Tunnelling and Underground Space Technology xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Underground spatial planning – Perspectives and current research in Germany

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ARTICLE INFO

Article history:
Received 6 August 2015
Received in revised form 26 November 2015
Accepted 26 November 2015
Available online xxxx

Keywords:
Underground space
Spatial planning
Urban land use planning
Conflicts of use

ABSTRACT

There has been a growing need over recent years for the coordination of utilizations in underground space. This study investigates rising demands on the utilization of underground space and associated conflicts related to space, responsibilities and priorities. Strategic, comprehensive, and holistic spatial planning is required to resolve these conflicts. This paper presents the current status of spatial planning regulations in Germany concerning underground space, and investigates possible planning solutions for its coordinated use. Findings of this study indicate that dedicated underground spatial planning should replace the common procedures towards designating exclusive areas for certain purposes in order to ensure the sustainable use of underground space.

1. Introduction: Necessity for underground spatial planning in Germany

The implementation of the German Federal Government's climate and energy policy goals, which encompass a gradual expansion of the share of renewable energies (wind, solar energy) and a commensurate reduction in electricity produced from fossil fuels (coal) and nuclear energy, will place higher pressure on energy-related underground technologies. For example, the expansion of renewable energies such as wind and solar power requires sufficient storage capacity for excess energy as well as ancillary sources of power to compensate for energy fluctuations, thereby ensuring grid stability. This implies a growing need for coordination in the planning and use of underground space. While in the past the predominant uses of underground space were the mining of raw materials and the extraction of groundwater, in future we can expect a rising demand for energy-related uses such as to exploit geothermal energy or for energy storage (i.e. natural gas, compressed air, hydrogen). Other underground utilizations such as the permanent storage of CO_2 (as an industrial byproduct) or the application of hydraulic fracturing in order to release natural gas deposits are other likely areas of conflict regarding underground space that will potentially increase pressure on this valuable resource. Suitable geological formations for such purposes are limited, and so it is vital to coordinate the various utilizations. The valuation of underground space appears to be a missing or hidden factor in land economics and planning. Yet ignorance of such a potential resource may seriously distort future underground land policies and their implementations (Pasqual and Riera, 2005).

Furthermore, despite the continued growth in the use of underground space beneath cities, there is a general lack of significant and wide-ranging planning measures to regulate these activities (Sterling et al., 2012). The popularity of urban development projects that make use of underground space has grown for multiple reasons such as the increasing scarcity of available space, population growth and public awareness (Godard and Sterling, 1995). Urban underground space is a valuable non-renewable resource that must be carefully considered in urban planning and should be incorporated into every city's development master plan (Bobylev, 2009). Examples for this already exist, such as the city of Helsinki, which has drawn up an underground master plan for its entire municipal area (Vähäaho, 2014). While underground masterplanning is still very much a novelty in Germany, many cities have actively and intensively been exploiting underground space. A case study in Berlin has revealed a significant figure of approx. of 3 m^3 of utilized underground space per m^2 in some city centre areas (Bobylev, 2010).

The objective of this paper is to discuss how existing spatial planning instruments in Germany can be applied to the 'deeper' underground, and to investigate which adaptations are necessary

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http://dx.doi.org/10.1016/j.tust.2015.11.023
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in order to achieve an optimal and sustainable use of underground space.

2. Potential conflicts of use in underground space

There are four general categories of use of underground space, namely:

1. storage (natural gas/oil storage; storage of H_2, compressed air);
2. deposition (Carbon Capture and Storage (CCS); underground waste disposal including storage of radioactive waste, brine injection);
3. productive activities (mining; use of geothermal energy as geothermal heat pumps/shallow geothermal systems, hydrothermal geothermal systems, petrothermal systems/hot-dry rock technology; storage of heating and cooling energy; utilization of mineral springs and groundwater);
4. underground structures (tunnels, technical structures; underground pumped hydro-electric power plants).

Conflicts in the exploitation of underground space are multidimensional and complex (see Fig. 1). Some forms of use are in direct competition, for example when several competitors want to use the same natural gas storage site (Dietrich and Schäperklaus, 2009). The different forms of uses also place a range of demands on the particular geological formations of underground space, of which the essential properties are impermeability, capacity and flexibility. For example, depleted natural gas/oil reservoirs, saline aquifers and salt caverns are suitable geological formations that can serve as reservoirs for natural gas storage. In these formations, however, other utilizations are also possible (Crotogino et al., 2009). For example, deep saline aquifers can also be used for the production of geothermal energy; sufficiently high temperatures exist at depths greater than 1000 m for geothermal heat utilization and power generation. Moreover, saline aquifers are also suitable for the application of the CCS technology. The geological formations with the greatest conflict potential and/or pressures on use are saline aquifers, salt caverns and exhausted hydrocarbon storage reservoirs (Crotogino et al., 2009; Dietrich, 2010). In northern Germany there exists a high potential for conflicts of use due to the presence of numerous saline aquifers as well as a high demand for underground energy storage from off-shore wind farms. The largely untapped deep saline aquifers in the North German Basin are suitable for these diverse kinds of underground space utilizations (Dietrich, 2010). For example, in the federal state of Mecklenburg-Western Pomerania, the demand for salt caverns for natural gas storage is certain to increase as a result of a new gas pipeline between Russia and Germany. At the same time, the demand for salt cavern storage systems for compressed air and/or hydrogen will also rise if proposed wind farms are constructed in the Baltic sea (German Bundestag printed item BT-Drs.16/9896, 1.7.2008, p. 22).

As the future demand for underground space is difficult to determine, it is necessary to keep options open for a range of possible activities. In particular, it is currently unclear how relatively new technologies such as the underground storage of compressed air and hydrogen will develop in the years to come. Thus it may prove necessary to assign coastal sites for this use before they are already designated to other utilizations (Crotogino et al., 2009).

Furthermore, a conflict in use can even arise between underground activities that do not directly impact the same geological formation. Thus the physical repercussions from an activity, whether concerns over safety or possible impairment of rock impermeability for gas storage, can hinder or exclude other competing uses (Schulze et al., 2015).

3. Data availability for spatial planning stipulations

Due to the heterogeneity of geological properties, data on the characteristics of underground space is inhomogeneous and, in some cases, lacking (ARL, 2012).

More comprehensive information is available for sites formerly used for exploration and mining activities (e.g. natural gas exploitation), though often only for restricted areas. However, there is a decided lack of data on the deeper underground for areas that have not been explored in this way. The heterogeneity of data concerning underground space increases with depth, as boreholes that provide such data generally do not reach very far underground. For example, in the German state of Lower Saxony less than 10% of the more than 330.000 holes reach depths of more than 100 m; only 3% go beyond 800 m. Another aggravating factor is the fact that the vast majority of deep wells and geophysical investigations are several decades old. Geophysical methods, however, are continually improving, and now provide better quality data. Recent technologies offer a more highly differentiated picture of the deeper underground, yet such geophysical information is only available for areas that have been closely investigated by companies engaged in commercial exploration (SGD et al., 2012).

The data quality required for the setting of spatial planning stipulations depends on the freedom of design and the degree to which the respective spatial planning stipulation is binding. Due to discretionary powers, the establishment of spatial planning principles ('Grundsätze der Raumordnung') places a range of requirements on data quantity and quality that differs from those in the case of spatial planning goals ('Ziele der Raumordnung'). The principles of spatial planning have to be applied to subordinate decisions based on the consideration of various interests, and involve a higher degree of flexibility. Goals of spatial planning, on the other hand, must be sufficiently concrete or precise, both spatially and substantively, and also carefully balanced. Nevertheless, the goals of spatial planning should be broadly formulated to allow new information to be taken into account, such as the suitability of geological formations to certain uses.

4. Spatial planning regulations in Germany

4.1. Existing planning instruments and suitability for underground space

In Germany the coordination of land use is subject to spatial planning. Such planning is legislated by the Federal Spatial Planning Act (Raumordnungsgesetz, ROG), which sets principles for spatial planning and for spatial planning procedures to be implemented by state organs with regard to individual sites and projects.

The comprehensive planning practice in Germany includes spatial plans (Raumordnungsplanung) and the urban land-use planning system (Bauleitplanung). The latter includes drawing up (a) zoning or preparatory land-use plans (Flächennutzungspläne), and (b) local construction development plans or legally binding land-use plans (Bebauungspläne).

According to the Federal Spatial Planning Act, it is possible to designate regions where priority is given to specific utilizations of the space or where such utilizations are not permitted outside these regions (priority areas ('Vorranggebiete'), reserved-function areas ('Vorbehaltsgebiete'), and suitable areas for development ('Eignungsgebiete'), according to Section 8 para. 7 ROG). While the concept of 'space' is not limited to the surface, a more detailed spatial underground planning regime is certainly conceivable (Weyer, 2013). In the coalition agreement, the German Government has stated that the basis for underground space use planning