



Publishable Summary for 17FUN09 UnipHied Realisation of a Unified pH Scale

Overview

To date, it is impossible to compare pH values of solutions made in different solvents. This situation is untenable, since it causes confusion and inaccuracies in many fields, extending far beyond the specific field of acid-base chemistry, to almost all spheres of life. The purpose of this project is to overcome this situation by putting the new theoretical concept of a unified pH_{abs} scale on a metrologically well-founded basis into practice. The project results will ensure that pH measurement systems are available to industry and academia for accurate pH testing in a wide variety of media.

Need

The pH of solutions is probably the most prominent chemical concept widely utilised outside the field of chemistry. It is used in a near uncountable number of areas, e.g., medicine and life sciences, biology, environmental science, agronomy, marine sciences, meteorology, material sciences, corrosion science, energy related sciences, etc. It plays an important role in virtually all material related processes, in their production (e.g., processing metals, paper, plastics, glasses, etc.) as well as in their reprocessing (domestic and industrial wastewater, extraction of solid wastes, etc.). Accurate analysis and monitoring of pH values is therefore an extremely important task in a wide variety of technologies. This variety entails a diversity of media in which those processes occur, i.e., different solvents, solvent mixtures, and dispersions. For basic thermodynamic reasons, valid comparability of pH values in different media has been impossible for a long time, even on the theoretical level. As a result, several pH scales exist in parallel, loosely correlated to each other, without the possibility of converting one scale into the other to the necessary level of accuracy. It is known that there are potentially 1.5 million pH electrodes used in industrial applications today, of which a number (10 % to 20 %) are placed in solvent mixtures that are not suitable for the current offerings and lead to rapid failures.

In 2010, the unified acidity (pH_{abs}) concept was introduced to overcome this untenable situation, enabling comparability of pH values between all phases, whether they are gaseous, liquid, or solid. Although conceptually excellent, putting this concept into practical use has proved tremendously difficult and has not yet been fully achieved. In order to be practically usable the knowledge of physicochemical quantities is required, access to which is not straightforward. Additionally, suitable measurement and calibration procedures are required, all of which still need to be developed.

Objectives

This project concerns the practical realisation of the theoretical concept of pH_{abs} . This includes the determination of the mentioned quantities, as well as the standardisation of the measurement and calibration processes of pH_{abs} . The major objectives laid out for this project are:

1. To develop and validate a reliable and universally applicable measurement procedure, that enables the measurement of pH_{abs} (expressed relative to the aqueous scale, as $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ -values) in non-aqueous and mixed solvents, colloids, etc., thereby enabling their acidities to be compared to the conventional aqueous pH scale. The target combined standard uncertainties to be 0.15 pH_{abs} in "good" (mixed aqueous, alcohols, etc.) and 0.25 pH_{abs} in "difficult" (colloids, aprotic, etc.) systems.
2. To create a reliable method for the experimental or computational evaluation of the liquid junction potential between aqueous and non-aqueous solutions where the bridge electrolyte is an Ionic Liquid, allowing correction of results from, for example, a glass electrode pH measurement setup calibrated with aqueous standards measuring non-aqueous samples.
3. To develop a coherent and validated suite of calibration standards (including procedure and sensor) for standardising routine measurement systems in terms of pH_{abs} values for a wide variety of media (e.g., industrial mixtures, soils/waters, food products, biomaterials).
4. Based on the outcome of the project, to contribute to the international specifications for bioethanol quality EN 15490 (e.g., by assigning values to existing certified reference materials) and other relevant

standards development organisations, and to disseminate the findings to the European measurement infrastructure.

Progress beyond the state of the art

1. *To develop and validate a reliable and universally applicable measurement procedure, that enables the measurement of pH_{abs} (expressed relative to the aqueous scale, as $pH_{abs}^{H_2O}$ -values) in non-aqueous and mixed solvents, colloids, etc., thereby enabling their acidities to be compared to the conventional aqueous pH scale. The target combined standard uncertainties to be 0.15 pH_{abs} in "good" (mixed aqueous, alcohols, etc.) and 0.25 pH_{abs} in "difficult" (colloids, aprotic, etc.) systems.*

Depending on individual requirements and technical possibilities, several pH scales have been developed over the last century. However, these scales suffer as a result of their incompatibility, *i.e.*, a certain value in one scale cannot be converted to a value on another scale with acceptable accuracy. This project will establish a practical method of measuring and expressing acidity of any medium on a universal scale (termed here as pH_{abs}), which will make pH values comparable between solvents/media.

A measurement procedure for $pH_{abs}^{H_2O}$ measurement has been developed on the basis of differential potentiometric method. Such methods allow direct comparison of potential difference between two electrodes without need of a reference electrode. To this end, each NMI project partner implemented the differential potentiometry setups. The system satisfies the previously established requirements for the main components: the cell, the electrodes as well as the system for measuring the difference of potential. The validation of the experimental procedure was successfully carried out using aqueous buffers with known pH values. A first version of a complete measurement uncertainty budget has been developed showing that the target uncertainty for "good systems" is attainable. The developed method is currently used for $pH_{abs}^{H_2O}$ measurements in more complicated systems such as ethanol, methanol, acetonitrile and their mixtures with water.

2. *To create a reliable method for the experimental or computational evaluation of the liquid junction potential between aqueous and non-aqueous solutions where the bridge electrolyte is an Ionic Liquid, allowing correction of results measuring non-aqueous samples.*

In potentiometric pH measurement a liquid junction is formed at the interface between two solvents, typically water and the non-aqueous solvent. The liquid-junction potential (LJP) that arises has a magnitude that is generally difficult to evaluate and control, and is, therefore, considered to be the major source of bias in classical pH measurement. The issue of liquid junction potential will be addressed in the present proposal by utilizing an "ideal" ionic liquid (IL) salt bridge composition. The ionic liquid selected for the project is the triethylammonium bis((trifluoromethyl)sulfonyl)imide also noted $[N_{2225}][NTf_2]$. The media to be studied are related to the applications that will be addressed during the project and contain solvents ranging from medium to high polarity (water), as well as protic (methanol, ethanol) and aprotic solvents (acetonitrile).

The LJP is now accepted as being composed of three components caused by differences at two sides of the junction in ionic mobility (part A), ionic solvation (part B) and solvent-solvent interactions (part C). For the proposed solvents, it was demonstrated that part A and B cancel each other out and only part C has to be measured. According to the current development, it seems that instead of measuring and accounting for part C it will be easier to use salt bridge composition that makes its contribution negligible. Experiments carried out at ALU have demonstrated that if $[N_{2225}][NTf_2]$ is used as a salt bridge electrolyte then part C contribution is negligible. Thus, a new methodology has been proposed as a result of collaboration between ALU-FR and UT.

3. *To develop a coherent and validated suite of calibration standards (including procedure and sensor) for standardising routine measurement systems in terms of pH_{abs} values for a wide variety of media (e.g., industrial mixtures, soils/waters, food products, biomaterials).*

Although pH measurements are primarily done in aqueous (water-based) solutions, they are used in a vast variety of industries and therefore in a diverse set of media *i.e.* different solvents, solvent mixtures, mixed aqueous/non-aqueous dispersions. These sample types can be challenging for classical pH sensors, with commercial sensors having to be tailored to the media in which it will be deployed, as conventional sensors suffer from unstable reading and drift, long response times and measurement errors. In separation techniques such as Liquid Chromatography (LC), the development of the analytical method involves the optimisation of several variables, mobile phase pH being highly relevant among these. Because mixed solvents of different

compositions are used in LC, adjusting the mobile phase pH is largely a matter of trial and error among practitioners.

ANB Sensors have started working on developing a sensor that can determine $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ values for non-ideal solutions. An electrochemical system has been found which operates as a pH sensor in the certain mixed solvent systems and this is currently being tested in a range of other solutions.

Results

1. To develop and validate a reliable and universally applicable measurement procedure, that enables the measurement of pH_{abs} (expressed relative to the aqueous scale, as $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ -values) in non-aqueous and mixed solvents, colloids, etc., thereby enabling their acidities to be compared to the conventional aqueous pH scale. The target combined standard uncertainties to be 0.15 pH_{abs} in "good" (mixed aqueous, alcohols, etc.) and 0.25 pH_{abs} in "difficult" (colloids, aprotic, etc.) systems.

The differential potentiometry method relies on the conversion of the measured potential difference between two electrodes immersed each in a solution separated by a salt bridge, into pH difference.

For measuring the pH_{abs} , the differential potentiometry measurement setups have been built up at all NMI partners and used to develop the pH_{abs} measurement procedure. The implemented setup has the particularity that an ionic liquid ensures the junction between the two compartments.

The development of the pH_{abs} measurement procedure involved the following major steps:

- Verify the quality of the measurement system including both the requirements for the instrument measuring the potential and the characterization of the electrodes. All solutions to be analysed within the project have a density smaller than the ionic liquid. Therefore, the cell was specially designed with a salt bridge below the measurement solutions. All partners have built their own cell. Depending on the institute, the salt bridge is jacketed or not.
- Build a pH_{abs} ladder allowing anchoring the assigned pH_{abs} values to a known pH_{abs} value. The ladder was built in water using three certified reference materials. The pH 7 was typically fixed as anchor point. This step enables to get the $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ measurement values directly traceable to the conventional aqueous pH (meaning that $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ 7 corresponds to the conventional pH 7).
- Obtain $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ values for an unknown solution based on a minimisation procedure. The determined consistency of standard deviation is considered as one of the sources of $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ uncertainty.

Initial uncertainty budgets for $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ measurements in aqueous solutions have been compiled. The first versions of the uncertainty budget based on GUM and Monte Carlo simulation approach shows that the target uncertainties of 0.15 fixed for $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ measurement values can be reached in "good" systems (mixed aqueous, alcohols, etc). A more sophisticated version of the measurement uncertainty budget is about to be developed.

All setups together with its associated procedure have been validated in aqueous media by comparing the assigned $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ values to the reference pH values in water. The validation highlights that the method is, to a large extend, independent of the user and the used equipment, including cell geometry. The quality (consistency standard deviation) of the fitted ladder data depends on the instrument and the electrodes. The input impedance of the instrument must be high for a successful measurement. From a metrological perspective it is desirable that a measurand does not depend on the instrument used to measure it. Therefore, it was investigated the dependence of unified pH measurement results on various kinds of electrodes that are designed for non-aqueous solutions and that are commonly available. All electrodes give acceptable results in standard aqueous buffers. However, poor results characterized by unstable potential reading were obtained for water-organic solvent mixtures. This translates in differences in the assigned $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ values up to one pH unit. The metal contact glass electrodes half-cells perform better compared to the electrodes with inner filling and are thus considered the most appropriate for $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ measurements in matrices other than water. Metal-contact glass electrodes can be calibrated against a chosen reference electrode like commercial Ag/AgCl electrode or calomel electrode.

The developed method seems to be robust enough for a wider adoption of the concept. Its use for more complex matrices i.e. water-ethanol mixture (50 wt% of organic content) and pure ethanol will be validated by an intercomparison approach, currently on going.

2. To create a reliable method for the experimental or computational evaluation of the liquid junction potential between aqueous and non-aqueous solutions where the bridge electrolyte is an Ionic Liquid, allowing correction of results measuring non-aqueous samples.

The minimisation of the liquid junction potential by using a salt bridge formed by an “ideal” ionic liquid (IL) was studied in three systems formed by water and non-aqueous solvents such as acetonitrile, ethanol and methanol. The ideal character of the IL requires, among others, identical transference numbers, or ionic mobilities, for cation and anion both in the pure IL and in solution while being inert by respect to the solvents. The IL [N₂₂₂₅][NTf₂] selected for the project satisfies these requirements.

A new methodology to determine the LJP was proposed by ALU-FR and UT. The approach is based on the network analysis. The network is an overdetermined system, i.e. a system of equations with more equations than unknowns. Generally, the more closely meshed the network the more reliable the result. The network is used to determine the Gibbs transfer energy of the redox system Ag⁺/Ag from water to various solvents $\Delta G_{tr}^{\circ}(\text{Ag}^+, \text{H}_2\text{O} \rightarrow \text{S})$. The network now comprises 145 individual measurements. Comparison of the obtained experimental values to the calculated values enabled assessment of the overall liquid junction potential hence establishing whether part C (related to solvent-solvent interactions) equals to zero.

The Gibbs transfer energy of the redox system Ag⁺/Ag from water to acetonitrile (AN), $\Delta G_{tr}^{\circ}(\text{Ag}^+, \text{H}_2\text{O} \rightarrow \text{AN})$, was determined to $-25.1 \text{ kJ mol}^{-1}$ with the accuracy level of 6 mV, see below. A widely accepted literature value is $-23.2 \text{ kJ mol}^{-1}$ having an estimated uncertainty of 3 – 6 kJ mol⁻¹. The literature value was obtained using the so-called reference electrolyte assumption that is considered to be the most reliable since it is supported by recent theoretical ab initio calculations using the cluster-pair approximation. The closeness between experimental value obtained in the project and literature value validate the setup used by ALU-FR and also the proposed network approach. Moreover, the difference of the LJPs in the given setup, i.e. LJP(H₂O-IL) – LJP(AN-IL), is constant and stable within 6 mV (equivalent to 0.61 kJ mol⁻¹ or 0.11 pH-units, respectively). For water-acetonitrile, LJPs are remarkably insensitive against the change of the ionic strength of the electrolyte solutions (silver salts of type Ag⁺Z⁻) and against influx of solvent into the ILSB. In addition, this indicates that the redox system Ag⁺/Ag under investigation doesn't affect the LJPs either.

Hence, for the water-acetonitrile system it was shown that part C does not occur.

The Gibbs transfer energy of the redox system Ag⁺/Ag from water to EtOH, $\Delta G_{tr}^{\circ}(\text{Ag}^+, \text{H}_2\text{O} \rightarrow \text{EtOH})$ was determined to 1.6 kJ mol⁻¹ and from water to MeOH, $\Delta G_{tr}^{\circ}(\text{Ag}^+, \text{H}_2\text{O} \rightarrow \text{MeOH})$ to 3.8 kJ mol⁻¹.

These findings can be considered reliable since are in good agreement with literature data. The consistency of the values is 0.55 kJ mol⁻¹.

All the measurements performed at ALU-FR were done using their home-made IL. The collaboration of ALU-FR with the company Iolitec, producer of IL, allowed the distribution to each partner of 50 g of ionic liquid [N₂₂₂₅][NTf₂] produced by this company.

3. To develop a coherent and validated suite of calibration standards (including procedure and sensor) for standardising routine measurement systems in terms of pH_{abs} values for a wide variety of media (e.g., industrial mixtures, soils/waters, food products, biomaterials).

ANB Sensors has started working on developing the transducers to be used in the sensing device and to be tested at the NMLs. Preliminary findings showed a workable sensors in buffered/mixed solvent systems, leading onto the development of an electrode array to test a variety of pH sensing chemistries. The tests show promise that at least one of the chemistries can provide a pH sensing response to the buffered/mixed solvent system. These chemistries are currently being built into a further device incorporating patented iRef technology. The iRef technology will account for reference electrode drift inside a conventional LiCl reference chamber system and the pH sensing chemistries will monitor the pH of the solution. It should be noted that in lower buffered systems the pH sensing chemistry currently being used starts to show inaccuracies. ANB Sensors is working on this with their oceanographic pH sensing system, which is tailored to lower buffered systems, however, the presence of the solvent is having a negative impact on the mechanical integrity of the current manufactured electrode. Optimisation of the low buffered pH sensing electrode is ongoing for the mixed solvent case.

Acidity measurements including pH_{abs} have been performed on several buffering agents used for liquid chromatography based analytical techniques. The analysed solutions have been prepared in aqueous solutions containing 25% (v/v %) of methanol as organic solvent. The obtained values have been used to connect the properties of buffering agents to the performances of separation of several pharmaceuticals. The study has been made by comparing new molecules such as perfluorinated alcohols to classical buffering agents e.g. ammonium acetate and ammonium bicarbonate. The work was published in a peer review journal. A number of several mobile phases have been characterised and pH_{abs} values determined. Repeating the measurements is in progress in order to evaluate the reliability of the values and determine, which mobile phases could be proposed as references for practitioners.

Impact

The project has submitted 7 scientific publications so far (6 open-access), and given more than 10 presentations (oral or by poster) at national or international conferences and 4 internal training workshops.

Impact on industrial and other user communities

The project aims to provide a reliable and practical method of measuring and expressing acidity of any medium on a universal scale (termed here as $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ -values).

It is expected that the outputs produced during the lifetime of the project will benefit manufacturers of pH meters by providing a reliable means to characterise and benchmark their devices in solutions other than aqueous, since they can directly compare the results of different types of devices in various matrices using the unified pH_{abs} scale as a root of traceability. The sensor device produced within the project lifetime will explore the possibility for implementing pH_{abs} measurement on a wider scale. To this end, the sensor produced will be tested by an academic stakeholder in food/beverage matrices. ANB sensors is working with a large number of glass manufacturers for one of its key technologies and therefore has the potential to make prototypes available to the mass market. Furthermore, they will use their own end user contacts to understand the market potential and deliver future sensors to these customers.

In the longer term, routine laboratories will be able to measure $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ whilst – very importantly – using their standard pH measurement equipment (i.e. there will be no need to install sophisticated differential potentiometry setups). This will be possible since the specific ionic liquid forming the salt bridge is commercially available worldwide.

Impact on the metrology and scientific communities

The main expected impact of this project on the metrological community is related to the transfer of knowledge related to pH_{abs} measurement from the academic field to chemical services providers; especially those using liquid chromatography and its derivative methods, electrochemists in the field of batteries or corrosion, and those working in the food industry. For instance, the work carried out in the project was disseminated through a scientific publication to demonstrate the possibilities offered by using new molecules as buffering agents in liquid chromatography mobile phase for the separation of several analytes. The acidity measurements including $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ have been used to study the effects of mobile phase acidity, organic solvent, organic solvent fraction and aqueous phase properties.

Unified acidity values ($\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ values) can be measured with various instruments and cell designs. An article has been published showing that all experimental setups used by 8 project partners were found suitable $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ for measurements. The developed $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ method is robust enough for a wider adoption of the concept, and the results from different setups are comparable. Symmetry of the measurement cell is important and helps to improve the accuracy of the measurement results, hence the $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ values. The workload halves if the electrodes used are similar. An interlaboratory comparison is currently on going to validate the applicability of the method to several matrices.

The work undertaken in this project will be incorporated into the efforts already started by IUPAC to address pH assessment in non-aqueous and mixed solvents. The UnipHied project was promoted in the News Magazine of IUPAC as an important opportunity to secure intercomparability of pH measurement results in

different media. A Technical Report presenting the state-of-the art of the meaning and assessment of pH in solvents other than water was submitted to IUPAC official journal, Pure and Applied Chemistry.

Impact on relevant standards

The project will encourage active participation in key European chemistry related committees such as the EURAMET TC MC, as well as knowledge transfer and exchange with international metrology in chemistry community such as BIPM CCQM. It is expected that the partners who are members of technical committees will inform them about the results of this project.

Within the project lifetime, pH_{abs} measurements in ethanol and water-ethanol mixtures will be performed. Therefore, findings of the project will support improving the comparability of acidity values of ethanol measured using the EN15490 standard method.

Longer-term economic, social and environmental impacts

Since pH is possibly one of the most important chemical parameters in science, technology, environment and health, the project's broader impact is potentially enormous, yet difficult to quantify. It is clear that any uptake of the project's outcomes by any fields regarding pH values or redox values in non-aqueous (but also aqueous and mixed-aqueous) solutions will also lead to further development within these fields. Thus, we reasonably expect beneficial effects for European industry as a whole, but also for the public sector. The measurement standards of pH_{abs} and/or $\text{pH}_{\text{abs}}^{\text{H}_2\text{O}}$ -values can be embedded into the European measurement infrastructure, thereby underpinning the whole area at an EU level.

The developments in the project will enable more efficient process control in the EU chemical industry, which is a large branch of the European economy, employing 1.2 million workers and contributing €519 billion annually.

The project will be a vector of innovation for the development of the next generation of electrodes. Such electrodes would be useful in the biomedical field, especially for cancer chemotherapy, and will contribute towards the reduction of the cost of cancer treatment.

Europe is a key player in addressing environmental sustainability and the global climate challenge. This project would contribute to a further understanding of the chemistry of water bodies (particularly sea water, a highly important ecological system). Extensive and continuing CO_2 absorption by seawater causes acidification, evidenced by a reduction in pH and changes in the ocean carbonate chemistry. Serious discrepancies have been noticed in established trends in seawater acidity due to the existence of several measurands for the same quantity. Establishment of the unified pH concept and pH_{abs} measurement procedures would enable the expression of seawater acidity on a comparable scale, hence increasing our understanding of processes in seawater media. To address this specific issue, a Researcher Mobility Grant (RMG) has been proposed aiming to create a metrological link between the concepts of pH_{T} and pH_{abs} . The work conducted on seawater would represent an extension of the project activities, with an application on a matrix of a different nature, with potential impact for the scientific community working on the ocean acidification issues.

List of publications

Sigrid Selberg, Sofja Tshepelevitsh, Ivo Leito, "Biphasic pK_a Values", Croat. Chem. Acta 2018, 91(4), <https://doi.org/10.5562/cca3405>

Heike Kahlert, Ivo Leito, "Generalization of Acid-Base Diagrams Based on the Unified pH-Scale", ChemPhysChem, 2019, 20, 1779 – 1785

<https://doi.org/10.1002/cphc.201900388>

Valentin Radtke, Katharina Pütz, Daniel Himmel, Ingo Krossing, "The Inverted Philosopher's Stone: how to turn silver to a base metal", J Solid State Electrochem,

<https://doi.org/10.1007/s10008-020-04633-y>

Ruta Veigure, Krit Lossmann, Max Hecht, Elisabeth Parman, Rasmus Born, Ivo Leito, Koit Herodes, Kari Kipper, "Retention of acidic and basic analytes in reversed phase column using fluorinated and novel eluent additives for liquid chromatography-tandem mass spectrometry", Journal of Chromatography A

<https://doi.org/10.1016/j.chroma.2019.460667>

Sofja Tshepelevitsh, Sandip A.Kadam, Astrid Darnell, JohanBobacka, Alo Rüütel, Tõiv Haljasorg, IvoLeito, "Log P° determination for highly lipophilic hydrogen-bonding anion receptor molecules", Analytica Chimica Acta, vol 1132, 123-133, (2020)

<https://doi.org/10.1016/j.aca.2020.07.024>

Agnes Heering, Daniela Stoica, Filomena Camões, Bárbara Anes, Dániel Nagy, Zsófia Nagyné Szilágyi, Raquel Quendera, Luís Ribeiro, Frank Bastkowski, Rasmus Born, Jaan Saame, Jaak Nerut, Silvie Lainela, Lokman Liv, Emrah Uysal, Matilda Roziková, Martina Vičarová, Alan Snedden, Lisa Deleebeeck, Valentin Radtke, Ingo Krossing, Ivo Leito, « Symmetric Potentiometric Cells for the measurement of Unified pH values », Symmetry 2020, 12(7), 1150.

<https://doi.org/10.3390/sym12071150>

Project start date and duration:		1 st May 2018, 36 months
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Internal Funded Partners:	External Funded Partners:	Unfunded Partners:
1. LNE, France	9. ALU-FR, Germany	
2. BFKH, Hungary	10. ANB Sensor, United Kingdom	
3. CMI, Czech Republic	11. FC.ID, Portugal	
4. DFM, Denmark	12. UT, Estonia	
5. IPQ, Portugal		
6. PTB, Germany		
7. SYKE, Finland		
8. TUBITAK, Turkey		
RMG1: UT Estonia (Employing organisation); LNE, France (Guestworking organisation)		