these performance requirements?" Traditional utility meters have a hardware display of some simple type, e.g. pointer-type, barrel-type or LCD, within their metrologically sealed housing. These technical implementations may be acceptable:

- They are transparent – any party can compare the measurement result indicated by the measuring instrument with the corresponding value on the bill and without having to trust the other party.

- They are trustworthy since the authenticity of the indicated result is assured.
- They are non-discriminatory if (and only if) no party can block the access to the authentic indication of the measurement result by sealing the interface, setting a password, requiring a tool that is not easily available to the other party, or locking the room in which the meter is mounted.

The latter requirement is becoming increasingly difficult to comply with. When it is not practical to mount utility meters inside the consumer's flat, they can be mounted in unlocked electrical cabinets, in which case data protection legislation is usually violated. This problem can be solved by locking the cabinet, in which case legal metrology legislation is usually violated. An additional problem that is specific to interval metering is that the display needs to make all the measurement results available. With a registration period of 15 min, 96 readings are generated each day. If, for instance, it was considered acceptable to require at most 100 keystrokes to access one of these readings and the consumer was expected to take 10 s to decide on each keystroke and execute it, it would take 26.5 h to read out the readings of a single day. In this estimation, the time to read and write down the reading is considered negligible and the consumer is expected to execute all keystrokes without any mistake. Clearly, it is not even possible to spend more than a day each day to read out the legally relevant data from such an implementation of the display requirement. Such an implementation does not satisfy the display requirement.

Another technical implementation of the MID's *display* functional requirement uses modern technology that is well proven to work in many domains of daily life: cryptographically signed data and a public key infrastructure. When this technical implementation is chosen by the manufacturer, the cryptographic signature must be applied in the meter and becomes part of the conformity assessment. The cryptographically signed data packet becomes legally relevant. Since the signature renders any tampering with this data packet as obvious as the breaking of the hardware seal, the data may be sent through any channel and stored on any device, including the internet and the cloud. The technical implementation may still be uncommon in this domain – it is not in many other domains of daily life such as online banking or COVID certificates –, but on a functional level, it is no different to installing Ferraris meters in electrical cabinets. The electrical cabinets can illegally hide metrological seals or even the display, but are not conformity assessed with respect to the MID.

In other domains of daily life, cryptographically signed data is generally accepted, for example an expired COVID-19 QR-code.

Modern "smart" electricity meter (Linky)

Photo: Benoît Prieur, CC0, via Wikimedia Commons
https://commons.wikimedia.org/wiki/File:
Compteur_Linky_tout_juste_install%C3%A9_%28France%29.jpg

4 Durable storage

4.1 Traditional requirement for non-utility applications

When a measuring instrument is used for non-utility applications in the absence of one of the trading parties, the MID requires the measurement to be recorded by durable means and a durable proof of the transaction to be made available on request. For interval metering, all interval readings are relevant for the billing. In case of litigation, they must be available for scrutiny. If the prescription period is ten years, does all this data need to be stored in the meter for ten years, for instance on a hard drive?

Again, the principle of proportionality favours a teleological approach. The aim is to make sure all parties can have confidence in the measurement and that no party can manipulate the result without the other party being able to notice this – in theory and in practice.

Traditional technical solutions can give guidance. The traditional solution for fuel dispensers, for instance, is a barrel counter showing the volume of petrol dispensed since the beginning of the transaction. This information is very volatile. As soon as a new transaction is started, the counter is reset. Another acceptable solution is to make the result of the measurement available on a hardcopy, e.g. on thermoprinted paper, instead of on a display. This is an accepted implementation of the performance requirement of the MID, but the durability of a thermoprint is very limited.

"Durable proof": Thermoprinted receipt, which can become hard to read over time

Photo: Ootahara, CC0, via Wikimedia Commons
https://commons.wikimedia.org/wiki/File:
Mention_printing_vote_sample_Thermal_paper_version.jpg

When measurement results are stored with a cryptographic signature, the durability is better than when thermoprints are filed. When one party is absent, the other party cannot avoid a reset of the counter after the transaction they intend to contest. For this reason, and for this reason only, the MID requires the measurement to be recorded by durable means and a durable proof to be made available on request. Any other reason would not justify this requirement to be waived when all parties are present.

Whether all parties are present or not, one or both of the parties are required to keep historic data such as the previous bill or the printout should they wish to question the correctness of the bill. Should they choose not the keep these proofs, then they forfeit this possibility. The other party cannot influence this choice and will not even be aware of it. This does not depend on the technical implementation – one solution is as good as the other in this respect. If the chosen technical implementation of this requirement relies on, for instance, the supplier keeping an archive of all relevant data for the duration required, the supplier can choose not to keep the archive as long as necessary. In this case, when a consumer questions the bill, the supplier will not be able to provide proof of their claim. If tax authorities require the data, the supplier will not be able to show it. Independently of the technical implementation, this is not – and has never been – a matter of legal metrology regulation concerning the making available of measuring instruments on the market. Therefore, there is no need to implement this function in the instrument and under legal metrology regulations concerning the making available of measuring instruments on the market. Without need, there cannot be a legally valid reason to require such an implementation. In addition, the requirements on acquiring historic data are not harmonised, so the MID cannot satisfactorily harmonise their implementation in measuring instruments.

Like many other aspects of measurements, compliance with requirements for the correct use of measuring instrument depends on suitable instructions for correct operation and any special conditions of use to be made available to the user, and also on the user following these instructions in practice. MID conformity assessment and market surveillance can only check the suitability of the instructions, but not whether they are followed in practice. The latter part can only be checked by general supervision of instruments in use and requires corresponding legal requirements. These are not harmonised by the MID, a directive "relating to the making available on the market of measuring instruments".

4.2 Transfer to utility metering

Following the same principles, the result of the measurement must be available to all parties also for utility meters, including interval meters.

The aim is to make sure all the parties can have confidence in the measurement and that no party can manipulate the result without the other party being able to notice this – in theory and in practice. The traditional solution for electricity meters, for instance, is a barrel counter showing the energy measured by the meter since it was produced. This information is very volatile. As soon as more energy is measured, the value changes. Even if the consumption was stopped to preserve the value until all the parties can physically look at the display, it cannot be proven that the consumption was really stopped. Nevertheless, this solution is fully compliant with the MID and fully accepted by society. Therefore, this solution can serve as a benchmark: the new solution must be at least as suitable as the traditional one. The traditional solution consists of a volatile reading that is copied by hand as part of the billing process. Usually, the consumer can know or guess when the meter is read and, given that the value is monotonously increasing – unless power generation is subtracted from consumed energy – check for plausibility of the most recent reading value on the bill. From this reading, the previous reading is subtracted to determine the energy that is still to be paid for. The latter value is stored permanently on the previous bill. Therefore, it has been perfectly acceptable to store billing-relevant, historical data outside the measuring instrument only. Modern technology allows, in addition, a proof of authenticity to be stored – a cryptographic signature. Since this modern solution is more suitable to achieve the intended aim, it may not be rejected just because it is more suitable than the traditional solution. The only conceptual difference between interval meters and other utility meters is that the reading is synchronised automatically. While the amount of data is much higher for interval meters, the principle is the same. There is no need to require the interval readings to be durably stored in the measuring instrument when it is perfectly accepted not to require this for traditional meters.

Moreover, data protection may well prohibit more personal data than absolutely necessary from being stored in utility meters. Often, utility meters are not protected very well against physical access by unauthorised parties, including neighbours.

Conclusion

Smart meters are the subject of many discussions and offer many new functions. In the context of legal metrology, the implications are limited when regulations are strictly limited to performance requirements. In many countries, this limitation is forced by the principle of proportionality – if performance requirements are sufficient to make sure all parties concerned by the measurement can have confidence in the result of this measurement, it is not acceptable for regulations to go further and define detailed technical specifications. The only aspect that is fundamentally new is the interval metering function. When the unit price becomes time-variant, the performance of the interval metering function impacts the price to be paid and hence the confidence the parties concerned by the measurement have in the result of the measurement. Therefore, the legal metrology requirements for the interval metering function are needed. These can be defined as performance requirements that apply to all interval meters, regardless of the quantity they measure.

Another aspect that is often discussed in the context of smart metering and data protection is the suitable technical implementation of the requirement to make the result of the measurement available to all concerned parties. This requirement is not specific to smart metering and neither is the requirement to store measurement results durably. However, the need for modern implementations is amplified by the large amount of data generated by interval meters. Where traditional meters generated one reading per year, interval meters for electricity generate one reading every 15 min – i.e. about 35 000 per year. The display is indispensable when the goal is to maintain the confidence of all the parties concerned. This is a functional requirement. Its technical implementation may use modern technology as long as the functional requirement is met. Namely, it may not place an excessive burden on the consumer. This applies both to modern and traditional solutions. Traditional solutions often violate either the requirements of legal metrology regulations or of data protection regulations such as the European Union's GDPR. Therefore, even for utility meters without an interval metering function, a modern solution has become unavoidable.

The question of durable storage of measurement results also became a subject of discussion with the advent of smart meters without being specific to smart meters. Traditional solutions that have been acceptable for more than a century may well be used in the future. Modern technology makes these solutions more convenient and more trustworthy, but this is not a valid reason to require the traditional solutions to be replaced by more complicated solutions. ■

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LIAISONS

72nd CECIP General Assembly

22 to 24 June 2022 London, United Kingdom

BIML

The BIML Director, Mr Anthony Donnellan, and the OIML-CS Management Committee Chairman, Mr Mannie Panesar, represented the OIML at the 72nd CECIP General Assembly which was held from 22 to 24 June 2022 in London.

The event was hosted and organised by the UK Weighing Federation, the recognised national trade association for manufacturers, system integrators, distributors, repairers, installers and service organisations involved in the weighing industry. It was a great opportunity to strengthen the existing, long-standing links between the OIML and the international weighing industry and it was especially good to see that the work of the OIML is fully supported by CECIP.

Participants are now looking forward to the International Congress of Weighing (ICW) 2023 event, at which both the global weighing industry and OIML membership will be present. ■

Mr Anthony Donnellan, BIML Director, giving an update on OIML activities

Mr Mannie Panesar, OIML-CS Management Committee Chairman, presenting the OIML Certification System

OIML Certification System (OIML-CS)

Introduction

The OIML-CS is a system for issuing, registering and using OIML Certificates and their associated OIML type evaluation reports for types of measuring instruments (including families of measuring instruments, modules, or families of modules), based on the requirements of OIML Recommendations.

The OIML-CS comprises two Schemes: Scheme A and Scheme B. Competence of the OIML Issuing Authorities and their Test Laboratories is demonstrated through self-declaration under Scheme B and accreditation or peer assessment under Scheme A.

The aim of the OIML-CS is to facilitate, accelerate and harmonize the work of national and regional bodies that are responsible for type evaluation and approval of measuring instruments subject to legal metrological control. In the same way, instrument manufacturers, who are required to obtain type approval in some countries in which they wish to sell their products, should benefit from the OIML-CS as it will provide evidence that their instrument type complies with the requirements of the relevant OIML Recommendation(s).

It is a voluntary system and OIML Member States and Corresponding Members are free to participate. Participating in the OIML-CS commits, in principle, the signatories to abide by the rules of the OIML-CS that are established in OIML B 18:2018 *Framework for the OIML Certification System (OIML-CS)*. Signatories voluntarily accept and utilize OIML type evaluation and test reports, when associated with an OIML Certificate issued by an OIML Issuing Authority, for type approval or recognition in their national or regional metrological controls.

The OIML-CS was launched on 1 January 2018 and has replaced the former OIML Basic Certificate System and the OIML Mutual Acceptance Arrangement (MAA).

OIML certificates

OIML certificates issued under Scheme A and Scheme B can be downloaded from the database on the OIML website at https://www.oiml.org/en/oiml-cs/certificat_view.

The database also includes certificates issued under the former OIML Basic Certificate System and the MAA. Although these two systems are no longer in operation, the certificates remain valid.

OIML Issuing Authorities, Utilizers and Associates

A summary of the approved OIML Issuing Authorities is published on the next page, followed by a summary of those Utilizers and Associates that have declared that they will accept OIML certificates and/or OIML type evaluation reports as the basis for a national or regional approval.

More information

For enquiries regarding the OIML-CS, please contact the OIML-CS Executive Secretary Mr Paul Dixon (executive.secretary@oiml.org). Visit the OIML website:

https://www.oiml.org/en/oiml-cs

OIML Certification System (OIML-CS)

List of OIML Issuing Authorities and their scopes

The list of OIML Issuing Authorities is published in each issue of the OIML Bulletin and can be downloaded at www.oiml.org/oiml-cs/oiml-issuing-authorities

Updated: 2022-06-06

		R 21:2007	R 46:2012	R 49:2006	R 49:2013	R 50:2014	R 51:2006	R 60:2000	R 60:2017	R 61:2004	R 61:2017	R 75:2002	R 76:1992	R 76:2006	R 85:2008	R 99:2008	R 106:2011	R 107:2007	R 117:1995	R 117:2007	R 117:2019	R 126:1998	R 129:2000	R 134:2006	R 137:2012	R 139:2014	R 139:2018
AU1	National Measurement Institute Australia (NMIA)					■							■	■													
CH1	Federal Institute of Metrology (METAS)							■						■			■							■			
CN2	National Institute of Metrology, China (NIM)						■	■	■	■	■		■	■													
CZ1	Czech Metrology Institute (CMI)				■		■				■			■	■					■	■			■	■		■
DE1	Physikalisch-Technische Bundesanstalt (PTB)				■		■	■	■	■		■		■													
DK2	FORCE Certification A/S				■	■	■	■	■	■	■			■			■	■					■	■	■	■	■
FR2	Laboratoire National de Métrologie et d'Essais (LNE)			■	■		■	■	■					■								■					
GB1	Office for Product Safety and Standards (OPSS) (formerly NMO)				■		■	■	■				■	■						■	■						
JP1	NMIJ/AIST							■	■				■	■					■	■	■						
NL1	NMi Certin B.V.	■	■	■	■	■	■	■	■	■	■		■	■	■		■	■	■	■	■		■	■	■	■	■
SE1	Research Institutes of Sweden (RISE)						■	■	■	■	■			■	■				■	■	■						
SK1	Slovak Legal Metrology (SLM)			■	■									■													

OIML Certification System (OIML-CS)

List of Utilizers, Associates and their scopes

The list of Utilizer and Associate scopes is published in each issue of the OIML Bulletin and can be downloaded at www.oiml.org/oiml-cs/utilizers-and-associates

Updated: 2022-05-27

1 = Scheme A only
2 = Scheme A and MAA
3 = Scheme A and B
4 = Scheme A, B and MAA
5 = Scheme B only

		R 21:2007	R 35:2007	R 46:2012	R 49:2006	R 49:2013	R 50:2014	R 51:2006	R 58:1998	R 59:2016	R 60:2000	R 60:2017	R 61:2004	R 61:2017	R 75:2002	R 76:1992	R 76:2006	R 81:1998	R 85:2008	R 88:1998	R 93:1999	R 99:2008	R 102:1992	R 104:1993	R 106:2011
AU	National Measurement Institute, Australia (NMIA)				1	1					1					1	1								
BE	Federal Public Service Economy	3		3		3	3	3			1		3		3		1		3			3			3
CA	Measurement Canada										2	1			1		2								
CH	Federal Institute of Metrology (METAS)			1	2	2	1	1			2		1		1		2								1
CN	State Administration for Market Regulation (SAMR)							1			2	1	1	1		2	2								
CO	Superintendencia de Industria y Comercio (SIC)	3		3	4	4	3	3			2		3		3	2	2		3			3			3
CU	Oficina Nacional de Normalizacion (NC)	3	3	1		1	3	1	3	3	1	1	3	3	3		1	3	3	3	3	3	3	3	3
CZ	Czech Metrology Institute (CMI)					1		1						1			1								
DE	Physikalisch-Technische Bundesanstalt (PTB)	5		3	3	4	3	3			2		3		3		2					5			1
DK	FORCE Certification A/S				2	2	1	1			2	1	1	1			2								1
FR	Laboratoire National de Métrologie et d'Essais (LNE)	1		1	1	1	1	1			1		1		1	1	1		1			1			1
GB	Office for Product Safety and Standards (OPSS) (formerly NMO)	3				4	3	3			2	1	3			1	1		3						3
IN	Legal Metrology Division, Department of Consumer Affairs	3		3		4	3	3			2		3		3		2		3						1
IR	Iran National Standards Organization (INSO)				4	4					2	1				2	2								
JP	NMIJ/AIST										2	1				2	2								
KE	Weights and Measures Department		3	3	4	4		3			4	4	3	3		4	4		3						3
KH	National Metrology Centre (NMC)	3		3	3	3	3	3			1		3		3	1	1		3			3			3
KI	Ministry of Commerce, Industry and Cooperatives	5	5	5	1	1	5	1		5	1	1	5	5	5	1	1	5	5						5
KR	Korea Testing Certification (KTC)															2	2								
LV	LNMC Ltd. Metrology Bureau																								
NA	Namibian Standards Institution			3	4	4	3	3			2		3			2	2		3						3
NL	NMi Certin B.V.	3		3	3	4	3	3			2	1	3	3	3	1	2		3			3			3
NZ	Trading Standards (Ministry of Business, Innovation and Employment) (MBIE)				4	4	3	3			2					2	2		3						3
RU	VNIIMS																								
RW	Rwanda Standards Board	3	3	3	3	3		3	3	3	1	1	3	3		1	1					3	3	3	3
SA	SASO (Saudi Standards, Metrology and Quality Organization)			3		1						1					1								
SE	RISE Research Institutes of Sweden AB							3			2	1	3				2		3						
SK	Slovak Legal Metrology (SLM)				2	2											2								
TN	National Agency of Metrology (ANM)	3		3	2	2	3	3			2		3				2		3			3			3
UG	Uganda National Bureau of Standards (UNBS)			3	1	3					1	1				1	1								
US	National Conference on Weights and Measures (NCWM)										2														
ZA	NRCS: Legal Metrology				3	3		3			1					1	1		3						3
ZM	Zambia Metrology Agency	3		3	3	3	3	3			1		3		3	1	1		3			3			3

OIML Certification System (OIML-CS)

List of Utilizers, Associates and their scopes (Cont'd)

The list of Utilizer and Associate scopes is published in each issue of the OIML Bulletin and can be downloaded at www.oiml.org/oiml-cs/utilizers-and-associates

Updated: 2022-05-27

1 = Scheme A only
2 = Scheme A and MAA
3 = Scheme A and B
4 = Scheme A, B and MAA
5 = Scheme B only

		R 107:2007	R 110:1994	R 117:1995	R 117:2007	R 117:2019	R 122:1996	R 126:1998	R 128:2000	R 129:2000	R 129:2020	R 133:2002	R 134:2006	R 136:2004	R 137:2012	R 139:2014	R 139:2018	R 143:2009	R 144:2013	R 145:2015	R 146:2016	R 148:2020	R 149:2020	R 150:2020
AU	National Measurement Institute, Australia (NMIA)																							
BE	Federal Public Service Economy	3			3					3					3	3								
CA	Measurement Canada																							
CH	Federal Institute of Metrology (METAS)	1						1		1			1		1									
CN	State Administration for Market Regulation (SAMR)																							
CO	Superintendencia de Industria y Comercio (SIC)	3		3	3			3		3			3		3	3								
CU	Oficina Nacional de Normalizacion (NC)	3	3		3		3	3	3	3		3	3	3	3	3	3	3	3	3	3			
CZ	Czech Metrology Institute (CMI)				1	1									1									
DE	Physikalisch-Technische Bundesanstalt (PTB)	3			3	1				3			1	5	3									
DK	FORCE Certification A/S	1			1	1				1	1		3		1	1	1							
FR	Laboratoire National de Métrologie et d'Essais (LNE)	1			1			1		1			1		1	1								
GB	Office for Product Safety and Standards (OPSS) (formerly NMO)	3		3	3	3				3			3											
IN	Legal Metrology Division, Department of Consumer Affairs	3			3					3			1		3	3								
IR	Iran National Standards Organization (INSO)																							
JP	NMIJ/AIST			1	1	1																		
KE	Weights and Measures Department			3	3			3					3	3	3	3	3							
KH	National Metrology Centre (NMC)	3		3	3			3		3			3		3	3								
KI	Ministry of Commerce, Industry and Cooperatives		5	1	1							5	5		5	5	5							
KR	Korea Testing Certification (KTC)																							
LV	LNMC Ltd. Metrology Bureau							3					3											
NA	Namibian Standards Institution	3		3	3			3		3			3											
NL	NMi Certin B.V.	3		3	3	1		3		3			3		3	3	3							
NZ	Trading Standards (Ministry of Business, Innovation and Employment) (MBIE)	3		3	3					3			3											
RU	VNIIMS			3	3																			
RW	Rwanda Standards Board		3	3	3		3	3		3		3	3		3			3	3		3			
SA	SASO (Saudi Standards, Metrology and Quality Organization)				3																			
SE	RISE Research Institutes of Sweden AB			3	3																			
SK	Slovak Legal Metrology (SLM)																							
TN	National Agency of Metrology (ANM)	3		3	3			3		3			3		3	3								
UG	Uganda National Bureau of Standards			1	1	1							3		3									
US	National Conference on Weights and Measures (NCWM)																							
ZA	NRCS: Legal Metrology	3		3	3			3		3			3		3	3								
ZM	Zambia Metrology Agency	3		3	3			3		3			3		3	3								

Countries and Economies with Emerging Metrology Systems (CEEMS)

2022 OIML CEEMS AWARD

Background

Many countries and economies with emerging metrology systems suffer from a lack of resources for the operation of a sound legal metrology system. Although these resources cannot be provided by the OIML, the Organisation supports initiatives for the development of legal metrology. To highlight the importance of metrology activities in CEEMS, and to provide an incentive for their improvement, in 2009 the OIML established an Award for *"Excellent achievements in legal metrology in Developing Countries"*.

Following the establishment of the Advisory Group on matters of Countries and Economies with Emerging Metrology Systems (CEEMS), and an increased focus on OIML activities in this area, it was decided to rename the Award the "OIML CEEMS Award" from 2018.

The OIML CEEMS Award is intended to raise the awareness of, and create a more favorable environment for legal metrology and to promote the work of the OIML. The Award intends: *"to acknowledge and honour new and outstanding activities achieved by individuals, national services or regional legal metrology organisations contributing significantly to legal metrology objectives on national or regional levels."*

Selection criteria and procedure

The criteria which will be used to assess the candidates' contribution or achievement will include:

- its significance and importance;
- its novelty;
- its attractiveness and adaptability for other legal metrology services.

The BIML will prepare a list of candidates highlighting the importance of the achievements. The Award winner will be selected by the CIML President and announced at the 57th CIML Meeting in October 2022.

The Award

The Award will consist of:

- a Certificate of Appreciation signed by the CIML President;
- a token of appreciation, such as an invitation to make a presentation of the Award-winning achievement at the next CIML Meeting or OIML Conference at the OIML's expense;
- an engraved Award trophy.

How can candidates be proposed?

Nominations may be made by any individuals or organisations concerned with legal metrology, including the individual or organisation seeking the Award.

Nominations should be sent to Ian Dunmill at the BIML and must contain facts, documents and arguments explaining why the candidate deserves the Award. The closing date is 31 August 2022.

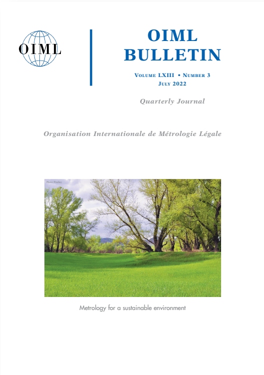
Past Awards

2021 - Mr Sophors Em, Cambodia
2020 - Mr Agus Suparmanto, Minister of Trade of the Republic of Indonesia
- Mr Veri Anggriono Sutiarto, S.E., M.Si., Director General of Consumer Protection and Trade Compliance, Ministry of Trade, Republic of Indonesia
- Dr Rusmin Amin, S.Si, MT, Director of Metrology, Republic of Indonesia
2019 - No Award was made in 2019
2018 - Prof. Carlos Augusto de Azevedo of the Ministerio Da Industria, Comercio Exterior e Serviços, Instituto Nacional De Metrologia, Qualidade E Tecnologia – INMETRO, Brazil
2017 - Superintendencia de Industria y Comercio, Colombia
- Dr Osman Bin Zakaria, Senior Director, National Metrology Institute of Malaysia (NMIM)
- Mr Dato' Roslan Bin Mahayudin, Director of Enforcement Division, Ministry of Domestic Trade, Co-operatives and Consumerism
- Mr Haji Ibrahim Bin Hamzah, Chairman Executive, Metrology Corp. Malaysia Sdn. Bhd. (MCM)
2016 - Institute of Trade Standards Administration, Kenya
2015 - Mr Nam Hyuk Lim, Director of Korea Testing Certification
- The Metrology Department, Saint Lucia Bureau of Standards
2014 - Serbian National Metrology Institute (DMGM)
2013 - Weights and Measures Agency, Tanzania
2012 - Mr Loukoumanou Osséni, Benin
2011 - Mr José Antonio Dajes, Peru and Mr Juan Carlos Castillo, Bolivia
2010 - Thai Legal Metrology Service
2009 - Mr Osama Melhem, Jordan

For more details, please contact:

Ian Dunmill
BIML Assistant Director
ian.dunmill@oiml.org

Promotion of the OIML Bulletin: Become a Mentor



The OIML Bulletin is one, if not the only, international publication dedicated to legal metrology topics.

In accordance with CIML Resolutions 2019/30 and 2020/21, there is a clear desire for the Bulletin to be an attractive publication for legal metrology worldwide, and for it to be an excellent advertisement for our Organisation.

This can be achieved through long-term planning of the future editions and identification of key topics of high interest, for instance, legal control of measuring instruments in the fields of energy, health and the environment, where important aspects such as new technology, legal requirements, or test/verification procedures will be addressed.

In addition, support is sought from CIML Members and Corresponding Member Representatives who are ready to take on the responsibility of acting as "**Mentors**" for certain key topics / editions and technical articles. These are not necessarily expected to be written by the "**Mentors**" themselves, but by experts that a "**Mentor**" has identified and contacted.

In order to identify key topics of significant interest and "**Mentors**" to lead them, it was proposed by the CIML President that the BIML prepares, and makes publicly available on the OIML website, a plan for the upcoming eight to ten editions of the Bulletin.

The table on the following page is intended to be "dynamic", i.e. proposed key topics may be moved to other editions depending on available "**Mentors**" and authors for technical articles. The table can also be found at www.oiml.org/en/publications/bulletin/future-editions.

All CIML Members and Corresponding Member Representatives are encouraged to support the OIML Bulletin, to share their legal metrology experiences with the legal metrology community worldwide, and to take responsibility either as a "**Mentor**" for one of the next editions of the Bulletin, or by promoting it at TC/SC/Project Group meetings, RLMO meetings, CEEMS AG meetings, and other opportunities.

CIML Members and Corresponding Member Representatives who would like to be a "**Mentor**" for a specific edition / key topic, or who would like to suggest that a new key topic be added to the list, are asked to contact the BIML (chris.pulham@oiml.org).

Edition	General key topic	Mentor	Proposed article submissions
October 2022	Training of inspectors / verification officers *Note:* *Content to be finalised*	CEEMS AG Chair?	▪ E-Learning material already available ▪ Revision of OIML D 14 *Training and qualification of legal metrology personnel* ▪ DAM (Deutsche Akademie für Metrologie) ▪ Summary of CEEMS AG achievements and outlook
January 2023	Feature on the 57th CIML Meeting	BIML	▪ Reports by the CIML President and the BIML Director, Resolutions, Awards, etc.
April 2023	Feature on Regional Legal Metrology Organisations (RLMOs) + Prepackages / Statistical control	Dr Chuck Ehrlich, NIST, USA	▪ TC 6 Prepackage control template ▪ Highlights of the status of legal metrology systems in the various Regions ▪ Information on prepackaging in the various Regions ▪ Type approval in the various Regions ▪ Prepackaging in the various Regions
Future editions	National / Regional Metrology Systems		
	Events		▪ Report on OTE (July 2023) in Bad Reichenhall (DE)
	Intellectual property		▪ Role of patents in legal metrology

2022-07-12

info

The OIML is pleased to welcome the following new

CIML Members

- **Egypt:** Eng. Ahmad Mahamoud Ahmad Sulayman
- **Ethiopia:** Mr Getachew Wollel Tiruneh

OIML Member State Readmission:

- Ethiopia

OIML meeting

18–20 October 2022
57th CIML Meeting

Committee Drafts

Received by the BIML, 2022.04 – 2022.07

Update of OIML V 1:2013: *International vocabulary of terms in legal metrology* (VIML)	1.1 CD	TC 1/p 4	PL	2022-06-21
New Document: *Guide for the application of ISO/IEC 17020 to the assessment of OIML Issuing Authorities under the OIML-CS*	1.1 CD	TC OIML-CS/SC 7/p 6	BIML	2022-04-06

Call for papers

OIML Members
RLMOs
Liaison Institutions
Manufacturers' Associations
Consumers' & Users' Groups, etc.

- Technical articles on legal metrology related subjects
- Features on metrology in your country
- Accounts of Seminars, Meetings, Conferences
- Announcements of forthcoming events, etc.

The **OIML Bulletin** is a forum for the publication of technical papers and diverse articles addressing metrological advances in trade, health, the environment and safety - fields in which the credibility of measurement remains a challenging priority. The Editors of the Bulletin encourage the submission of articles covering topics such as national, regional and international activities in legal metrology and related fields, evaluation procedures, accreditation and certification, and measuring techniques and instrumentation. Authors are requested to submit:

- a titled, typed manuscript in Word or WordPerfect either on disk or (preferably) by e-mail;
- the paper originals of any relevant photos, illustrations, diagrams, etc.;
- a photograph of the author(s) suitable for publication together with full contact details: name, position, institution, address, telephone, fax and e-mail.

Note: Electronic images should be minimum 150 dpi, preferably 300 dpi.

Technical articles selected for publication will be remunerated at the rate of 23 € per printed page, provided that they have not already been published in other journals. The Editors reserve the right to edit contributions for style, space and linguistic reasons and author approval is always obtained prior to publication. The Editors decline responsibility for any claims made in articles, which are the sole responsibility of the authors concerned. Please send submissions to:

The Editor, OIML Bulletin
BIML, 11 Rue Turgot, F-75009 Paris, France
(chris.pulham@oiml.org)