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Managing Urban Shallow Geothermal Energy (Preliminary Results of the MUSE Project)

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ABSTRACT

In 2018, the MUSE project (Managing Urban Shallow Geothermal Energy) was launched under the umbrella of the GeoERA initiative of the European Geological Surveys (http://geoera.eu/). Partners from 16 European Geological Survey Organizations investigate potential of shallow geothermal energy (SGE) and possible conflicts associated with its use in the European urban areas. The project runs until June 2021 and outputs represent key geoscientific subsurface data delivered to targeted stakeholders via a user-friendly web service hosted at the GeoERA information platform project (GIP-P).

The assessment of geothermal resources and conflicts of use will lead to the development of management strategies considering both efficient planning and monitoring of environmental impacts to feed into the general framework strategies of cities like Sustainable Energy Action Plans (SEAPs). The developed methods and approaches will be tested and evaluated together with input from the local stakeholders in 14 urban pilot areas across Europe, which provide different boundary conditions for the use of SGE. The pilot areas are geologically and climatologically diverse and provide different legal and socio-economic settings making the project outcomes and obtained knowledge relevant to the whole of Europe and beyond.

The project addresses all relevant aspects by capitalizing on existing knowledge inside the project consortium, identifying and closing specific knowledge gaps and providing joint proposals on methodologies, criteria and concepts on SGE management. We adapt workflows to focus on local scale investigations suitable for densely populated urban areas, where heating and cooling demand is generally the highest, and which will represent the most important SGE market in the future. The outcomes of the project represent a comprehensive collection of methods, approaches and tools, which can be transferred to other urban regions in Europe and adapted by other organizations.

1. INTRODUCTION

Shallow Geothermal Energy is an environmentally friendly, renewable and sustainable energy source and has become increasingly important in European energy policy and strategy. The SGE installations for spatial heating, cooling and seasonal thermal energy storage contribute to reduction of CO_2 and dust emissions across Europe (Sarbu, Sebarchievici 2014). Nevertheless, market development of SGE varies very much among the European countries which is caused not only by the natural conditions and suitability for deployment of this type of technology but, to a large extent, by national and regional legal regulations, strategies and policies (Somogyi, Sebestyén, Nagy 2017). Intensive application and rapid development of new installations in European cities and towns may shortly result in non-sustainable utilization leading to constraints of use, deficiencies of resources and environmental threats (Hähnlein et al. 2013). This is why there is an urgent need for unification of guidelines and legal regulations on pan-European level leading to a better management of SGE resources (Tsagarakis et al. 2018).

Managing shallow geothermal energy is a multidisciplinary topic which draws on many geoscientific sub-disciplines such as geology, hydrogeology, geothermics, thermogeology, hydraulics, hydrochemistry, borehole and well design and completion, geoengineering and geohazards, and IT. In addition, it also covers wider issues related to energy economics, environmental laws, regulations and good practices, district heating and cooling systems, energy-decarbonisation and land-use planning.

A significant body of geoscientific knowledge is already available from numerous national and international projects. However, these projects often address only some selected specific issues within the above mentioned topics or cover certain European regions or countries. This leads to various and partly contradictory methods and concepts to address resources and constraints of use as well as to fragmented strategies for managing efficient and sustainable SGE management. In this context, it should be emphasized that even a uniform definition of shallow geothermal energy is not yet available for Europe as a whole.

For the time being, there is a challenge in efficiently conveying geoscientific datasets on resources and possible constraints to the decision-makers, such as: managing authorities, planners, city administrations and investors. In particular, the overall cumulative effect of competing SGE uses can be difficult to be assess properly based on the static geoscientific datasets like thermal conductivities or expected maximum thermal capacities of SGE installations. Therefore, MUSE aims at providing valid solutions for identification of issues and opportunities to enable interactive decision support tools, methods and workflows. The ambition of the project is to develop a comprehensive and integrated set of methods, concepts and strategies allowing for local-scale management of SGE in European urban areas, which can later be applied by other Geological Survey Organisations (GSOs), decision makers and other stakeholders in European urbanized areas.

This paper describes the objectives of the project, its progress and preliminary results and as such it is an update of information provided by the project team for the European Geothermal Congress 2019 (Herms at all 2019).

2. AIMS AND OBJECTIVES

The main aim of the MUSE project is to accelerate and support development of concepts and methodologies for an efficient and sustainable management use of SGE in European urban areas addressing heating, cooling and seasonal heat storage. In order to reach the overall project goal, the following objectives have been set up:

1) Identifying, summarising and developing state-of-the-art methods including harmonised standards for: quantifying the potential of SGE use in urban areas, evaluating cost-efficient geophysical exploration and monitoring tools, assessing constraints of use associated with open- and closed-loop systems and evaluating the efficiency and impacts of SGE installations.

2) Developing strategies for efficient and sustainable use of SGE in European urban areas by means of: evaluating current legal regulation, identifying and promoting prospective technical concepts and summarising criteria, strategies and actions for planning, managing and monitoring of SGE use in cities.

3) Transferring these methods and integrating them into strategies in urban pilot areas across Europe. For example, in order to estimate the resources for SGE use, monitor the thermal state of the subsurface and assess and map the resources and constraints of use associated with SGE utilisation.

4) Disseminating shared knowledge by displaying spatial output datasets via the web-hosted services integrated in the GeoERA Information Platform and other dissemination actions.

5) Contributing to the overall GeoERA objectives by knowledge exchange and interacting with other projects of GeoERA covering overlapping and cross-cutting aspects of SGE use in the urban areas as well as providing technical concepts and datasets for implementing geoscientific knowledge related to SGE use in the European Geological Data Infrastructure (EGDI) information platform.

MUSE cooperates with the active international projects of the GeoERA programme, dealing with SGE and subsurface use, and builds upon the outcomes of previous EU projects, such as: GRETA (Interreg Alpine Space), GeoPLASMA-CE (Interreg Central Europe), ThermoMap (ICT PSP), REGEOCITIES (Intelligent Energy Europe), SUB-URBAN (COST), ESTMAP (H2020), CheapGSHPs (H2020),Geothermal4PL (EEA Grants) and GeothermalMapping (EU IPA).

3. PARTNERS

In total, 16 Geological Survey Organizations from 15 European countries (Tab. 1 and Fig.1) are participating in the MUSE project. The individual members of the consortium represent complementary levels of knowledge and experience, important aspects to have an overarching vision of the different issues in the scope of the SGE and thus achieve the project objectives:

- 14 out of 16 partners have already performed national studies on relevant topics including exploration, geoscientific modelling, mapping resources and constraints of use;
- some GSOs also represent managing authorities or perform consulting on behalf of their local and /or national authorities.

4. METHODOLOGY AND WORK PACKAGES

MUSE pools knowledge on managing the efficient and sustainable use of shallow geothermal energy in the selected European cities. SGE covers the uppermost tens to hundreds of meters of the subsurface, including aquifers accessed by the geothermal schemes within that depth range. The project flow pursues the process circle (Fig. 2), which consists of the following main stages:

Stage 1 covers **compilation of methods and workflows** for providing key geoscientific data and creating strategies for efficient and sustainable SGE use.

Research includes exploration and monitoring of the subsurface, assessing, processing and mapping of the key data, as well as creation, evaluation and validation of static and dynamic geoscientific models. A catalogue of joint methods appropriate for the wider range of thermogeological characteristics of the pilot areas will be created using literature reviews, partner questioners and technical working group meetings. The management circle also includes analysis of the legal framework and regulatory dimensions, administrative procedures, social dimensions and policies, as well as aspects of land-use and subsurface spatial planning, often using 3D visualisations of geospatial data.

Stage 2 of the project focuses on the **implementation of the joint methods and workflows in 14 pilot areas across Europe**. All of them represent selected urban areas affected by different climatic and geological conditions, legal settings, different supply and infrastructure as well as different thematic focuses of the proposed investigations. Using the compiled concepts and standards will lead to interoperable and comparable project outputs. The project pilot areas are evenly distributed throughout Europe (Fig.1) and act as the test and demonstration sites for applying modern management approaches strongly based on geoscientific data and expert knowledge.

Table 1: Partners of the MUSE project

Partner acronym and full name		Country
GBA	Geologische Bundesanstalt	Austria
BGS-UKRI	British Geological Survey – UK Research and Innovation	United Kingdom
ICGC	Institut Cartogràfic i Geològic de Catalunya	Catalonia (Spain)
HGI-CGS	Hrvatski Geološki Institut – Croatian Geological Survey	Croatia
CGS	Česká geologická služba – Czech Geological Survey	Czech Republic
BRGM	Bureau de Recherches Géologiques et Minières	France
GSI	Geological Survey Ireland	Ireland
RBINS-GSB	Royal Belgian Institute of Natural Sciences – Geological Survey of Belgium	Belgium
GeoZS	Geološki zavod Slovenije	Slovenia
IGME	Instituto Geológico y Minero de España	Spain
SGU	Sveriges Geologiska Undersökning	Sweden
TNO	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek	The Netherlands
PIG-PIB	Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy	Poland
SGIDS	State Geological Institute of Dionýz Štúr	Slovakia
GEOINFORM	State Research and Development Enterprise State Information Geological Fund of Ukraine	Ukraine
GEUS	Geological Survey of Denmark and Greenland	Denmark

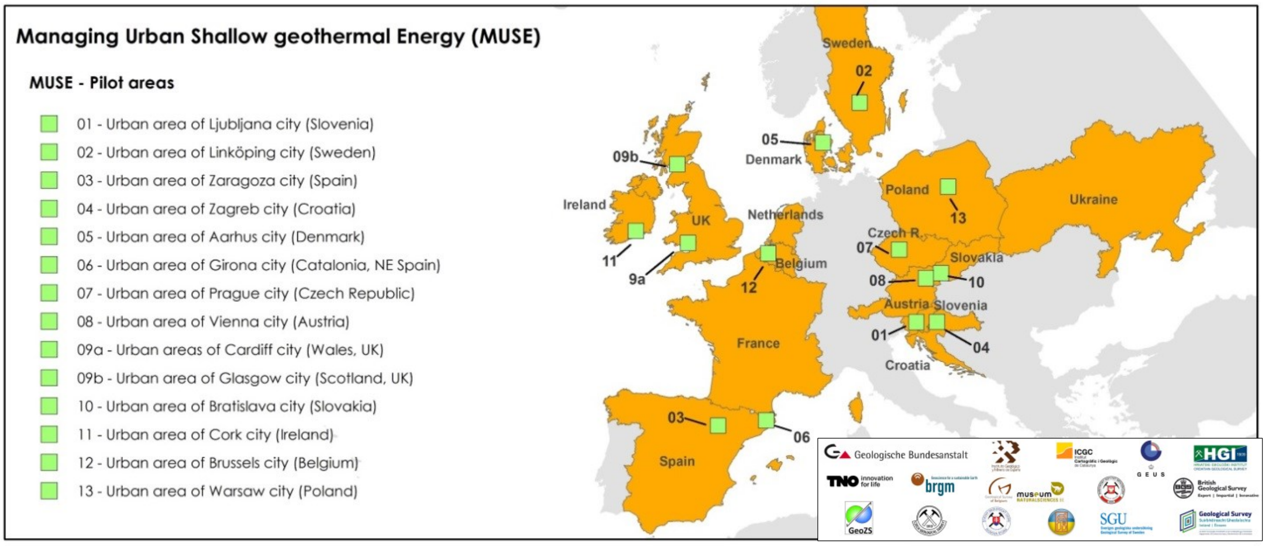

Figure 1: Participating countries and the project pilot areas of MUSE.

Stage 3, the final stage of MUSE, covers a **feedback round from the pilot areas to the initially compiled catalogues of methods, workflows and concepts**. Based on the outcomes and lessons learned in the pilot areas, the project team will update and modify the preliminary collection of methods and concepts into a final version for general dissemination among other regions and institutions across Europe and beyond.

The development of the overall project is structured in the following work packages – WP1-WP6:

WP1: **Project management, internal communication and general dissemination**. This WP concerns project implementation and reporting to the programme management. It will also establish efficient decision-making and implement quality control measures. Additionally, this WP includes disseminating the project outcomes to scientific community, technical experts, local and national government, as well as all interested stakeholders.

WP2: **Technical aspects of shallow geothermal energy use in urban areas**. This WP focuses on assessing resources for SGE use in urban areas and possible constraints of use associated with open- and closed-loop systems. Furthermore, the project team will collect examples of operational monitoring of the installations performance and the environmental impact, allowing definition of risks and possible hazards due to inappropriate technical concepts and operation.

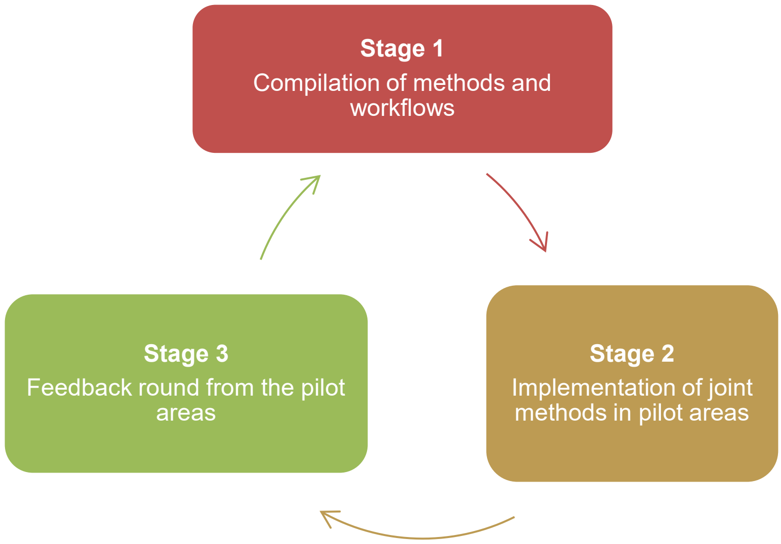

Figure 2: Main stages of the MUSE project

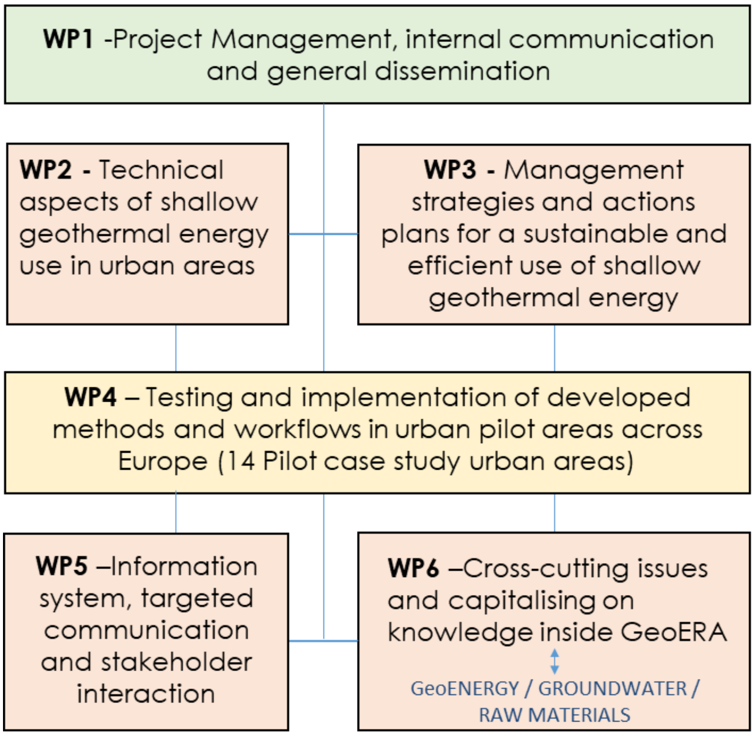

Figure 3: Work packages and interactions of the MUSE project.

WP3: **Management strategies and action plans for a sustainable and efficient use of shallow geothermal energy**. This work package concentrates on analysing the existing regulation measures for SGE in Europe dealing with technical guidelines for managing the resources and with environmental protection action plans.

WP4: **Testing and implementation of developed methods and workflows in urban pilot areas across Europe**. The project team will implement and test developed joint methods of assessment and mapping of SGE resources, derived from WP2, in the specific urban pilot areas and case studies for open- and closed-loop systems. The activities under WP4 will enable assessment of scientific methodologies and workflows in order to allow comparison of different kinds of parameters as a function of data availability. It also includes the assessment and evaluation of existing regulation measures and application of the developed methods and management concepts, derived from WP3. The outputs will include documented spatial output datasets in the pilot areas delivered via the web-based GeoERA Information Platform, resulting from the cooperation with WP5 and the project website.

WP5: **Information systems, targeted communication and stakeholder interaction**. A major project's results dissemination tool is the MUSE web portal, which is part of GIP-P. The end user oriented display interface and web tools to present thematic outputs and spatial datasets from the pilot areas have been designed and are in the development phase.

WP6: **Cross-cutting issues and capitalising on knowledge inside GeoERA**, i.e. identifying existing or possible conflicts in the shallow subsurface between water supply, heat supply and mineral resources extraction in the urban areas with different geological settings with other GeoERA projects, including the Groundwater and Mineral Resources research areas. Under WP6 the knowledge exchange workshops, web conferences, and stakeholder communication is co-organized.

5. PILOT AREAS

MUSE has 14 pilot areas (Fig.1) located in 12 EU member countries. The geological and hydrogeological settings are different in each pilot area, such as: the Cretaceous, Paleogene, Neogene and Quaternary sediments (case of Warsaw agglomeration), Miocene fault systems (pull-apart Vienna basin) and Proterozoic to Ordovician fractured sedimentary rock aquifers covered by highly permeable river terrace (as in Prague), all of them showing however some similarities – building up the shallow urban aquifers.

Climatic conditions are also quite different between the 14 pilot areas, so they present a diverse range of energy demands. Table 2 shows the values of Heating and Cooling Degree Days (HDD and CDD) as a proxy for the heating and cooling energy demand and loads for buildings. As expected, pilot areas located in northern Europe have a double value of the HDD compared to locations in southern Europe and vice versa for the CDD values.

Table 2: Preliminary Heating and Cooling Degree Days estimation (HDD and CDD) for each pilot area for 2017 (source: Eurostat)

Pilot area	HDD*	CDD**
Linköping, Sweden	4682	-
Bratislava, Slovakia	3152	-
Glasgow, Scotland, United Kingdom	3054	-
Warsaw, Poland	3054	-
Prague, Czech Republic	2985	53
Aarhus, Denmark	2722	-
Ljubljana, Slovenia	2551	218
Vienna, Austria	2468	213
Brussels, Belgium	2440	17
Zagreb, Croatia	2396	196
Cardiff, Wales, United Kingdom	2275	5
Cork, Ireland	2083	2
Zaragoza, Spain	1749	283
Girona, Catalonia, Spain	1733	228

* baseline temperature is 15.5 ^{O}C

** baseline temperature is 22 ^{O}C

The degree of SGE use is also at different levels of deployment or maturity across the pilot areas considered. Some pilot areas are in a very preliminary stage of development with no knowledge about the number, power and characteristics of the installed open- and closed-loop systems, while other are already well developed and continue working on thermal interferences and environmental impacts of SGE use. Therefore, major goal for all participating European countries is to optimise their developments with the benefit of shared learnings by GSO specialists.

6. PRELIMINARY AND PLANNED RESULTS

The outcomes of MUSE will be a comprehensive collection of methods, approaches and tools, which can be transferred to other urban regions in Europe and adopted by other organisations. Elaboration of two catalogues is foreseen: One of evaluated methods and guidelines on exploration, assessment and technical monitoring of SGE use in urban regions, and the second one compiles factsheets of evaluated and characterised SGE concepts of use in urban areas.

Project activities planned in **WP2** concentrate on the assessment and mapping of SGE resources and possible constraints of use associated with deployment of open- and closed-loop systems in urban areas. At present, the project team members have selected several examples in the partnering countries illustrating SGE installations for spatial heating, cooling and seasonal heat storage. Gathered information and data will allow identification and characterisation of proven and prospective technical solutions for SGE, as a set of best practices. Some of the installations will be visited during the future project workshops. In addition, several working groups have been established in order to investigate more closely such issues as: geothermal mapping, closed- and open-loop system resources, thermal conductivity measurements, groundwater observations, Thermal Response Test (TRT) and Fibre Optics Distributed Temperature Sensing (DTS), geophysical exploration, SGE monitoring (focused on the ground side), subsurface seasonal heat storage. The members of the working groups will elaborate the catalogues of methodologies as well as recommendations for field and laboratory work equipment for exchange of know-how and experience to build consensus of "good practice" for Europe.

Based on the analysis performed within **WP3** a report on the current legal frameworks, procedures and policies on SGE use in the partnering European countries is under development. With means of a partner questionnaire the project team gathered information on national legal regulations, which will allow a comparative analysis and subsequent an elaboration of guidelines for integrating and managing the use of SGE in urban areas to be applied in the partnering countries and across Europe. In **WP4** it is planned to obtain documented thematic spatial datasets for web presentation of our pilot areas. These output datasets (GIS based vector and raster datasets as well as 3D datasets) will be compiled and transferred into **WP5** for web hosting. All generated datasets will be accompanied by annotation reports, which will also be published on the GIP-P related web platform.

For the pilot areas, a compilation of fact sheets (Fig.4) provides an overview of (1) the current situation on SGE use, (2) the outline of relevant constraints and impacts of SGE use and (3) a summary of the activities and results achieved. The fact sheets will be updated and complemented by a summary report describing the outcomes in the pilot areas throughout the project duration. All partners have already started the project activities in the pilot areas. Now, those focus on collecting basic data on hydrogeological and thermal properties of underground, operation of present SGE installations as well as conducting field and laboratory measurements. Later activities include an implementation of all gathered information into the new geoscientific models and databases.

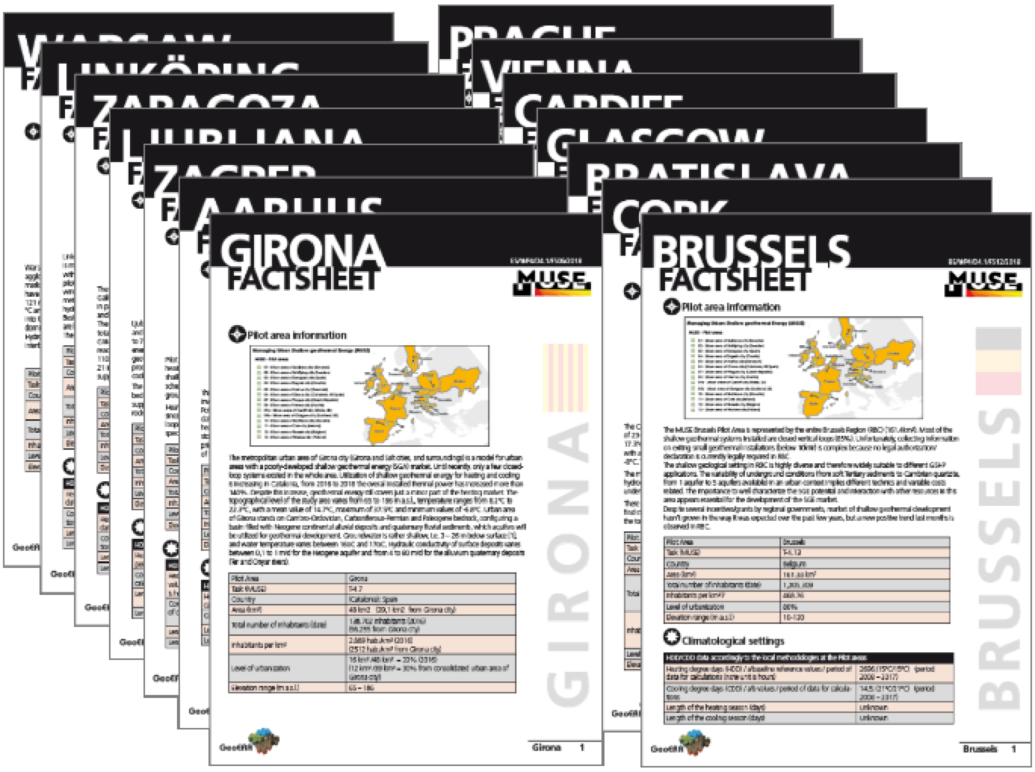

Figure 4: Factsheets of the Pilot areas. http://geoera.eu/projects/muse3/pilot-urban-areas-in-the-muse-project/.

WP5 focuses on the web platform of MUSE (http://geoera.eu/projects/muse3/) and the Data Management Plan for the specification of output data formats, data types, attributes, expected semantics and the description of required functionalities related to the display on the GIP-P. The guidelines on the delivery of spatial geoscientific data and knowledge related to SGE to the GeoERA and the guidelines on the use of the SGE web platform tools at the GIP-P will be published to assist future SGE use in urban areas outside MUSE. Finally, an activity report on capitalising activities with other project teams inside GeoERA will log and summarise all major activities in overlapping pilot areas. The project team have already elaborated the White Book which contains the specification of output data formats, required SGE data types and attributes, expected semantics and the description of required functionalities related to the display on the EGDI and will allow for data transfer into the GIP-P.

7. DISSEMINATION OF RESULTS

The project team have already elaborated a preliminary general communication, dissemination and exploitation plan. It contains a list of dissemination activities such as planned presentations at conferences and expert workshops and research papers in the relevant journal. The project web portal (http://geoera.eu/projects/muse3/) is updated regularly with information about outcomes of accomplished meetings and the pilot areas. A project leaflet (Fig.5) is already completed and available at the MUSE web portal. This a main dissemination tool of MUSE which addresses all involved stakeholders: national and local authorities in the pilot areas scientific community, international entities from other EU countries and members of other GeoERA consortia, as well as general public. More specifically, for the group of the GeoERA projects, EU and national stakeholders and scientific community, different seminars and workshops will be held during which the use of our web portal and knowledge transfer activities will play an important role. The project team has already co-organized two joint workshops in order to exchange knowledge and experience: in January 2019 – together with the HotLime project team, and in July 2019 together with the HEATSTORE project team.

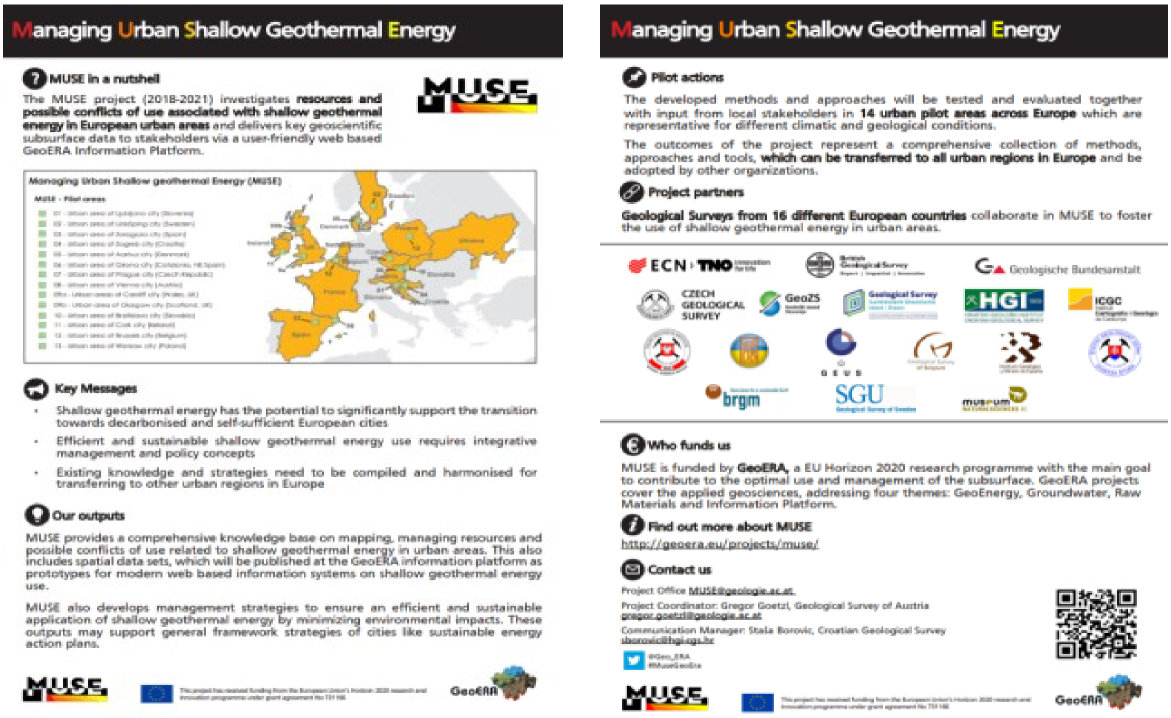

Figure 5: Project leaflet available on the MUSE website.

8. CONCLUSIONS

The MUSE project (*Managing Urban Shallow geothermal Energy*) investigates resources and possible constraints of use associated with SGE deployed in selected European urban areas and delivers key geoscientific subsurface data to stakeholders via a user-friendly web based GeoERA information platform.

MUSE leads to the development of management strategies considering both efficient planning and monitoring of environmental impacts in order to feed into general framework strategies of European cities like SEAP's.

The project team will test the developed methods and approaches and evaluate them together with input from local stakeholders in 14 urban pilot areas across Europe which are representative for diverse natural and socio-economic conditions.

The outcomes of the project will represent a comprehensive collection of the methods, approaches and tools which can be transferred to other urban regions in Europe and adopted by other organizations and stakeholders.

9. ACKNOWLEGEMENTS

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REFERENCES

CheapGSHPs: Cheap and efficient application of reliable ground source heat exchangers and pumps. EC funded Horizon 2020 project (https://cheap-gshp.eu/)

ESTMAP: Energy Storage Mapping and Planning. EC funded Horizon 2020 project

GeoPLASMA-C: Shallow Geothermal Energy Planning, Assessment and Mapping Strategies in Central Europe. INTERREG VA Programme. Central Europe. European Union (www.geoplasma-ce.eu)

Geothermal4PL: Support for Sustainable Development and Use of Shallow Geothermal Energy within the Areas of the Mieszkanie Plus Programme in Poland. European Economic Area Grants. Norway Grants.

GeothermalMapping: Research and the promotion of use of shallow geothermal potential in Croatia. EU IPA funded project (http://geothermalmapping.fsb.hr)

GRETA. Near-surface Geothermal Resources in the Territory of the Alpine Space. INTERREG VA Programme. Alpine Space. European Union (https://www.alpine-space.eu/projects/greta/en/home)

Hähnlein S., Bayer P., Ferguson G., Blum P.: Sustainability and policy for the thermal use of shallow geothermal energy. Energy Policy, 59, (2013), 914-925

Herms I., Goetzl G., Borović S., García-Gil A., Ditlefsen C., Boon D., Veloso F., Petitclerc E., Janža M., Erlström M., Kłonowski M.R., Holeček J., Hunter Williams N. H., Vandemeijer V., Černak R., Malyuk B.: MUSE- Managing Urban Shallow geothermal Energy. A GeoERA geo-energy project, Proceedings, European Geothermal Congress 2019, Den Haag, The Netherlands (2019)

SUB-URBAN TU1206 (COST Action). EU Framework Programme Horizon 2020

ReGeoCities. Shallow Geothermal Energy. Intelligent Energy Europe Programme of the European Union

Sarbu I., Sebarchievici C.: General review of ground-source heat pumps systems for heating and cooling of buildings. Energy and Buildings, 70, (2014), 441-454

Somogyi V., Sebestyén V., Nagy G.: Scientific achievements and regulation of shallow geothermal systems in six European countries – A review. Renewable and Sustainable Energy Reviews, 68, (2017), 934-952

ThermoMap: Mapping shallow geothermal potential across Europe. (2010-2013). Funded by the FP7 ICT-PSP

Tsagarakis K. P., Efthymiou L., Michopoulos A., Mavragani A., Anðelković A., Antolini F., Bacic M., Bajare D., Baralis M., Bogusz W., Burlon S., Figueira J., Genç M. S., Javed S., Jurelionis A., Koca K., Ryżyński G., Urchueguia J. F., Zlender B.: A review of the legal framework in shallow geothermal energy in selected European countries: Need for guidelines. Renewable Energy, in press, corrected proof (2018), https://doi.org/10.1016/j.renene.2018.10.007