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DELIVERABLE 5.1

State of the art of subsurface planning and management, and avenues for improvement

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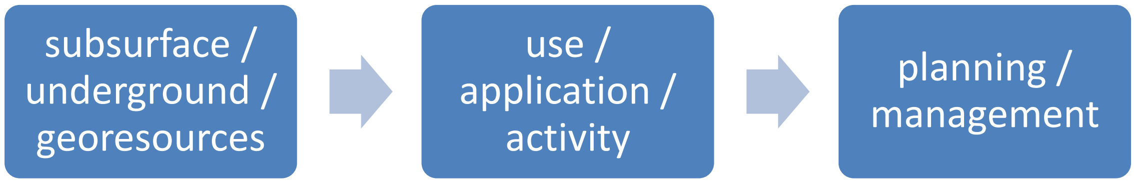
1 GLOSSARY

Terms and vocabularies has been defined and collected in groups (instead of simple alphabetical order) to reflect logical relations. By defining underground space firstly it is easer to define possible applications and further management tools. This should facilitate common undersatnding of the concepts.



SUBSURFACE

geological formation – a lithostratigraphical subdivision within which distinct rock layers can be found and mapped (by Directive 2009/31/EC of the European Parliament and of the Council)

georeservoirs – parts of an underground space with defined conditions suitable for gas or fluid trapping, energy and substances storage; can refer to porous and fractured-karstified formations (heat, gas storage) but also include man-made engineered openings like salt caverns (hydrogen, compressed air, methane storage)

subsurface – the whole space beneath the Earth surface. Here natural resources are hosted (e.g. fresh and mineral water, hydrocarbons, ores etc.) but it also offers a volume for storage of energy or substances, thus the whole space should be considered as a georesource, a commodity which needs to be optimally used. The subsurface is characterised by the geological conditions, such as lithology, porosity/permeability, temperature/pressure and structural features. Despite the vastness of the subsurface space only its parts are suitable for use. Preferable conditions include deep and permeable aquifers, salt caverns, depleted hydrocarbon reservoirs, mining shafts etc. Synonyms: **underground space, geological space, mass rock**

SUBSURFACE USE

subsurface use – every activity conducted from the land surface or in a geological space that affects big volumes of underground formations such as extraction of resources (drinking water, mineral raw materials, heat, etc.) or large-scale storage or disposal (natural gas, liquid or liquefied hydrocarbons, carbon dioxide, radioactive waste, etc.). In practice, this is an industrial activity related to the utilization of the deep underground. Synonyms: **subsurface/underground + application/activity/project/ undertaking/use/development**

disposal – the emplacement of spent fuel or radioactive waste in a facility without the intention of retrieval (by Council Directive 2011/70/EURATOM), can apply for any other waste entitled

disposal facility – any facility or installation the primary purpose of which is radioactive waste disposal (by Council Directive 2011/70/EURATOM), in broader sense - a facility or installation the primary purpose of which is waste disposal; Synonyms: **geological disposal facility**

extractive use (application) – an industrial activity that aims at exploiting mineral resources from the subsurface deposits (minerals, hydrocarbons) and/or aquifers (water, heat, etc.)

geological storage of CO_2 – an injection accompanied by a storage of CO_2 streams in underground geological formations (by Directive 2009/31/EC of the European Parliament and of the Council)

geothermal applications – industrial activities that aim at exploiting Earth heat from underground space, both from aquifers (hydrothermal) and hard rock (petrothermal), for heating purpose or power production; the name also applies to low enthalpy heating and cooling installations with heat pumps but they occupy only shallow subsurface zone down to 200-300 m

non-extractive use (application) – any industrial or non-industrial activity conducted underground or with use of underground space which does not involve exploitation of natural resources

operational uses – in this report – features of subsurface use widely implemented; industrial enterprises successfully operating within subsurface, full-scale activity with proven effectiveness and outcomes

pore-space application – the use of geological space that takes advantages from favourable conditions (e.g. available volume and confinement as a result of porosity, temperature and pressure conditions etc.) to accumulate and store substances or energy

prospective uses – in this report – the concepts and ideas considered as future options for subsurface applications, e.g. storage of energy carriers (compressed air, H_2, etc.), waste, CO_2, heat, new types of mining or energy resources exploitation

storage complex – the storage site and surrounding geological domain which can have an effect on overall storage integrity and security; that is, secondary containment formations (by Directive 2009/31/EC of the European Parliament and of the Council)

storage site – a defined volume area within a geological formation used for the geological storage of CO_2 and associated surface and injection facilities (by Directive 2009/31/EC of the European Parliament and of the Council), can apply to any stored medium

storage use (application) – an industrial activity which involves placement of substances (or energy) in a part of underground space with particular favourable conditions (in terms of volume available – pore space or man-made cavities, temperature, pressure and confinement), can be permanent, with no intention of retrieval, temporary – with retrieval on demand or cyclic, when storage is e.g. a part of technological process

urban applications – applications of geoengineering in shallow underground e.g.: use of underground space for transportation, infrastructure network, basements, etc. (out of scope for this report)

uses under review – in this report – industrial enterprises in phase of testing, including prototypes and pilot installations

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SUBSURFACE MANAGEMENT

area of influence is a 3D volume of geological space with vertical and horizontal extents within which a particular subsurface activity's impact is observed (changes in pressure, temperature, volume displacement, etc.). This volume varies widely depending on the type of activities and geological conditions.

conflict of use is a situation when more than one application for the same volume of subsurface is possible and the decision is to be made about the superiority of one of them. Also potential conflict of use may be defined, as a situation when the same volume of space is suitable for different purposes. As an example, low energy geothermal activity and gas storage (CO_2, natural gas) require similar deep and permeable aquifers. Likewise, compressed air storage, hydrogen storage, and liquid hydrocarbon storage are different uses for salt caverns.

direct conflict of use occurs when two subsurface activities target the same underground volume, but for different applications. Direct conflicts will normally be settled during the planning and permitting stage in favour of one the possible applications.

hazard derived from the use of underground space is a possible change in the state of natural conditions that can be triggered by this activity due to its character; needs to be assessed based on both natural conditions in the area of interests and technical features specific for a particular activity.

impact is a measurable effect of a subsurface activity on existing features (natural conditions, infrastructure, standard of living and satisfaction incl. health and sense of security, etc.).

indirect conflict of use occurs when the influence radius of a subsurface activity reaches the influence area of another subsurface activity.

risk is a combination of an importance or a magnitude of perceived hazard and a probability of its occurrence; an importance or a magnitude need to be evaluated based on actual impact measurements together with a case related modelling or, when no measurements are available, solely on modelling, probability of occurrence is a complex factor which is to be estimated based on global experience with regard to normal operation and also to any kind of accidental situations.

synergy of use is a situation when two different kinds of subsurface use can be complementary to each other; can refer to simultaneous activity, when one activity benefits from effects of the other being conducted or to re-use of effects of former activity for a later one.

subsurface management covers all considerations, planning, decisions and actions to allocate specific uses to appropriate subsurface locations. Management process should include prediction of complex and interacting effects on (1) targeted space (e.g. the storage formations), (2) neighbourhood (e.g. formations in close vicinity) and also (3) protected compartments/entities (like groundwater, soil, ecological functions, humans' wellbeing). To successfully employ subsurface systems, possible mutual influences of intended usage options with other existing or planned uses of subsurface should be considered. Optimise use of subsurface include avoiding (resolving) conflicts and looking for potential synergies.

2 INTRODUCTION

Planning, management and control of subsurface use need to be understood as a complex task derived from needs, responsibilities and desires of many subjects. In many cases, these stay in opposition to each other, but can also be complementary, provided all constrains are known well ahead and are taken into account in systematic manner for mutual benefits.

Even though subsurface management is an important issue guaranteeing constant and undisturbed development of traditional exploitation of deposits as well as new features such as e.g. storage technologies, it is still often treated as “out-of-sight-out-of-mind”. Such attitude may cause use of subsurface not compliant with sustainable approach principle according to a “first-come-first-served” rule (Volchko et al., 2020). With regard to this, an urgent need for creation of legal frameworks for further development of subsurface space has been pointed out in many scientific papers and reports (Sterling, R., 1996).

Subsurface needs to be seen as a “multifunctional natural resource, which provides physical space, water, energy, materials, habitats for ecosystems and support for surface life, while also acting as a repository for cultural heritage and geological archives” (Volchko et al., 2020). In the years to come the subsurface is expected to play an even more significant role since in addition to traditional use, technologies of storage of energy (heat, compressed air, H_2, CH_4 etc.), CO_2, substances or waste have developed and reached advanced stages. Such way of underground space use can generate new problems resulting from potential conflicts arising from plans of using the same space for different projects.

Because of these multifunctional opportunities as well as the fact that the subsurface has no borders (except for natural structural and lithological ones), its sustainable use will require wide cooperation of a number of authorities on local, regional, national and international levels.

One of the main aims of the Work Package 5 of the GeoConnect³d Project is to assess the actual status of subsurface planning and management in Europe and to provide overall recommendations regarding these processes. This report presents a summary of contemporary visions and scientifically developed needs for subsurface management, existing European legislation that directly or most often indirectly apply to subsurface development, review of underground activities that were and/or still are conducted in particular Member States and some important aspects which need to be taken into account while speaking of sustainable, in this case meaning safe and effective, subsurface use.

3 SUBSURFACE MANAGEMENT UP TO PRESENT

Historically the use of subsurface was limited to exploitation of natural mineral deposits of various kinds. In the 20th century the underground free space left after extraction of minerals and mining and the free pore space in depleted oil and gas fields started to be utilised as waste repository, especially for dangerous liquid waste, which was in many cases injected without any safety measures. Along with the global climate change problem identification and new initiatives and tasks that have been established in order to counteract it, new technologies need to be developed to enable a full transition towards carbon-free energy sources and these technologies require new patterns of the underground space use. Geological formations are not only supposed to deliver mineral raw materials or to be final disposal for troublesome waste. In addition, they need to become safe and reliable storage objects for energy in various forms. Anticipating a competition in utilisation of certain formations, it becomes obvious that careful planning of subsurface use will be crucial to ensure the optimal management of available space that might be suitable for more than one purpose. For example since salt caverns are recognized as proper for storing hydrogen, compressed air and methane, there is a need to develop regulations which will establish rules and procedures for the optimal selection of a medium to be stored (Bauer et al., 2013).

The need for a careful planning and management of the subsurface was already indicated over 100 years ago by Philadelphian chief engineer and surveyor George S. Webster (1914), though his concerns were related to shallow underground used mostly in towns for engineered infrastructure. In Europe the challenge of regulation of subsurface planning was recognized by the Organisation for Economic Co-operation and Development (OECD) in early 1970s also mainly with regard to shallow subsurface for engineering projects. In 1974 the International Tunnelling and Underground Space Association was established with objective focused not only on promotion of rational use of underground space but also on stimulation of research and development on tunnelling. Following this decision a working group on subsurface planning was founded in 1975 but it completed its work in 2002. The scope of work conducted was then incorporated into the tasks of a working group “Urban problems – Underground solutions”. Since the group`s goal was to create an “overview of the typical challenges of urban city planning and the solutions which are offered by the underground space”, all expected outcomes were dedicated to the urban areas. However, the subsurface planning outside of the cities remained an unaddressed topic, since there was no international body dealing with the subsurface planning on a larger scale.

This problem seems to be even more pressing nowadays when potential conflicts may arise when e.g. oil and gas production or CO_2 storage cross paths with low energy geothermal activities since they all demand similar deep and permeable rock formation. And what about the potential conflicts that may influence quality of life of citizens? Will people accept it when, or if, potable groundwater reservoir is polluted due to incorrect subsurface planning, or even worse – due to lack of subsurface planning?

Unfortunately, subsurface management is still often treated as "out-of-sight-out-of-mind" by decision makers, and related activities in many cases are regulated by different pieces of legislation, which might disable awareness of possible interactions between particular projects and their mutual impact on natural and human environment. Such attitude may cause ineffective or even unlicensed use of subsurface according to another popular principle: "first-come-first-served" (Volchko et al., 2020). Growing consciousness of this led to a conclusion that there is a significant need for creation of legal frameworks for further development of subsurface space expressed in numerous scientific papers and reports (Sterling, 1996). Bauer et al. (2013) added a statement that all legal regulations to be created should stimulate multiuse of the underground space.

Kabuth et al. (2017) stressed the need for a development of a proper underground planning and licensing since without identification of priorities and reserved areas for specific types of subsurface use, potential storage sites may become inaccessible. According to Field et al. (2018), subsurface should be considered a valuable resource itself as it can be used as a storage space for various media, starting with wastes and ending with energy. Moreover, use of the subsurface as a storage space in one site can remotely impact other subsurface activities located in the proximity or those on the land surface (Ma et al. 2020). Therefore, as detailed as possible knowledge on the subsurface and understanding of geological, physical and chemical processes occurring in geological formations are essential for making a decision on the investment. Legal regulations and scientific tools should be designed in such a way that they allow avoiding a situation when one wrong decision will block other developments that might be possible and more beneficial with regard to local, regional or broader demand.

Need for a development of regulations towards planning of subsurface use was presented in 2016 by Bartel & Janssen who stressed that a holistic approach for spatial and subsurface planning is essential to deal with the increasing range of demands for the utilization of underground space. Regulations are also needed for a better management of direct and indirect conflicts of subsurface use as well as for ensuring the sufficient storage capacity in the geological formations for e.g. storage of energy.

A new initiative towards subsurface management at the EU scale was raised by van Gessel et al. in 2017. Authors stressed the need to establish a uniform and interoperable European Geological Service that will support the collaborative management and protection of subsurface resources and capacities. This support will be based on the complete, up-to-date and harmonized subsurface data delivered by national and regional geological survey organisations (GSOs).

Quattrocchi (2019) directly stated that there is an urgent need to establish a "Unified European Directive for use of subsurface and lands to produce energy/heat/resources" as well as to create a "unified exploration permit". The author draws attention to the Italian situation, common also in other European countries, that subsurface use aspects are covered by several different pieces of legislation which are not necessary consistent with each other and not connected in any manner. A newly developed directive should refer to all energy-heat technologies which are getting more and more interconnected and also include waste disposal. It needs to be clear and simple to ensure a smooth transition from the linear to the circular economy with careful reuse of mineral raw materials and preliminary planning of harmonized and rational use of land and subsurface.

Recently the UN Expert Group on Resource Management proposed a new concept of United Nations Resource Management System (UNRMS) – a comprehensive, sustainable resource management system, which is expected to be future-facing and support stakeholders in various goals, including aiding the progress towards a circular economy. The UNRMS will consider various resources (with the underground space as one of them) not as isolated or independent sectors, but as a part of the whole resource base of an area, region or country. The concept indicates, among others, a need to introduce a common terminology that will allow mutual understanding of stakeholders, and intends to start the work with identification of stakeholders' needs and priorities at each level for development of a system addressing the challenges and requirements of resource management at a user level. The authors believe that once developed, the UNRMS will become a voluntary global standard for integrated resource management, within the framework of public, public-private and civil society partnerships, though it's not quite obvious how they intend to force it without incorporating into legal regulations.

The lack of a professional common language was also addressed by Volchko et al. (2020), who postulate a creation of an understandable terminology which scientists, engineers, constructors, decision- and policy makers and citizens may understand and which could be used for better communication between all groups.

4 EUROPEAN REGULATIONS

As mentioned above, there is no European regulation regarding subsurface management as a whole, but one must look for guidelines how to deal with subsurface projects in a number of European Council directives and decisions. These cover particular aspects of both planning and conducting activities related to mining, waste disposal, energy, water management, etc. usually not directly with regard to subsurface activities. In this chapter we try to present these pieces of European regulations which need to be followed in subsurface projects of various kinds.

Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste amended by the Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste

The directive regulates waste disposal issues, including their underground storage. This Directive introduces the concept of the underground storage and classifies the underground landfills into three classes: hazardous waste, non-hazardous waste and inert waste landfills. Furthermore, it defines both technical and procedural conditions for storage of waste.

Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to Directive 1999/31/EC

The decision specifies detailed criteria, test methods and limit values for each class of landfill including the underground storage repositories (this information is provided in the attachment). Each storage site requires a site-specific safety assessment to be carried out, including, among others, site-specific risk assessment for both the operational and post-operational phases. The assessment has to address:

- geological, geomechanical and hydrogeological conditions;
- geochemical characteristics of repository;
- biosphere impact assessment;
- assessment of unacceptable risks during the operational phase;
- long-term assessment with regard to possibility of opening pathways to biosphere;
- impact assessment of all surface facilities at the site.

Moreover, waste which might undergo undesired physical, chemical or biological transformations after they have been deposited, for example: biodegradable waste, waste that has a pungent smell, waste and their containers which might react with water or with the host rock under the storage conditions are excluded from underground disposal possibility.

Waste may be stored in the underground storage only if the storage process is accordant with site-specific safety assessment. The criteria for the underground storage apply to all underground facilities but differ with regard to disposal site class (inert, non-hazardous or hazardous waste). There are additional considerations for salt mines and hard rock storage.

In case of an underground storage, the Decision addresses the Water Framework Directive (2000/60/EC) and requires demonstrating the long-term safety of the installation. For a deep storage in the hard rock (according to additional considerations) this requirement is met if no discharges of hazardous substances from the storage will reach the biosphere, including the upper parts of the groundwater system accessible for the biosphere, in amounts or concentrations that will cause adverse effects. Therefore the water flow paths to and in the biosphere should be evaluated.

Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC

The Directive refers to the management of waste from extractive industries (except for sea areas), the waste arising from the prospecting, extraction (including the preproduction development stage), treatment and storage of mineral resources and from the working of quarries.

In terms of the underground storage, it provides rules for placing extractive waste back into the excavation voids for rehabilitation and construction purposes. This may be conducted only under following conditions:

- a stability of the extractive waste is sustained;
- a monitoring of the extractive waste and the excavation void is established;
- prevention measures of soil, surface water and groundwater pollution are introduced.

Council Directive 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste

The Directive concerns principally the safety of nuclear installations but it also contains rules for ensuring a safe management of spent fuel and radioactive waste, including storage and disposal in waste disposal facilities. In case of high-level radioactive waste and spent fuel considered as waste, deep geological disposal is considered to be the safest and most sustainable option which is accepted by technical procedure.

According to the Directive, all Member States must establish and maintain national policies on spent fuel and radioactive waste management and elaborate national programmes for responsible and safe management of spent fuel and radioactive waste.

The rule is that radioactive waste needs to be disposed of in the Member State in which it was generated, unless there is an agreement between the state concerned and another country to use a disposal facility located in this country territory. National programmes must not only include the concepts or plans and technical solutions for spent fuel and radioactive waste management from generation to disposal but also cover the post-closure period requirements for appropriate controls and the means to be employed to monitor that facility for needed time.

Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006

The Directive regulates rules for safe geological storage of CO_2 in the geological formations in territories of EU Member States, their exclusive economic zones and on their continental shelves. It formulates conditions under which storage permits can be obtained and rules of operation, closure and post-closure of geological CO_2 storage sites and determines the corrective measures in case of leakages or significant irregularities which must be implemented by operators.

Member States which intend to allow for geological storage of CO_2 in their territory shall undertake an assessment of the storage capacity available in parts or in the whole of their territory. The characterisation and assessment of the potential storage complex and surrounding area is to be done in three steps according to best practices valid at the time:

- Step 1: data collection (necessary to construct a volumetric and three-dimensional static (3-D)-earth model for the storage site and storage complex including the caprock and the surrounding area, including the hydraulically connected areas);
- Step 2: building the three-dimensional static geological model;
- Step 3: characterisation of the storage dynamic behaviour, sensitivity characterisation and risk assessment.

The storage of CO_2 in a geological formation may be located under condition that there will be no significant risk of leakage and no environmental or health threats.

Adequate monitoring is the most important safety measure during all phases of CO_2 geological storage: operation, closure and post-closure. Co-disposal of other waste with the CO_2 stream is not allowed. Operators are obliged for at least once a year reporting to competent authorities, including the information about monitoring results and monitoring technology employed as well as quantities and properties of the CO_2 streams delivered and injected.

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy (amending)

The superior objective of the Water Framework Directive (WFD) is a protection, enhancement and restoration all water bodies including groundwater in Member States with assurance that a balance between abstraction and recharge of groundwater will be kept. This directive presents strategies of groundwater protection according to which adequate measures to prevent and control groundwater pollution should be adopted, including criteria for assessing good groundwater chemical status and criteria for the identification of significant and sustained upward trends.

With regard to management of underground space the most important point in the European water policy is the prohibition of direct discharges of pollutants into groundwater and the requirement of prevention from deterioration of the status of all groundwater bodies. There may be exceptions from these general rules, which allow for reinjection of water used for geothermal purposes but only into the same aquifer that it was extracted from. Moreover, specific conditions may also be laid down by Member States for injection and reinjection of different substances into geological formations (in such a way that discharges do not compromise the achievement of the environmental objectives established for particular groundwater body). This opportunity applies to:

- injection of water containing substances resulting from the operations for exploration and extraction of hydrocarbons or mining activities, and injection of water for technical reasons, into geological formations from which hydrocarbons or other substances have been extracted or into geological formations which for natural reasons are permanently unsuitable for other purposes. Such injections shall not contain substances other than those resulting from the above operations;
- reinjection of pumped groundwater from mines and quarries or associated with the construction or maintenance of civil engineering works;
- injection of natural gas or liquefied petroleum gas (LPG) for storage purposes into geological formations which for natural reasons are permanently unsuitable for other purposes;
- injection of carbon dioxide streams for storage purposes into geological formations which for natural reasons are permanently unsuitable for other purposes, provided that such injection is made in accordance with Directive 2009/31/EC on the geological storage of carbon dioxide or excluded from the scope of that Directive pursuant to its Article 2(2);
- injection of natural gas or LPG for storage purposes into other geological formations where there is an overriding need for security of gas supply, and

where the injection is such as to prevent any present or future danger of deterioration in the quality of any receiving groundwater;

- construction, civil engineering and building works and similar activities on, or in the ground which come into contact with groundwater;
- discharges of small quantities of substances for scientific purposes for characterisation, protection or remediation of water bodies limited to the amount strictly necessary for the purposes concerned.

Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration

Generally, this act complements the provisions of preventing or limiting inputs of pollutants into groundwater already contained in WFD, and aims to prevent the deterioration of the status of all bodies of groundwater.

Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment

So-called EIA Directive provides a list of public and private projects which may have significant effects on the environment, and which are obligated to elaborate environmental impact assessment (EIA). This list contains projects that are or may be conducted with use of underground space:

- thermal power stations with a heat output of 300 megawatts or more;
- installations designed for the final disposal of irradiated nuclear fuel;
- installations designed solely for the final disposal of radioactive waste;
- landfill of hazardous waste;
- groundwater abstraction or artificial groundwater recharge schemes where the annual volume of water abstracted or recharged is equivalent to or exceeds 10 million cubic metres;
- extraction of petroleum and natural gas for commercial purposes where the amount extracted exceeds 500 tonnes/day in the case of petroleum and 500 000 cubic metres/day in the case of gas;
- installations for storage of petroleum, petrochemical, or chemical products with a capacity of 200 000 tonnes or more.
- carbon dioxide geological storage sites;

The Directive indicates also additional projects, for conducting or extension of which each Member State determines whether the EIA shall be applied. The choice is to be established by means of a case-by-case examination or thresholds or criteria set by the

Member State. Among these projects there are some that require or may be conducted with a use of subsurface:

- underground mining;
- deep drillings, in particular: (i) geothermal drilling, (ii) drilling for the storage of nuclear waste material; (iii) drilling for water supplies;
- industrial installations for the production of electricity, steam and hot water (other than in the first list);
- underground storage of combustible gases;
- installations for hydroelectric energy production;
- storage of petroleum, petrochemical, or chemical products other than in the first list
- groundwater abstraction and artificial groundwater recharge schemes not included in the first list;
- installations for the disposal of waste not included in the first list;

The main elements of the EIA procedure are preparation of an environmental impact assessment report and public consultations (including international public consultation if it is necessary). As an EIA report must contain, among others, description of the project and all its relevant features, description of the likely significant effects on the environment and description of the reasonable alternatives relevant to the project and an indication of the main reasons for the option chosen, it requires implementation of planning tools and procedures as known for surface enterprises. The report is examined by the competent authority and their reasoned conclusions have to be integrated into any of the decisions.

During the public consultations, the society shall be informed by all appropriate means, of project consent application and further of environmental decision-making procedures. People must have access to the EIA report for not shorter than 30 days and have right to enquire and get sufficient response to their own concerns. This rule enables societies to be a partner in decision making of subsurface use planning.

Directive 2014/89/EU of the European Parliament and of the council of 23 July 2014 establishing a framework for maritime spatial planning

The Directive refers only to Member States with access to a sea. It requires preparation of maritime spatial plans no later than till 31 March 2021 which have to ensure a framework for maritime spatial planning. In these plans which need to take into account land-sea interactions and environmental, economic, social and safety aspects, features that concern underground space use are included, e.g.:

- installations and infrastructures for the exploration, exploitation and extraction of oil, gas and other energy resources, of minerals and aggregates, and for the production of energy from renewable sources;
- raw material extraction areas.

In the process of an establishment and implementation of plans the public and stakeholders opinion must be involved.

Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE)

The INSPIRE Directive establishes an infrastructure for spatial information in Europe to aid Community environmental policies, and policies or activities related to impact on the environment. It defines spatial data themes needed for environmental applications with key components specified through technical implementing rules.

The Directive does not refer directly to an underground space but forced introduction of definitions (by Commission Regulation (EU) No 1253/2013 of 21 October 2013 amending Regulation (EU) No 1089/2010 implementing Directive 2007/2/EC as regards interoperability of spatial data sets and services) which ought to be implemented also in subsurface planning framework:

- “existing land use” as an objective depiction of the use and functions of a territory as it has been and effectively still is in real life;
- “planned land use” means spatial plans, defined by spatial planning authorities, depicting a possible utilization of the land in the future;
- “zoning” means a partition where the planned land use is depicted, making explicit the rights and prohibitions regarding new constructions that apply within each partition element.

Also, some spatial data sets in the infrastructure for spatial information created according to this Directive relate to underground space and activities. These are: geology, production and industrial facilities (including mining and storage sites), area management/restriction/regulation zones and reporting units, natural risk zones, energy resources, and mineral resources.

5 FEATURES OF SUBSURFACE USE IN MEMBER STATES

The information presented in this chapter has been gathered mainly based on direct input of the Project partners delivered as a response to the Partners questionnaire number 1. The overview includes only countries represented in the GeoConnect^{3}d Project.

Mining for exploitation of natural deposits is the most traditional and the oldest feature of use of underground space. People started to dig for mineral raw materials in quarries and open pits once they decided to leave caves and create more suitable shelters for their growing up consciousness and community building. With society development, new skills and knowledge allowed for searching deeper and deeper so today it's hard to find a country with no mining activity along its history. Underground mines of coal, lignite, salt, barite, gold, silver, copper etc. opened the subsurface in many regions in Europe, though, as the map below shows – this feature of underground activity in some European states becomes a history (Fig. 5.1).

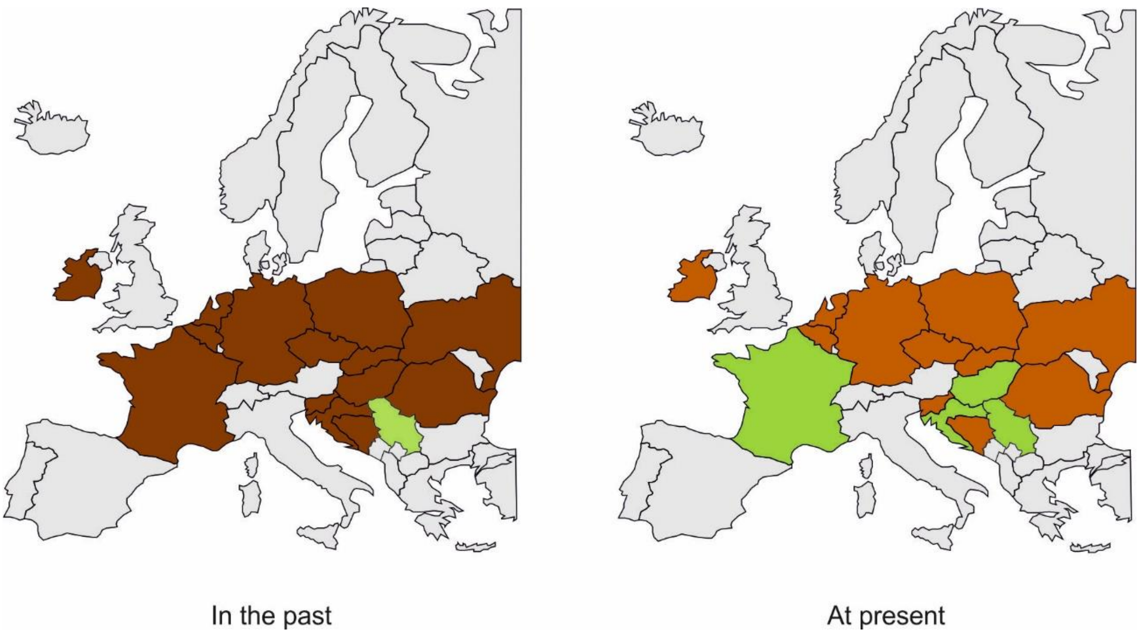

Fig. 5.1. Underground mining in Partner countries in the past and at present time (in green countries with no activity of this kind).

No matter if still operating or abandoned, underground mines occupy certain volumes of subsurface in Europe, making them useless for other purposes but also giving a possibility for reuse of underground shafts for certain applications (see Chapter 7).

History of the crude oil exploitation, which started in the Subcarpathia (nowadays south-east Poland) and developed into oil and gas industry, dates back to the mid-19th century. Since that time, the need for hydrocarbons and technology of obtaining them have spread all over Europe and the whole world. In fact, the only factor that could hinder exploitation of these raw materials has been a lack of documented deposits (Fig. 5.2).

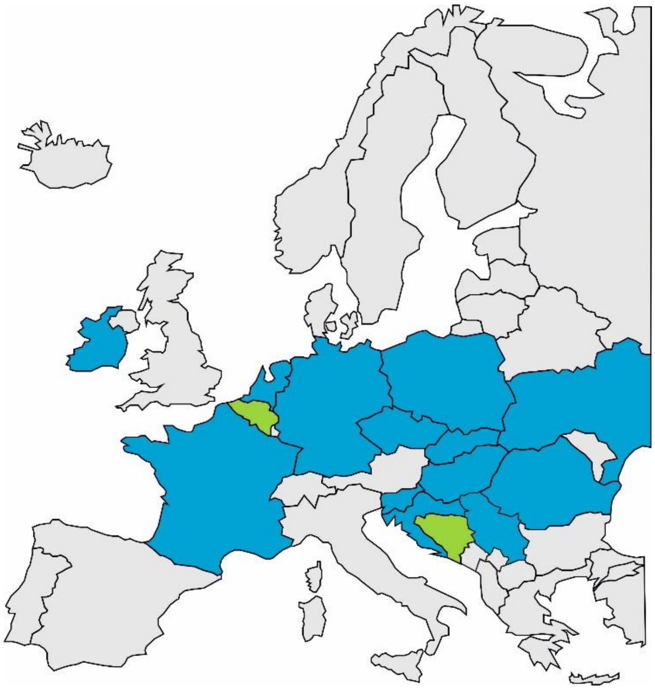

Fig. 5.2. Hydrocarbon exploitation in Partner countries (in green countries with no activity of this kind).

Hydrocarbon production does not require sending people underground as it is conducted with use of boreholes and developing technology allows for more and more effective drainage of products from geological formations where they are trapped (so called conventional oil and gas deposits). Even so, the exploitation affects natural conditions in subsurface space, causing sometimes negative environmental changes both under and on the land surface. Such unwanted impact together with emissions from combustion of hydrocarbon products combustion are the main reasons why hydrocarbons are considered energy carriers the days of which will soon be over (oil probably sooner, gas later).

No matter how long the production will continue, the underground space developed as natural traps for hydrocarbons, can be reused for underground storage of these or similar media.

Though the most obvious, depleted hydrocarbon traps are not the only formations recognized as suitable for underground storage of substances and/or energy. Many countries in Europe have already experience in an underground storage of hydrocarbons (Fig. 5.3).

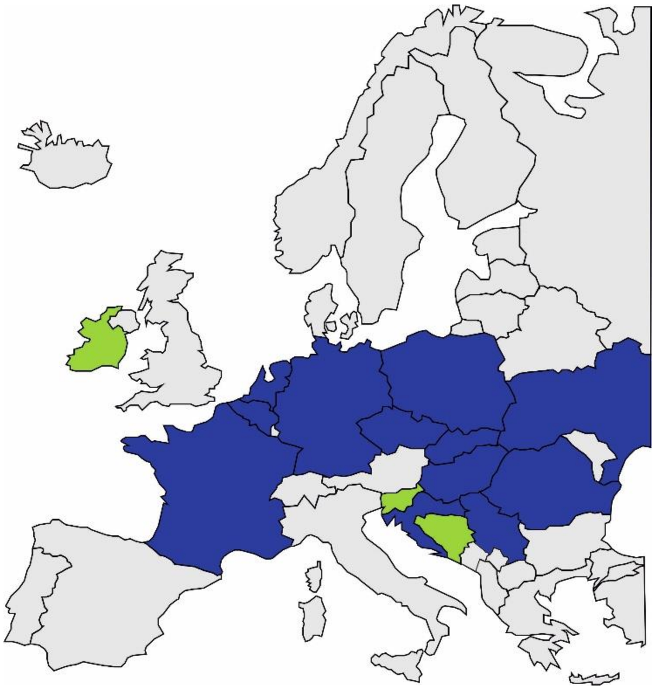

Fig. 5.3. Underground storage of hydrocarbons in Partner countries (in green countries with no activity of this kind).

Projects of underground storage of other energy carriers (hot water, hydrogen, etc.) that require similar or even tougher storage conditions are still in a development stage with some pilots mainly within scientific/industrial cooperation projects.

Carbon dioxide underground storage projects in Partners countries so far have been conducted only in Germany, France and the Netherlands. Croatia and Hungary employ CO_2 injections in order to foster oil production (EOR), in Poland CO_2 and acid gases are being injected in order to enhance natural gas and oil production. The new ideas that are supposed to combine CO_2 sequestration with e.g. geothermal applications or power-to-gas methane synthesis are still under development, but they will also require utilisation of underground storage capacity of geological formations.

Closing the topic of storage of substances, underground waste disposal on industrial scale was reported by some Project Partners in their countries (Fig. 5.4). This refers separately to liquid and solid wastes (including radioactive), which definitely require different storage conditions, technology and infrastructure.

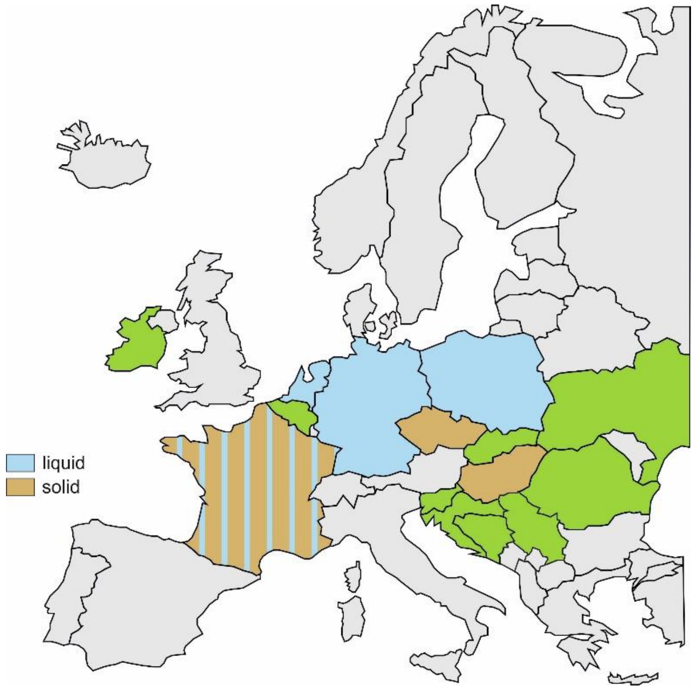

Fig. 5.4. Underground waste disposal in Partner countries (in green countries with no activity of this kind).

Geothermal energy is utilised in all Members States represented in the GeoConnect³d Project. In most of them only a conventional type of technology is introduced, which relies on an amount of water available due to formation conditions (hydraulic conductivity and pressure). Only France and Croatia (Fig. 5.5) declared operation of enhanced geothermal systems, which involve hydraulic stimulation of water flow in geothermal aquifer to enable bigger water intake in case of natural hydrothermal systems or to allow for creating artificial water flow between geothermal doublets in non-aquifer formations with insufficient hydraulic conductivity to naturally deliver and/or absorb the requested volume of water for the needed amount of heat. Such a petrothermal project conducted in the past with currently no continuation was reported only in Croatia.

Depending on the temperature available, geothermal systems deliver energy for power generation, production of heat for district heating grids, individual premises and for recreation as spa and water parks. The last ones often utilise residual heat from water after power generation and heating grids supply.

All partners also confirmed that shallow geothermal heating (and cooling) systems with a use of heat pumps are more and more commonly utilised in their countries.

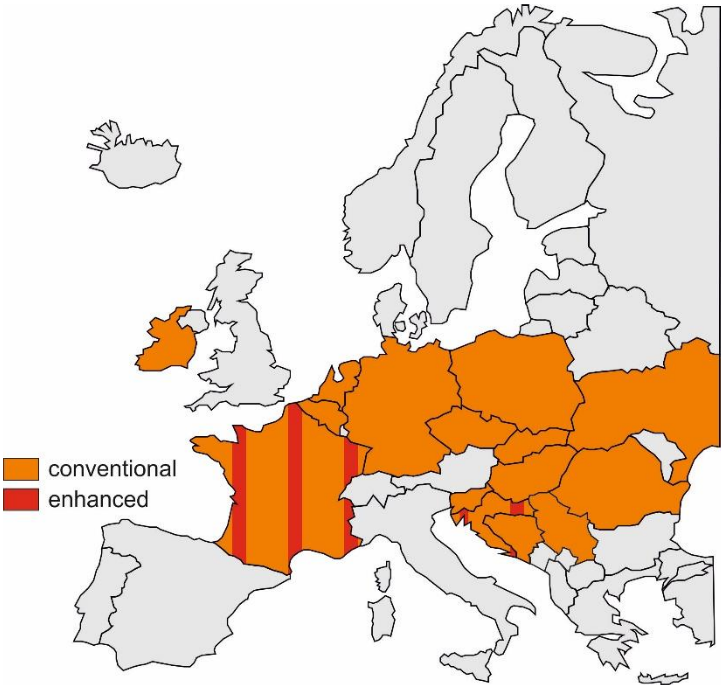

Fig. 5.5. Deep geothermal applications in Partner countries.

To complete the whole picture of subsurface use in the GeoConnect³d Project Partner countries, extraction of mineral water from various depths was indicated by all, which means that deep aquifers in many regions are already utilised for some purposes and possible use of them for other tasks like e.g. CO_2 storage will have to compete with the on-going utilisation.

Based on recent literature data available there are two operating compressed air energy storage (CAES) facilities worldwide, one of them in Germany using salt caverns for storing the compressed air and the other one in the USA (Wang, 2018).

6 MANAGEMENT PRACTICES IN MEMBER STATES

Within the framework of work already conducted in the GeoConnect3d Project an analysis of procedures in Partners' countries has been performed to study existing administrative schemes for subsurface planning and management as well as subjects/parties entitled to and engaged in permitting, approving and conducting activities in subsurface.

In Project Partners' countries, among the parties interested in the use of underground space, the most frequently mentioned stakeholders are private investors, both industrial and private people, followed by state-owned companies and local administration. In several countries also state governments and state-private partnership entities are directly interested in projects connected with the subsurface use.

It is much more difficult to identify all authorities that are or may be involved in a long chain of spatial planning, environmental and technical procedures related to the use of subsurface. The information collected among Project Partners is of great diversity and degree of detail, which is mainly due to the administrative and political environment of the country concerned. The diversity of authorities and differences in the competence are derived from national and local legislation, different in each country, as well as different patterns in organization of state, regional and local administration.

It is not possible to establish a single pattern of managing the underground space for all countries, as a number of institutions are involved at both central and local levels. Some state level offices, especially in countries with no federal states, are pretty obvious to be dedicated for some responsibilities related to exploitation of strategic geological deposits or nuclear waste underground storage and their environmental safety, but as it goes down in the administrative hierarchy, interests and responsibilities go to local institutions and are assigned according to local regulations with different patterns in different countries.

At present none of the countries surveyed within the GeoConnect^{3}d Project could confirm that it has incorporated a subsurface use planning and management as a complex issue into a legal system like e.g. surface land use planning. Defragmentation of regulations and "dispersion" of competences allow admittedly for management of particular procedures but do not help in creating a comprehensive system to ensure safe and efficient use of resources of geological space.

Within the existing legal frameworks in European countries many limitations on subsurface use result from spatial planning, regional and local legislation, already on-going enterprises, infrastructure protection, etc. Some inconsistencies in legal regulations resulting in lack of or overlapping of some competences create problems for proper planning and management of a use of underground space, especially when legal framework cannot keep up with a technology development. Such examples have been collected among the GeoConnect³d Project Partners and are presented below.

In Poland no underground activities can be permitted within protective pillars of documented mineral deposits, regardless it can or cannot affect mining activity or protective function of the pillars.

In Germany the present version of the mining law allows only for one type of subsurface utilization per license area. Exceptions are very rare for the few cases where the applicant for a new activity can ascertain that there will be no impact on the pre-existing use, neither short-term nor long-term. Only recently a pre-parliamentary discussion has started about the consideration of revision of these provisions of the Federal Mining Law (Bundesberggesetz) in the context of site location process for a deep radioactive waste repository and possibility of overlapping of license areas at different depth levels.

Similar generic rule applies to groundwater protection areas in Germany: within the protected area no drilling or mining activities are permissible due to possible threats to water resources. The only exception is possible for deep (> 2000 m) hydrothermal utilization providing that hydrothermal reservoir is separated by at least one thick barrier horizon at depth and drilling still requires to fulfill special precautions.

Based on anticipated groundwater contamination and induced seismicity hazards, hydraulic fracturing for unconventional hydrocarbons exploration and production was banned in several countries, including e.g. France and Ireland, hindering technology development and improvements within security area.

As an example of inconsistency in subsurface management within an existing legal framework the situation from Belgium can be presented. The same aquifer is suited for several subsurface applications: two adjacent license areas for gas storage and deep geothermal exploration fall under different competences. The gas storage falls under federal law and has been active since 1985. The deep geothermal project falls under Flemish competence and will soon start. Mutual interferences between uses might occur but the regulations for both parties are different and a conflict of competence could make the proper management quite difficult.

Some decisions have to be made despite there are still missing solutions related to some activities. Again in Belgium, though a permitting system for nuclear waste storage is still not set up, deep geothermal production has been approved and has been initiated close to the principal site explored for storage of high-level nuclear waste.

In Ireland a potential for deep geothermal energy to be e.g. included in existing district heating schemes or be obtained from deep mine waters is being already investigated by several projects. The problem is that the legislation for geothermal exploitation and related subsurface management is not yet developed. In turn study of a potential for

CO_2 storage at an offshore depleted gas field is partially compromised by the Government licensing requirement to decommission the site.

A need for public engagement in subsurface use planning and project implementation results from legal provisions. In most of the cases public consultations are required based on EIA Directive (85/337/EEC with amendments 2011/92/EU and 2014/52/EU) and its implementation in national legislations, but not every subsurface activity is subjected to an EIA procedure. Some novel technologies or activities not yet implemented in a country might not be put on a list of projects for which an EIA procedure is obligatory. In some countries like the Netherlands, activities that require public consultations are defined based on a depth of its localization. As reported, among Partner' countries only in Slovenia public consultations are not directly required by law, but also within the EIA procedure there is a place for taking the public awareness into account as it arises. In some countries, public engagement can be initiated in certain cases on request, e.g. in Bavaria (Germany) all applications for licensing mining and deep geothermal activities are promulgated via the internet and upon any objections or dissent of interest groups or even persons concerned, hearings and public consultations need to be held. Also the minimum obligatory duration of public consultations in some countries like e.g. in Poland is set up by legal provisions.

7 AVENUES FOR IMPROVEMENTS

It is not an ambition of this report to present ready-to-use recipes for proper, long term and sustainable subsurface use planning and management. It rather aims to indicate issues that need to be taken into account in future management practice and opens a discussion how to take them into account in the broadest context and in the most efficient way.

Hopefully, on the basis of findings of this report and planned stakeholders interactions, some more detailed guidelines and conclusions will be prepared in the next report at the end of the Project.

7.1 Conflicts/synergies identification

Similarly to any activity on a land surface, some underground projects can stand in conflict to each other especially when they need to use the same space. But it is also possible that two different activities may be complementary or one can pave a way for conducting the other.

There is also possible that the underground projects may create hazards to other activities or initiatives (e.g. protected natural reserves, Nature 2000 zones) undertaken by surface land use planning especially when accidents or abnormal operations are encountered.

In most of the cases, it is never a holistic conflict, but interactions that hinder one uses can reinforce others. For example - increasing formation pressure promotes extraction of fluids, while lowering it – enables storage or injection.

Having all this in mind, it seems to be quite obvious that efficient and sustainable use of all accessible resources require a careful analysis of all relevant factors to identify in advance possible conflicts as well as complementary activities to enable making informative decisions which desired scheme of subsurface use is the most fitting both needs and opportunities of particular localization. Good practices need therefore to be collected, summarized and implemented to estimate the degree of interaction that can be tolerated (e.g. percentage of pressure changes in some zones) and should be taken into account in proper subsurface operations / applications planning.

<u>Conflicts</u>

The term conflict with regard to underground use can be understood in two ways. First is a direct collision of two or more possible projects to be conducted in the same geological formation, where each makes the others impossible. Such conflicts can be defined only up to certain point which is placed by a currently known technology. What the future brings can still surprise us, so overall prediction of all direct conflicts is not possible (Le Guenan et al., 2016) and any future subsurface planning and management scheme must find a way to deal with this limitation.

Other possible conflicts of use of the subsurface were divided by Le Guenan et al. (2016) into indirect conflicts and long term conflicts. Indirect conflicts were as a potential unwanted reactions caused by an underground space use pattern both under and on the land surface. Such conflicts are difficult to predict with holistic approach and should be assessed on a case-by-case basis with use of geological and hydrogeological modeling as well as other methods of risk assessment suitable for particular case.

Long term conflicts need to be understood more as impact of an underground activity, which can cumulate over years in case of gradual change of natural conditions (e.g. natural formation pressure that affects resources of water in somehow connected potable water aquifers). It is also possible that once chosen, an underground project may put in question some patterns of development in future, especially when it has a certain level of risk.

In opposite, in present legal systems some underground activities are limited due to legal regulations which stop industrial activities in, e.g., water protection or nature protection zones. In most of the cases novel types of subsurface use do not pose significant hazards to protected subjects like fauna or flora so there is no actual conflict, but restrictions in such areas are set up generally with no hazard and risk assessment related particularly to certain activity.

The survey conducted among the GeoConnect^{3}d Project Partners revealed some already experienced real life conflicts derived from subsurface applications, as well as expected based on scientific projects' analysis. These limitations/conflicts or interactions have been identified as follows:

- mines (metallic and non-metallic exploitation) flooded by thermomineral CO_2-rich groundwater (penetration and emissions of CO_2) which forced mines closure;
- coal and uranium mines operations caused changes in hydraulic regime, quality and yield of potable groundwater reservoirs or reservoirs of healing water used in balneology; water contamination quite often caused by incorrect exploitation practices in the past;
- coal mining associated with subsidence of the overburden (often up to the surface) which hinder any activity above the exploitation depth;
- there are cases of overexploitation of geothermal resources (drop down in initial thermal parameters and yields) when insufficient recognition of conditions and/or too dense geothermal installations targeting one reservoir cause poor performance;
- underground gas storage generates seasonal changes in water table level in potable water aquifer thus changes in water level in wells and in spring yields are observed;

- conflicts are expected between production of hydrocarbons and possible future use of high temperature thermal waters which in many cases can be achievable at the same depths of the same reservoirs (no matter if water is natural or needs to be injected in enhanced geothermal system installation);

- there are also a number of limitations derived from legal regulations that do not represent physical conflicts, such as the rule to assign only one license type to one area (i.e. no overlapping activities are possible, no matter if they can have any interactions or not).

Good examples of case studies on subsurface use to overcome possible future conflicts can be found in literature. For instance, opportunities for large-scale energy storage in geological formations in Portugal were analyzed by Carneiro et al. (2019). Authors presented the methodology and results of the first screening conducted in Portugal aiming at identification of geological formations that might be used as energy storage sites. Among the prospective reservoirs authors named salt formations with the existing and planned salt caverns (as natural gas storage in caverns has already been applied in two salt mines). Moreover, saline aquifers were identified as suitable for compressed air (CAES) and underground gas storage (UGS). CAES and UGS linked to power-to-gas were named as the technologies that have the most promising potential for application in the Portuguese geological conditions.

<u>Synergy / re-use</u>

In addition to tools that allow better prevention of conflicts in the use of underground space, it is also important to consider tools that promote possible synergies between these applications. The three main types of synergies listed by Le Guenan et al (2016) are: (i) joined liquid and heat extraction, (ii) the extraction of the raw material that creates space for the injection of other materials / substances, (iii) using the product obtained from one underground space application during the implementation process of another application in the same space.

Synergy benefits in combining CCS and geothermal energy production were identified and described by Nielsen et al. (2013), Buscheck et al. (2016), and van der Molen (2019). Since injection of CO_2 into the subsurface causes pressure build up not only in the injection site but also in its vicinity, this phenomenon can be used to combine CCS and geothermal energy production. Kervévan et al. (2014) presented a possibility to use CO_2 as a working fluid in geothermal power systems on a local scale, which in addition would significantly reduce costs related to CO_2 transportation from the source to the injection site.

Van der Molen et al. (2019) go even deeper and indicate four types of possible synergies between oil and gas and geothermal projects. A first type concerns a dual play concept for exploration of natural gas and geothermal prospects. Based on this concept an exploration well failing to prove the presence of hydrocarbons (dry well) may technically be successful in tapping a hot water-bearing reservoir. It is also possible to convert old hydrocarbon production wells into geothermal wells (reusing single well or multiple wells as geothermal doublet). The next case is when a part of the extracted geothermal water is injected into an oil-bearing reservoir in order to lower the viscosity of the heavy oil and increase the recovery factor (EOR). The last concept of synergy presented is placing a geothermal doublet in the water leg of a gas field close to a producing gas well. If configured correctly, a balance between extracted and injected water can slow down water encroachment in the gas cap and thus delay the timing of water breakthrough at the gas production well. This method will allow for extending the period of exploitation of the gas well.

Benefits from combining CCS and hydrocarbons production from conventional sources in so called enhanced oil/gas recovery technique was described i.a. by Roelofse et al. (2019). Injection of CO_2 into the gas trap in proper distance from production wells can keep a production pressure on desired level, when presence of CO_2 can additionally foster CH4 desorption from solid phase of reservoir. Captured anthropogenic CO2 has been used for enhanced oil recovery in many projects, especially in the USA and Canada (Kuuskraa et al., 2013). The CO2 acts here as an agent lowering oil viscosity and helping to move the remaining oil out of the rock formation towards the production wells. All of the injected CO_2 either remains sequestered underground or is back-produced and re-injected, which means that in the end it is permanently stored in a depleted field.

Simultaneous CO_2 injection and brine production to help to control pressure buildup and increase the effectiveness to expand the subsurface storage capacity was presented by Santibanez-Borda et al. (2019). The method tested in two locations in the Central North Sea proved the increase in the CO_2 storage capacity between 112 and 145% in comparison to injection without brine production.

Based on the survey conducted between the GeoConnect^{3}d Project Partners the following examples of synergies between different types of subsurface use including re-use have been observed in the Partners countries:

- in Federation of Bosnia and Herzegovina:
    - simultaneous extraction of thermomineral water for spa and CO_2 for food industry from the same well in Gračanica – operational stage;
- in Croatia
    - CO_2 extracted from gas fields and pumped in producing oil field for enhancement of oil production – operational stage;
- in the Czech Republic:
    - seven depleted hydrocarbon fields transferred to natural gas storage sites with total storage capacity of more than 40% of annual consumption; one of them – the Dambořice field – the on-going oil production is combined with a gas

storage function; a natural gas storage has been built in an abandoned uranium mine – operational stage;

  - so-called institutional radioactive waste, which is produced in the healthcare, industry, agriculture and research sectors, has been disposed in a radioactive waste repository in one section of the underground complex of the former limestone mine since 1964; the repository includes a certified test facility for testing of waste containers and special radioactive materials – operational stage;
  - several abandoned mines have been transformed into underground research laboratories – operational stage;
  - an abandoned gold mine in the Zlaté Hory region has been used for children's speleotherapy since 1995 – operational stage;
  - an experimental pilot underground pump hydro plant in the abandoned coal mine near Ostrava – prospective stage;

- in France:
  - the heat from water co-produced at an oil and gas exploitation site (Vermilion, the Landes region) is used for greenhouses heating – operational stage;
  - in the Gardanne abandoned mine (Bouches-du-Rhône region) an eco-district heating/cooling system based on the mine waters thermal potential is under construction; heat storage in the mine waters is also under consideration – prospective stage;
- in Germany:
  - several depleted hydrocarbon deposits are re-used for natural gas storage (no CO_2 storage permissible) – operational stage;
- in Hungary:
  - re-use of depleted gas fields for subsurface storage - gas storage in operational stage, prospective stage for CO_2 storage;
  - co-development geothermal-gas production - many of the thermal water wells have high gas content – under review
- in the Netherlands:
  - re-use of gas fields and salt caverns for subsurface storage – operational stage;
  - hydrocarbon-geothermal double play (conversion of dry hydrocarbon well into geothermal well) – prospective stage;
  - possibly co-development of geothermal and gas production (to enhance gas recovery by delaying water break through) – prospective stage or under review;

- in Poland:
  - use of waste for backfilling of mine's underground excavations – operational stage;
  - use of abandoned boreholes for re-injection of formation water derived together with hydrocarbons – operational stage;
  - use of acid gases re-injection for reservoir pressure build-up - enhanced oil and natural gas recovery – operational stage;
  - use of CO_2 for coalbed methane enhanced recovery – pilot stage, not continued;
  - coal bed methane exploitation in front of mine excavation – resource recovery and health risk minimization – prospective stage;
  - use of caverns of salt exploited deposits for underground storage of hydrocarbons – operational stage;
- in Serbia:
  - use of waste for backfilling of mine's underground excavations – operational stage;
- in Slovenia:
  - use of waste ash from lignite combustion based thermal power plant for backfilling of mine's underground excavations – operational;

7.2 Need for long term planning

The content of previous chapters illustrates that at present a responsible subsurface use management has to combine many procedures which are in competences of various institutions which may not even be aware of the scope of the whole issue. In addition, any assessment of a planned activity requires at the most evaluation of possible alternatives within the scope of the type of activity in question. There are no requirements at the moment for discussion of alternative uses possible in the same place, which should be a basis for choosing the best long run option and approval or rejection of any application.

As already mentioned in chapter 2, a need for a European legal and procedural framework for sustainable long term planning of subsurface use becomes more and more obvious. Increasing awareness is identified especially among scientists who deal with new mining and energy related technologies, geologists involved in national geological surveys responsibilities, but also economists, industrial developers, environmental NGOs or even sociologists with special focus on civil and information society development.

Long term planning is important with regard to subsurface use because of at least three reasons:

1 - it refers to activities which in many cases are practically irreversible and once started, need to be managed and controlled despite changes in approaches or global and local policies;

2 - it refers, to some extent, to technologies that are not operational yet or sometimes even not developed, so there must be a space left for possible future applications;

3 - it must take into account possible impact on local and regional natural conditions which may gradually grow and pose hazards in a difficult to predict future.

7.3 Tools for long term planning

Like in every planning of anything, the process has to start from recognizing of a current state. In case of subsurface use a scope of information needed for placing such a basic point seems to be quite broad. It needs to contain at least:

- an overview of social and environmental components (meaning: economic needs and requirements, societal challenges, policies, established restrictions, etc.) existing on and near land surface;
- an overview of any subsurface industrial activity at present and in the past;
- an overview of general geological and hydrogeological conditions, including tectonics and natural processes that occurred in the past as well as these currently active.

The first point lays within competences of state, regional and local authorities which need to communicate and prepare a list of preferences for particular regions based on individual task and policies of each of them.

The second point is more technical and should rely on objective information arranged in such a way which allows for establishment of comparable assessment of current status of underground space impacted by human activity. One can imagine that a perfect tool to be used for such task would be a register of subsurface use – a database gathering generic features as well as attributes specific for particular types of activities. In some European countries represented in the Project such a tool has been established already. The Netherlands created a Key Register of the Subsurface which is supposed to collect and maintain authentic data on subsurface activities and is responsible for guaranteeing the quality of that data. All subsurface activities are obliged to be reported to it within a scope of information requested and new planned activities must be confronted with the stored data. In Poland so called MIDAS system gathers all information on mineral deposits documented and concessions granted for mineral exploration and exploitation as well as for subsurface storage and waste disposal. It has a space for underground CO_2 storage concessions information, though no permit of this kind has been granted so far. The Mining Area register module stores all the administrative records on subsurface activities. MIDAS also provides services for sharing a part of information but not the whole resources are publically available. Moreover, in Poland, a special publication (Balance of prospective mineral resources) is being prepared in a 10-year cycle devoted to regions with prospective mineral resources. Thus prospective deposits can be also taken into account in planning of development of underground space.

Finally, the last point is a responsibility of geological surveys and individual experts who, to full-fill this task, must rely on available geological information and their academic and practical skills. The challenge is to merge the geological context (mostly regarded as a kind of mysterious knowledge) with subsurface activities and societal- and environmental components, into a concept of a civil and information society. To meet these requirements, a new tool, accessible via internet for anyone who wants to get familiar with subsurface issues without academic courses, is being developed in the GeoConnect^{3}d Project. This tool, with the working name “structural framework”, gradually being developed for the whole of Europe, is believed to become a geological “first aid” for sustainable planning and management of subsurface use[1]. This is being done by a novel methodology that reorganizes and simplifies the representation of geology based on its explicit boundaries, or geological limits[2]. As a simple but robust model, the structural framework is built to provide context and improve the understanding of information that may be difficult to understand from geological maps and 3D models. With this approach, geological processes that happened or are happening in the subsurface are also represented through geomanifestation data, aiming to show where and how processes and structures may be linked. The first version soon will be tested and advertised among potential stakeholders of subsurface planning and management.

[1] For more details about the use of the structural framework for planning and management of subsurface use, please refer to the GeoConnect³d webinar on subsurface interactions.

[2] For a brief explanation of the methodology, please refer to the GeoConnect³d presentation at the EGU 2020 conference.

8 CLOSING REMARKS

As the subsurface has no borders except for geological ones, its proper use cannot be considered as a one-country competence but needs to be in advance treated as transboundary or even pan-European issue. A proper planning and management of subsurface use is a big challenge for scientists, entrepreneurs and administration with regard to sustainable resources management as well as to minimization of environmental impact.

Currently, the European legal regulations concerning the use of underground space are dispersed in several directives, which does not help to treat the subsurface management issue as a complex field. There is a need for new coherent regulations referring to all traditional subsurface uses as well as all emerging geo-energy technologies as they are getting more and more interconnected and also including waste disposal. They need to be clear and simple to ensure a smooth transition from the linear to the circular economy with careful reuse of mineral raw materials and preliminary planning of harmonized and rational use of land and subsurface. Legal regulations of subsurface use must not be limited to the cities and agglomerations since most of the present-day conflicts of use arise from use of the deeper subsurface, exceeding the limits defined by a municipal activity. Moreover, such regulations should not only focus on opportunities of use of subsurface but also on its protection against pollution or damage of resources that cannot be exploited at present but may be of a significant value in the future.

To enable more conscious commitment of societies and to ensure more knowledge-based decision making, it is necessary to deliver better geological service in terms of accessibility, comprehensibility and accuracy towards certain tasks. Adequate tools must be developed and delivered both for subsurface use data storage and for prospection of future possibilities. Only with decent recognition of all relevant natural and economic conditions, a proper tackling of present and future conflicts/synergies between subsurface uses and/or other operations can be possible, presented and communicated to all stakeholders including local societies and property owners. Informative approval of final decisions from all interested parties thus would confirm that the best possible solution has been chosen.

To be able to formulate any guidance or best practice for subsurface planning and management to be of any help for Member States it seems necessary to harmonize the naming of administrative decisions in all aspects of underground space management or even to create an “unified European permit” though this would require far more work and approval of all Member States.

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