Publishable Summary for 20NRM01 MetTLM
Metrology for temporal light modulation

Overview

LED-based lighting contributes to energy saving and the reduction of the environmental impact of lighting. However, LED lamps can show fluctuations in the light output known as temporal light modulation (TLM) which could, above certain limits and under certain conditions, impact the health, well-being and safety of people. Pursuant to the EU Directives 2009/125/EC, on ecodesign requirements, Commission Regulation (EU) 2019/2020 sets limitations on TLM of light sources. The overall aim of this project is to create the metrology infrastructure for the measurement of TLM in LED lighting and the visual effects induced by TLM, known as temporal light artefacts (TLAs). This project will develop and validate measurement methods for quantitative measurement of TLAs, such as flicker and the stroboscopic effect, and it will advance the development of a metric for the phantom array effect. The project results will underpin the development of standardisation on TLM and will provide the lighting industry, instrument manufacturers and market surveillance authorities with undisputable results of their TLM measurements.

Need

LED-based lighting is ever increasing, and the market is estimated to be worth more than 70 € billion in 2022. The ongoing transition to LED lighting is an important step in achieving the European goals on improved energy efficiency. However, LED lighting may show temporal variation of the light output, covering a large range of waveform shapes and frequencies. This temporal variation can often be perceived by humans. And as stated by the International Commission on Illumination (CIE) in TN 006:2016: “can lead to a decrease in performance, increased fatigue as well as acute health problems like epileptic seizures and migraine episodes”. Also, distorted perception of moving objects could give rise to safety concerns, for instance, in traffic or work environments.

The three types of TLAs, caused by variations in light output, as defined in the TN 006:2016 by the CIE, are: i) flicker, which is the direct perception of temporal changes of the light output; ii) stroboscopic effect, which is observed as a discretised motion of moving objects resulting from illumination by a temporally modulated source; and iii) phantom array effect (or ghosting), which corresponds to a change in perceived shape or spatial position induced by saccadic eye movements across a temporally modulated light source. While metrics for flicker and the stroboscopic effect have been recommended by CIE, the metric for the phantom array effect is still missing due to a lack of the required research.

The need for worldwide harmonised TLM measurements has been recognised by the CIE. The European Commission has explicitly required the development of standards for the measurement of flicker and stroboscopic effect (Mandate M/519, Ares(2013)205169), and in 2021 the Commission Regulation (EU) 2019/2020 has entered into force. In view of public health and safety, the regulation has introduced limits on the allowed modulation of light sources for flicker and the stroboscopic effect. To demonstrate compliance with the regulation, lighting industry, measurement instrument manufacturers and market surveillance authorities need to be able to perform reliable, mutually comparable measurements of these TLAs. However, the metrology infrastructure to provide validated and SI-traceable measurements of TLM and TLAs is currently not available and international agreed standards do not exist.

Real scenes and life environments, such as offices and tunnels, are often illuminated with a combination of multiple light sources and daylight presenting an effective luminance pattern of high contrast and an inhomogeneous distribution of TLM parameters. Mapping the TLM of such environment would require multiple measurements with a single spot TLM measurement device. Such measurement procedures are inefficient and do not provide a full assessment regarding TLA perception. Multispectral cameras could map the spatially distributed TLM as seen from an observer’s position. This provides a promising approach to map spatially resolved TLM and thereby to judge about the perception of TLAs in illuminated scenes. Although commercial state-of-the art image sensors, used in industrial cameras and imaging luminance measurement devices (ILMDs), already contain fast modes that provide the needed temporal resolution, methods for the evaluation of spatially resolved TLM are not yet available. Also, light sources comprised of multiple temporally modulated coloured LEDs potentially induce temporal colour modulation, often leading to the perception of colour-breakup in the phantom array effect. Although spectroradiometers have become widely available for spectral measurements, a framework for spectrally resolved TLM measurements is missing.

Objectives

The overall aim of this project is to create the metrology infrastructure required for the measurement of TLM and to contribute to the development of standardisation on the measurement of TLM. The specific objectives of the project are:

1. To establish methods for traceable TLM measurement of individual light sources and luminaires with a focus on flicker and stroboscopic effect. These should be based on IEC TR 61547-1 and IEC TR63158 and include: (i) methods for generating and measuring optical waveforms in the time-domain and power spectra in the frequency-domain, (ii) calibration and characterisation of TLM measurement devices and the evaluation of uncertainty budgets, (iii) quality metrics (e.g. frequency response, dynamic range of signal) for the classification of TLM measurement instruments.
2. To validate the traceable TLM measurement methods, developed in Objective 1, through an interlaboratory comparison between metrology institutes and industry, whilst ensuring compliance with the new EU Ecodesign 2019/2020 regulation. To develop a recommendation on associated standardised measurement conditions.
3. To develop novel methods for measuring TLM of the illuminated environment in extended scenes (e.g. offices, roads or tunnels) and for multispectral TLM measurement of light sources.
4. To develop a model for the visibility of the phantom array effect based on perception experiments that measure the visibility threshold for various lighting conditions (e.g. modulation frequency, amplitude, shape of the modulation and light level). This model should be shared with CIE TC 1-83 or its successor in a suitable format that enables its use in a future metric for the phantom array.
5. To facilitate the take up of methods, technology and measurement infrastructure developed in the project by the standards developing organisations (e.g. CIE) and end-users (e.g. regulatory bodies, lighting industry and instrument manufacturers). This should include providing input to CIE TC 2-89 and CIE TC 1-83 (or its successor) and support for a new CIE TC for addressing the measurement of spatially resolved TLM and colour TLM.

Progress beyond the state of the art

At the start of this project standardised and validated methods for traceable measurement of TLM were not available and measurement conditions had not yet been defined. Methods for testing equipment for flicker and the stroboscopic effect have been developed (IEC TR 63158:2018 and IEC TR 61547-1:2020), but these do not consider SI traceability or the measurement uncertainty for these quantities. So far, the efforts of national metrology institutes (NMIs) to provide SI traceability to TLM measurement devices and sources had been very limited and did not cover the TLA metrics for short-term flicker severity (PstLM) and stroboscopic visibility measure (SVM) used in the EU Ecodesign regulation.

This project will deliver validated methods and measurement conditions for traceable measurement of temporal light modulation for flicker and the stroboscopic effect, and has supported the development of standardisation on TLM measurement. It has contributed to the development of TLM measurement capability at NMI level. The developed TLM calibration methods will be validated by an interlaboratory comparison. The project outcomes will be summarised in a publicly available good practice guide (GPG), which will support CIE in the development of standardisation of TLM measurement via CIE TC 2-89 ‘Measurement of Temporal Light Modulation of Light Sources and Lighting Systems’. The overall goal is to provide stakeholders with reliable measurement results and well-underpinned measurement uncertainties for their TLM measurements, which is a prerequisite for the implementation and enforcement of regulations on modulated light sources.

Currently only single dimensional TLM measurement devices are available to measure TLM locally. However, for the phantom array effect, the spatial luminance pattern is important and imaging techniques are nowadays widely used to characterise lighting situations regarding its time-averaged luminance distribution. This project has investigated high-speed imaging as a new approach to measure the TLM distribution of structured luminaires and in extended scenes. This work is expected to contribute to the next generation of TLM measurement instruments.

With Red, Green, Blue (RGB) modulated displays and multispectral Red, Green, Blue, White (RGBW) or tuneable white luminaires temporal colour modulation is also gaining attention. Measurement methods to quantify colour (or spectral) TLM and temporal colour modulations have been developed. In this project, methods to assess colour- and (multi)spectral TLM have been investigated and demonstrated.

A metric for the phantom array effect has currently not yet been defined. Although several studies on the human perception of the phantom array effect have been executed, there is currently insufficient scientific evidence available to serve as a base for a definition of the phantom array effect.

Representative perception experiments measuring the visibility threshold for various lighting conditions have been performed aimed at the development of a model for the visibility of the phantom array effect. This model should contribute to the definition of a suitable metric for the phantom array effect.

Results

Methods for traceable and validated measurement of temporal light modulation (Objectives 1 and 2)

Based on the models given in IEC TR 63158:2018 and IEC TR 61547-1:2020, uncertainty components, which affect TLM quantities for flicker and the stroboscopic effect, have been identified. To propagate uncertainties, from the time domain to PstLM and SVM, models have been built. Using these models, sensitivity coefficients for uncertainty propagation have been determined for various waveforms. This uncertainty analyses will be used for the calibration of TLM measurement devices. Further investigation into the models revealed shortcomings of the current definitions as well as of reference implementations of TLA metrics. In addition, the improved models have been implemented in a luminous flux measurement setup which has been used to measure a large number of light sources for TLM.

For validation of implementations of TLM models a dataset containing discretised mathematically generated waveforms, named “MetTLM TLM waveform set 1”, has been released on Zenodo, an open access repository. A report accompanying the dataset will be released soon on the MetTLM community on Zenodo.

Typical performance of measurement devices can be expressed in quality indices, which characterise how a physical effect influences the instrument’s reading. For TLM measurement devices, quality indices have been defined for frequency response and dynamic range of signal. An LED-based facility has been built with the aim of characterising TLM measurement devices, which will be used to assess dynamic range. A laser-based facility has been realised, and procedures to measure the frequency response of TLM measurement devices have been tested. The frequency response of various commercially available TLM measurement devices has been characterised and compared against the developed TLM models, for flicker and the stroboscopic effect. An approach for a quality index for frequency response has been tested and will be further developed. Quality indices can be used for instrument classification, helping prospective instrument buyers selecting suitable TLM measurement equipment.

To validate the traceable TLM measurement methods developed in Objective 1, work on an interlaboratory comparison has started by selecting and evaluating artefacts, and drafting the protocol.

Novel methods for TLM measurement (Objective 3)

In an experimental study, conducted in an environment illuminated with multiple light sources, image sequences at frame rates of 8 kHz and 4 kHz have been taken with RGB cameras. For each colour channel of the cameras, (namely, red, green, and blue) the TLM waveforms have been extracted for a region of interest marked in the image sequences. The results reveal the operation principle of tuneable white LED-based lamps, which consist of various types of white LEDs or RGB-LEDs. The study underlined the need to evaluate TLM by (multi-)spectral and spatially resolved measurements. Vivid examples have been obtained by imaging TLM measurements of field scenes: a Christmas tree with different fairy lights; car headlights and daytime running lights; road lighting; a car dashboard with head-up display. Heat maps of SVM have been generated for relevant TLM metrics.

For multi-spectral TLM measurement, a hyperspectral camera was used to measure LED luminaires in office scenes. In addition, a four-channel based tristimulus TLM-meter has been set up as a unique product and is currently being evaluated.

In laboratory-based measurements, a set of three TLM luminance sources with patterned transmissive filters have been used to generate luminance contrast patterns which are then measured by using cameras. Doing so, limitations identified regarding the sampling theorem, resulting from the charge accumulating principle as used in most pixel-based detectors, could be addressed. The linearity of the TLM luminance source in constant luminance mode and during transient operation (regarding the actual TLM waveform compared to the nominal one) was investigated which revealed issues regarding modulation depth (offset) and small deviations resulting from internal decay time constants of the electrical circuit, in addition to the well-known droop effects attributed to the included LED strains itself revealed. This information is a prerequisite for facilitating these sources in a characterization of TLM measurement devices.

Measurements taken with an imaging luminance measurement device (ILMD), on different lamps and luminaires, demonstrated the feasibility of TLM measurements with such devices. Results from this feasibility demonstration resulted in an improvement of the measurement modes implemented in a commercial complementary metal oxide semiconductor (CMOS)-based ILMDs which will be further developed and demonstrated. Also, the impact of TLM on ILMD measurements of the average luminance was demonstrated. Errors as encountered during measurement for glare assessment from artificial light at night caused by high-intensity discharge lamps (HID-lamps), or pulse-width-modulated LEDs have been studied. In addition, the possibility of using conventional cameras that provide a high frame rate mode of up to 1000 Hz, such as compact cameras or smartphone cameras dedicated for slow motion recordings, are investigated. As such cameras are widely used, this is expected to increase the uptake of results.

Model for the visibility of the phantom array effect (Objective 4)

The investigation of the visibility of the phantom array effect has started with a literature review. Based on this, the effect of temporal frequency, colour of the light source, saccade amplitude and velocity, and ambient illumination on the visibility of the phantom array effect will be studied. Three psychophysical experiments have been designed, and the experimental protocols have been approved by the Ethical Review Board (ERB) at Eindhoven University of Technology. All three experiments use a two-interval forced-choice (2IFC) task for the observers, in which observers need to indicate in which of the two sequentially presented stimuli the phantom array effect is visible to them. Changing the modulation depth in the pair of stimuli in combination with the QUEST+ method (a Bayesian adaptive psychometric testing method), enables adaptive collection of data, thus reducing the number of perceptual experiments needed. By doing so, the visibility threshold of the phantom array effect can be determined for the various lighting conditions.

Experiment 1 focuses on the effect of temporal frequency and the chromaticity of the light source on the visibility of the phantom array effect. The results of Experiment 1 show an inverted U-shaped bandpass sensitivity function for the phantom array effect as a function of temporal frequency for all three chromaticities (i.e., red, green, and warm white) used in the experiment. The 3rd-order polynomial fit indicates a peak sensitivity at a temporal modulation of 600 Hz in all three cases. This finding is in line with earlier results in literature. However, the experimental peak differs from the provisional model presented in CIE 249:2022, in which the sensitivity peaks around 1000 Hz for an averaged luminance of 1000 cd/m2. In our study, the luminance is 50 cd/m2, which might partially explain the discrepancy. The fitted curves look similar across the three chromaticities used. However, the peak sensitivity is higher for red than for green and white. The MD (Modulation Depth) visibility threshold is about 3% for red, whereas it is 6-7% for green and white. In addition, the low-frequency slope is not as steep for the red colour, compared with the green and warm white colours. This indicates the phantom array effect is more visible at low frequencies for the red colour than for green and white colours. The curve for the green chromaticity seems to fit the least with the data, since we measured, on average, a constant sensitivity between 300 Hz and 1200 Hz. In addition, a 3rd-order polynomial fit is unlikely to reflect the underlying visual processing mechanism of observing the phantom array effect. As a result, other fitting functions, such as Barten's model used in CIE 249:2022, will be carefully evaluated and compared in the coming modelling efforts. Since the phantom array effect is a spatiotemporal visual phenomenon, modelling its sensitivity as a function of temporal frequency alone clearly has its limitations; expressing the sensitivity as a function of a spatially transformed variable (i.e., when the saccade speed is known) seems more appropriate. Substantial individual differences in sensitivity to the phantom array effect are also found in Experiment 1.

Experiment 2 focuses on modelling the temporal contrast sensitivity function to the phantom array effect, while Experiment 3 focuses on the effect of saccade-related characteristics (i.e., saccade amplitude and velocity) and the effect of ambient illumination on the visibility of the phantom array effect. The use of eye-tracking technology for Experiment 3 would help us understand to what extent the differences in their saccade speeds can explain the individual differences.

A description of the setup (for Experiment 1 and 2) and methods were presented at the CIE Expert Tutorial and Symposium on the Measurement of Temporal Light Modulation in Athens, Greece, October 2022. The results of Experiment 1 will be presented at the CIE 2023 conference in Ljubljana, Slovenia, September 2023, while the data collected for Experiment 2 and 3 will be analysed and modelled following the recommendations given in CIE249:2022. Two scientific papers will be written and submitted to peer-reviewed journals.

Impact

The first results of the project, related to calibration of TLM measurement devices, have been presented at the CIE Midterm Meeting hosted by MyCIE, the Malaysian CIE committee, in 2021. The project contributed to the CIE Expert Tutorial on the Measurement of Temporal Light Modulation in Athens, Greece, October 2022. The attendees were trained in measurement of TLM, estimation of measurement uncertainties and uncertainties in calculation of predictors of TLAs. The tutorial was followed by a project stakeholder meeting, which was attended by about fifty participants. After the presentations, the consortium and stakeholders engaged in open discussion. Stakeholders endorsed the need for guidance on implementation of TLM models as well as on the propagation of uncertainties. In addition, stakeholders endorsed the need for spectrally resolved TLM measurements, referring to colour-breakup perceived in light sources comprised of multiple temporally modulated coloured LEDs.

A project website is regularly updated: https://www.mettlm.eu/. So far, 74 people have registered on the website to receive a periodic project update via email. Registrants include EU Member State representatives, government experts, test organisations, manufacturers of measurement instruments, NGOs and other associations. As a result of direct engagement with stakeholders, 7 stakeholders confirmed the need for standardized measurement methods for TLM. To generate further awareness of the project, results have been presented at CIE, DIN, IEA SSL Annex and TC-PR. In addition, a YouTube video has been released aimed at explaining definitions related to TLM to the general public.

Impact on industrial and other user communities

The availability of reliable TLM measurements and related temporal light artefacts is important for the lighting industry, because the Ecodesign Commission Regulation (EU) 2019/2020 sets limits for flicker and the stroboscopic effect of the light sources and luminaires they bring to the market. The project outcomes will support the lighting industry in its efforts to demonstrate compliance of lighting products with the regulation. Similarly, market surveillance authorities will benefit from the availability of metrological methods and calibrated TLM measurement instruments, which is required for them to fulfil their role to enforce compliance with the regulation.

The project will provide novel methods using luminance and radiance imaging measurement devices to measure TLM of extended scenes or large area luminaires and displays. The findings already initiated an improvement of the TLM measurement mode implemented in a commercial imaging luminance measurement device (ILMD). This work could be especially relevant to end users who want to measure the quality of lighting in field installations e.g., in an office space under mixed lighting conditions or on a building façade. A metric for the phantom array effect will provide the automotive industry, the entertainment industry and lighting manufacturers with a quantitative measure for the visibility of this effect. This will enable them to improve lighting products such that the visibility threshold for the phantom array effect is not exceeded, enhancing the safety and consumer appreciation of their products.

To promote the uptake of the project's outcomes by the lighting industry and instrument manufacturers, the consortium has invited stakeholders from these sectors to participate in the interlaboratory comparison. To increase the number of participants the comparison will be joined with the IEA 4E SSL Annex comparison.

The consortium built up LED- and laser-based facilities to characterise and calibrate TLM measurement devices. The first commercially available TLM measurement devices have been tested against the facilities. Further characterisation and calibration of TLM measurement devices is foreseen to support regulatory compliance assessments. Preliminary tests were conducted on several (commercially available) TLM sources, using a variety of imaging devices, demonstrating the benefit of imaging TLM measurement modes.

Impact on the metrology and scientific communities

The project will strengthen the knowledge and measurement capabilities of national metrology institutes on the characterisation and calibration of TLM measurement devices and TLM sources. This will enable NMIs to establish calibration services of TLM measurement devices and/or reference sources for their stakeholders. The project will publish a set of representative computer-generated and real-life waveforms and the corresponding values and measurement uncertainties for flicker and the stroboscopic effect. This will allow scientists and metrologists involved in TLM measurement to validate their models and uncertainty calculations. Within the project, novel techniques for measuring temporal light modulation of complete scenes will be investigated, based on high-resolution time-resolved and spatially resolved imaging. The development of metrology for this type of measurement is new and challenging and is expected not only to impact the field of TLM measurement, but also the wider field of metrology for time and spatially resolved photometry. The project will impact the research field on human perception of TLM. In particular, it will progress scientific knowledge on the phantom array effect with the work on the development of a metric for this TLA. More generally, the developed metrology on TLM measurement will support ongoing research on health, performance and safety effects of TLM.

To promote the uptake of the project results by the metrology community, two presentations have been given at the CIE midterm meeting (2021). In the first presentation, a laser-based TLM calibration facility is evaluated for characterisation of TLM measurement devices, in relation to the Ecodesign Commission Regulation (EU) 2019/2020. In the second presentation, the findings of sensitivity analyses of TLM measurements to noise and sampling frequency have been shown. The findings of both presentations are taken into account in the current draft of the technical report on measurement of TLM, by CIE 2-89.

At the CIE Expert Symposium on the Measurement of Temporal Light Modulation in Athens, Greece, October 2022, the setup to determine the visibility of the phantom array effect was presented. The first results have been presented as well as an outline of methods that will be used to evaluate the data.

At Lux junior 2023 in Dörnfeld bei Ilmenau, Germany, June 2023, arranged by LitTG and Technische Universität Ilmenau two presentations were given on the characterization of TLM in scenes using imaging devices.

To facilitate impact a Zenodo community has been established: https://zenodo.org/communities/mettlm20nrm01, where data items related to TLM in general and MetTLM specifically will be curated and collected. So far, the dataset has been viewed 73 times and downloaded 57 times.

Impact on relevant standards

The project is contributing to the work of the technical committee under the CIE, TC 2-89 “Measurement of Temporal Light Modulation of Light Sources and Lighting Systems”. One of the project deliverables is a GPG on metrological methods, instrumentation and conditions for calibration of TLM measurement devices, which will contribute to an international CIE standard on TLM measurement. CIE is the Chief Stakeholder of the project and the involvement of TC 2-89 in the stakeholder board of the project will ensure that CIE needs will be met and that project results are taken up effectively. Since CIE and CEN have a formal agreement on technical cooperation, it is expected that CEN will adapt the CIE standard once available. This will help CEN to respond to the mandate issued by the European Commission (Ares(2013)205169), requiring the development of standardisation on LED lighting and the development of standards for flicker and the stroboscopic effect. This project aims to deliver a significant contribution to scientific data on the sensitivity for the phantom array effect and the development of a metric for this TLA. This will contribute to the work of CIE TC 1-83 (or possibly a new CIE TC) that is tasked with visual aspects of time-modulated lighting systems. Other standards and guidelines that may be impacted by this work are IEC TR 63158:2018 and 61547-1:2020.

The project’s outcomes are being disseminated to standardisation bodies via the involvement of project partners in technical committees such as CIE TC 2-89, CIE TC 1-83, CEN 169, ISO 274, IEA 4E SSL Annex and two new TCs of CIE that are responsible for the revision of ISO/CIE 19476 on the “Characterization and performance of illuminance meters and luminance meters”, which will include characterisation of photometers with relation to TLM, and the revision of CIE S 025/E:2015, which specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of LED lamps, LED modules and LED luminaires.

Over the past 27 months of the project, the consortium was actively involved in the following international standardisation committees: CIE TC 2-89, CIE TC 2-96, CIE TC 2-97, CIE RF-02, CEN TC 169, ISO TC 274 JWG1, and the national standardisation committees DIN- NA058-00-03AA and DS-061. On behalf of the consortium direct input has been provided to the draft technical report of CIE TC 2-89, to ISO/CIE 19476:2024 "Characterisation of the performance of illuminance meters and luminance meters", which should be published in 2024 and falls under the responsibility of CIE TC 2-96, and to CIE S 025/E:2015 Test Method for LED Lamps, LED Luminaires and LED Modules, which should be published in 2024 and is being prepared by CIE TC 2-97.

Longer-term economic, social and environmental impacts

The project outcomes will support the execution of the EU Ecodesign Commission Regulation (EU) 2019/2020, which protects EU citizens against potentially negative health, performance and safety effects resulting from modulated light sources like LED lighting. Having only compliant light sources on the market protects people against these potentially negative effects like decrease of performance, fatigue, eye strain or more severe effects like migraine episodes or epileptic seizures.

This EU regulation currently focuses on light sources that produce flicker and/or the stroboscopic effect and will be revised in 2024. The availability of a metric for the phantom array effect may serve as the basis for the incorporation of this temporal light artefact in the revision of the regulation. Requirements on dimmed light sources, known for exhibiting TLM, will probably also be included in the revision.

The project indirectly contributes to energy saving and reduction of the environmental impact of lighting by supporting regulations that put limits on the allowed TLM of light sources. The ability to enforce compliance with regulations, based on appropriate standardisation, will be supportive to the adaption of LED lighting by the public and the phase-out of incandescent lighting. This serves European and international goals on energy saving and reduction of the emission of greenhouse gasses. End users such as building owners and governmental organisations will benefit from the outcomes of the project, since it supports them in their efforts to save energy and cost by using efficient lighting.

List of publications

- Nordlund, R, ‘Validation for measurement of Temporal Light Artefacts on LED light sources’, Master’s thesis. Aalto University, Mar. 2022 – https://aaltodoc.aalto.fi/handle/123456789/113709.
- Dekker P, van Bloois A. Facility for calibration of photometers for measurement of temporal light modulation. Light Res Technol. 2023 Jun 1;55(4–5):414–9. – https://doi.org/10.1177/14771535231159289.

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

<table>
<tr><td colspan="2">Project start date and duration:</td><td>1 May 2021, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Paul Dekker, VSL Tel: +31 15269 1500 E-mail: pdekker@vsl.nl
Project website address: https://www.mettlm.eu/</td></tr>
<tr><td colspan="2">Chief Stakeholder Organisation: CIE</td><td>Chief Stakeholder Contact: Dong-Hoon Lee</td></tr>
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2. Aalto, Finland
3. PTB, Germany
4. RISE, Sweden</td><td>External Funded Partners:
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7. ICCS, Greece
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