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Explanatory for the applied Traffic Light Model (TLM)

1. INTRODUCTION

This explanatory report is made for the better understanding and use of the TLM. The model was created to visualise and support the management of competitive usages of the geological space within the Pannonian Basin.

The AOI (area of interest) of the model is dual, it covers 2 pilot areas within the Pannonian Basin: Battonya High (1) and Mura-Zala basin (2).

The method of the implementation in the two areas is slightly different. In case of the Battonya High the model space is 3D, while in case of the Mura-Zala Basin it is 2D.

The delivered product is a state of the art, static model to visualize the possibilities of use of such a model in policy and geospace management tasks in the member countries of the European Union and beyond. It is important to highlight that to our best understanding, this is the very first attempt to create some concrete application for the better understanding of competitive subsurface uses that goes beyond the theoretical considerations (e.g. FIELD et al. 2018, VOLOCHKO et al. 2020). The further development of the model should be towards an interactive scenario model, where users can ask questions, e.g. what if I make a thermal water doublet in my village? At which depth should I count with competitive usages? The interactivity means that the model should be changed every time parameters and conditions are changed, or when information about new research results, abandoned mining activities, new concessions, etc is available.

The basic philosophy of the TLM model is that we colour the different pixels or voxels of the 3D geological model according to their current state of use based on different criteria parameters. A pixel/voxel is red in general if a criteria parameter shows non suitability, or occupation of a usage for that pixel/voxel. A pixel/voxel is green in general if a criteria parameter shows suitability or nonoccupation of a usage for that pixel/voxel. We define intermediate values for protection areas, for transitional parameter values in yellow colour. For detailed explanation see chapter 2.

The essential base of the model is the 3D voxel geologic model of the infilling formations of the Pannonian Basin delivered within this project. The lower boundary of the model is 8 km.

Since there is no uniform colouring method for all the potential usages at the same time (geothermal, hydrocarbon, etc.), in case of an interactive model the user must choose a route at the beginning of the scenario creation according to the basic aim of the planned usage. This could be i.e. use of drinking water in shallow depth or use of thermal water at the deeper pore space, or use of hydrocarbons at the same depth, or CO_2 storage. After deciding the usage target, the built-in criteria parameters colour the model space. In this report we introduce the route of the usage of the thermal water and hydrocarbons in the 3D model space, and thermal water in relation to drinking and mineral waters and hydrocarbons in the 2D model space.

2. 3D TLM model of the Battonya High

Fig.1 shows the sketch of the Battonya High. It is a crystalline body of the basement delineated by faults and covered by young basinal sediment formations and with human social space on the top.

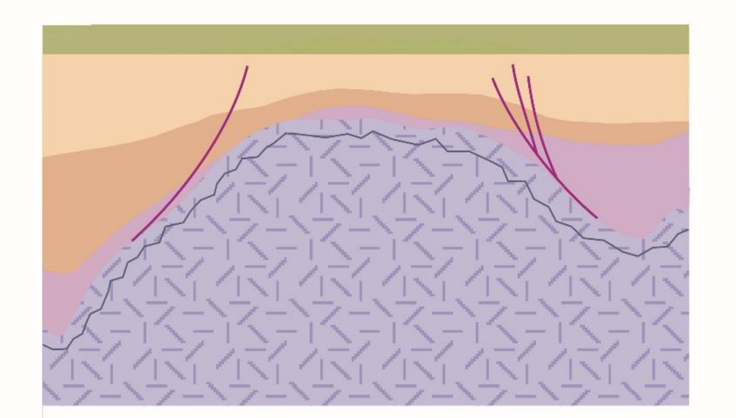


Fig.1. Sketched section of the Battonya High. Crystalline body (greyish blue) covered by Neogene and Quaternary sediments (pink, brown, khaki, green)

We show here the modelled route or scenario of the competitive usages between the thermal water and hydrocarbon explorations as follows.

A/ Criteria of potentials coming from the geology of the area

There is a sort of potentials, depending mainly on the investigated territory. The colouring in general is (1) potential with green, (2) questionable potential with yellow (boundary conditions), (3) no potential with red. Without detailed geological descriptions of the thermal water and hydrocarbon reservoirs of the Pannonian Basin, some general geological and hydrogeological criteria are the followings.

- Above the Pannonian (Late Miocene-Pliocene) slope formation (Late Miocene) green (porous aquifers), within the slope red (clayey aquitard) (Fig.2),
- In early Miocene Formations (Fig.2) green (porous and fractured aquifers),
- In the basement formations (Fig.2) green (fractured and karstified aquifers),
- Above thermal isotherm levels (30 °C and 50 °C) red (“too cold”), below them green.

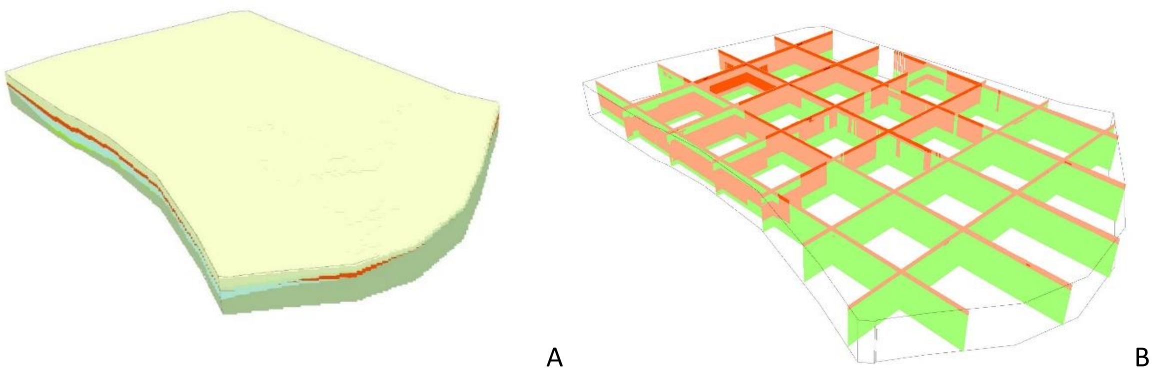


Fig.2. Geological (A) and the 50°C hydrogeological (B) criteria horizons and voxel model of the Battonya High territory

B/ Criteria of geospace usages of the area

Another group of the model parameters are the bodies of the usages. A theoretical usage distribution is shown of Fig. 3.

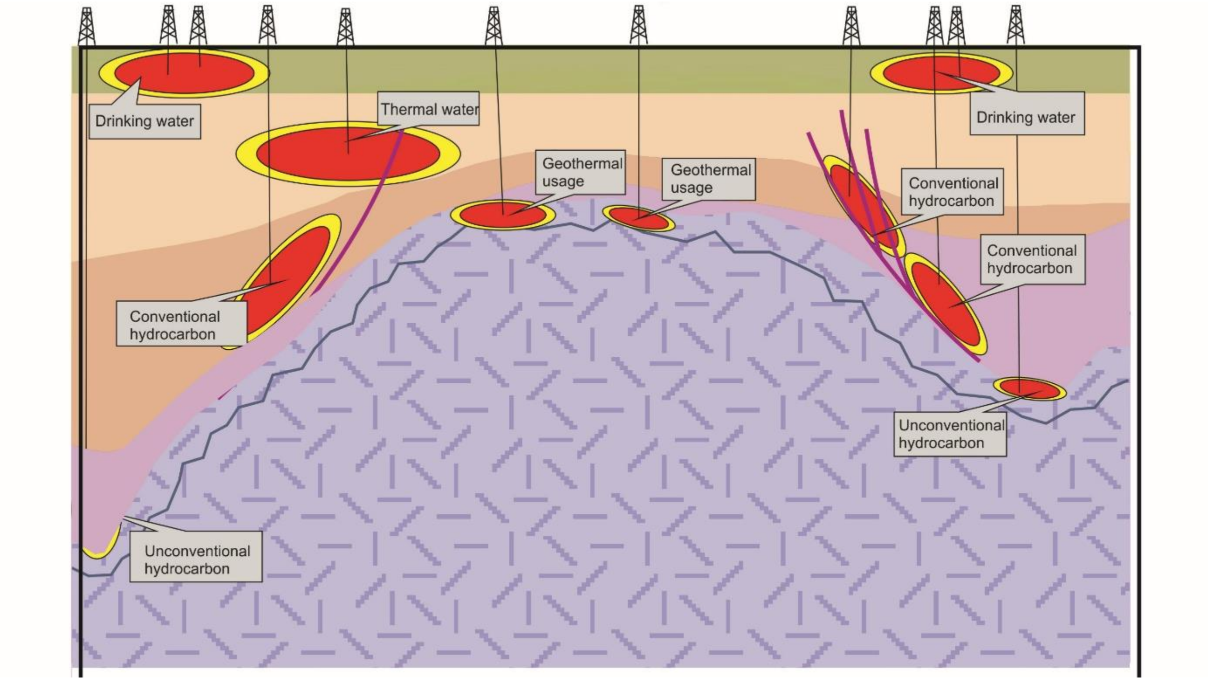
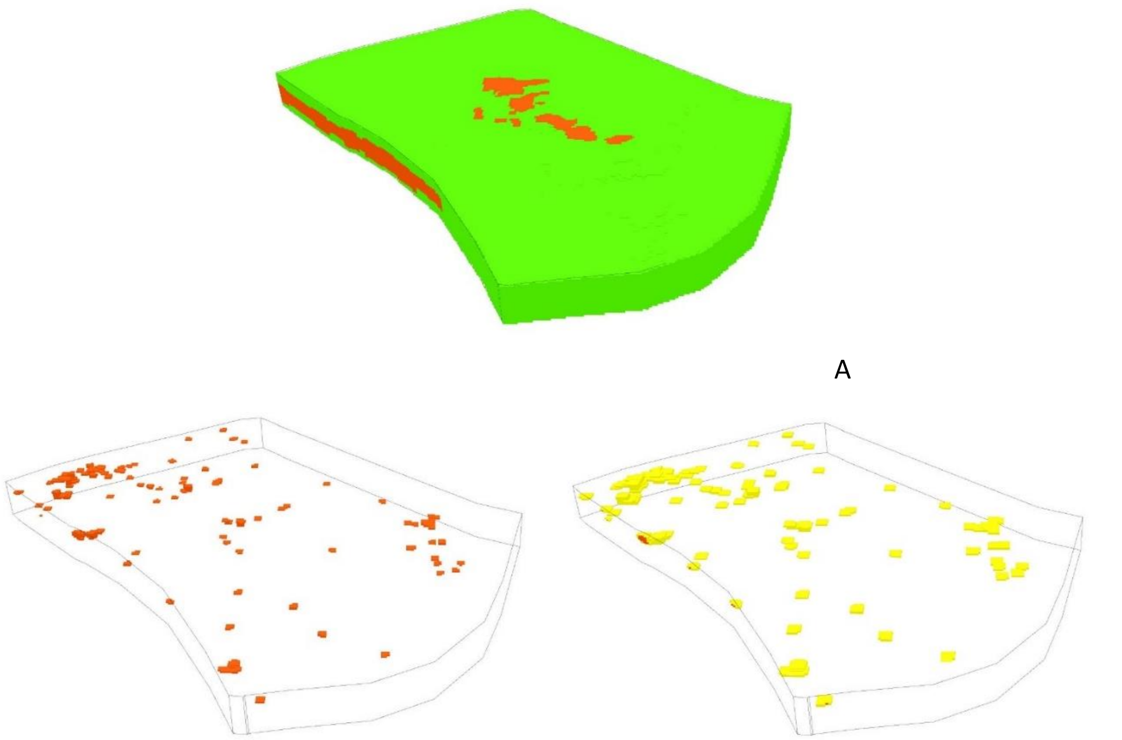


Fig. 3. Theoretical section of potential/suitable usages in the Battonya High territory.

The demonstrated scenario of the model contains a group of concrete and current usages. These are 3D blocks of mining activities of oil and gas, geothermal, or wells of drinking/thermal water. Further restrictive criteria can be taken into consideration in the future, such as protected areas (e.g. Natura 2000), geoparks, densely populated cities, military establishments, etc. The used criteria in this scenario are the followings.

- CH concession blocks (outside green, inside red)
- Geothermal concession blocks (outside green, inside red)
- Screened interval in a well (red, and around yellow)



A

B C

Fig.4. Criteria of several types of usages in the geospace of the Battonya High territory. A: hydrocarbon concession blocks, B: thermal water wells and screened intervals, C: thermal water wells with protection area around.

In case of merging the two types of model elements, the final distribution of the coloured space bodies will be formed: red bodies with yellow rims within green spaces.

C/ Colouring of the model

We defined criteria at first (see above). All criteria divide the geospace into two parts, a potential/suitable or not used (green) and a non-potential/non-suitable or used/occupied (red) part. For instance (Fig.2), space above a thermal isotherm is non-suitable (red), below it is suitable (green). We coloured our model criteria by criteria to red and green, then we combined all the criteria. The result of the combination with the final colour: if red meets red, it is red, if green meets green, it is green, if red meets green, it is red.

In addition, we decided to make visible the information on the number of criteria that finally results a red area. In this case and scenario presented above, we need three () shades of red colour. If only one criterion makes it red, the final colouring will be light pink. If two criteria make kit red, the final colouring will be medium red. If three criteria make it red, the final colouring is dark red.

The yellow colour is interpreted as a transition space between the suitable and non-suitable geospaces. The user should define it in case of criteria that are worth making transitions, i.e. screened intervals of wells, geological surfaces. But it should not be applied for very definite blocks or area for instance the border of a concession area. We applied one voxel yellow space around screened intervals, which means 500 m horizontally, 50 m vertically.

The colouring in this case will: if yellow meets whatever red, makes red. If yellow meets green, it will be yellow.

The final result of the coloured model for this hydrocarbon versus thermal water usage scenario is shown on the Fig.5.

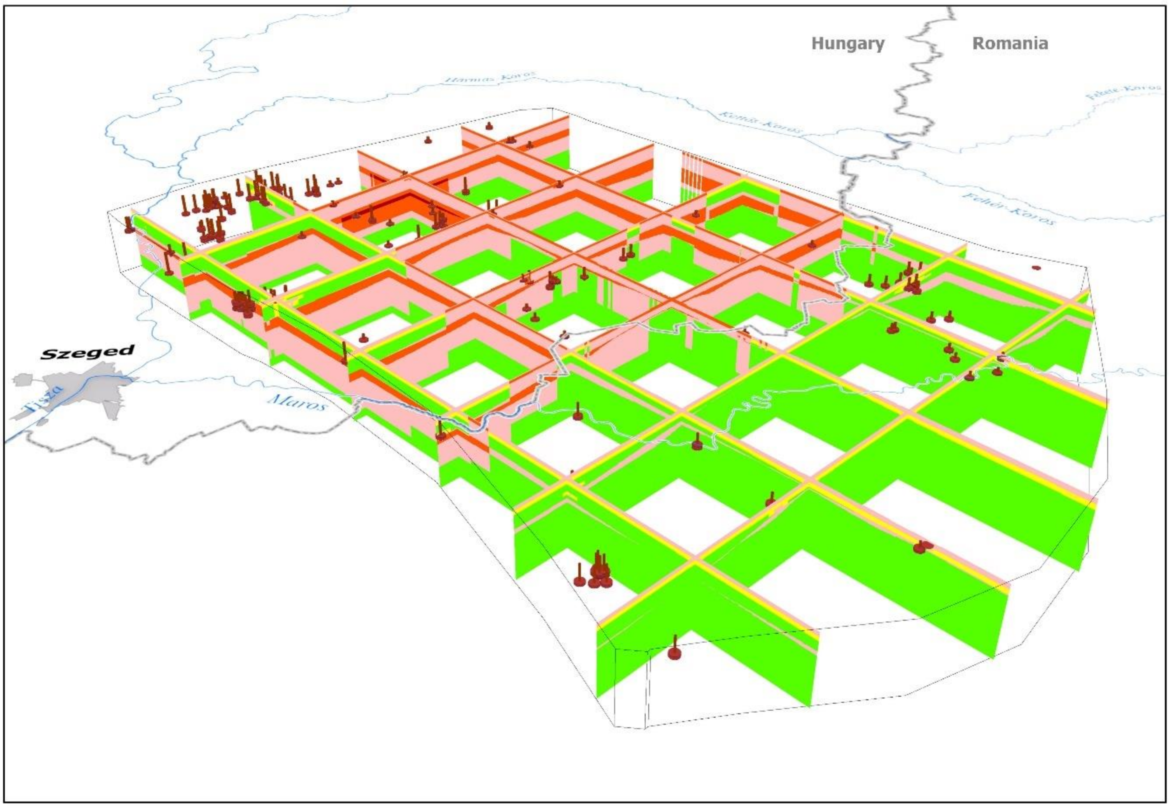


Fig.5.Coloured geospace of the TLM in the Battonya High territoty for the HC vs. thermal water scenario

D/ 3D specifications of the 3D TLM model

Software used

ArcGIS ArcMap (10.5.1)
ArcGIS Pro (2.7.0)
GRASS GIS (7.8.3)

Basic preferences for GIS process

Coordinate reference system:
ETRS89_ETRS_LCC
EPSG:3034
Unit: meter
Voxel/3D raster extent/region:
north: 2306302

south:	2198802
west:	4745873
east:	4858873
top:	200
bottom:	-8000
north – south resolution:	500
east – west resolution:	500
top – bottom resolution:	50
rows:	215
columns:	226
depths:	164
cells 2D:	48590
cells 3D:	7968760

Preparation of subsurface grids
Input layers/datasets:
- Battonya_Base_20210318.dat
- Battonya_Base_slope_20210318.dat
- Battonya_Top_slope_20210318.dat
- Battonya_Rift_climax_20210318.dat
- Battonya_Rift_initiation_20210318.dat

Following operations were implemented on the subsurface grids exported from JewelSuite:
- setting coordinate reference system
- resampling for the resolution required
- clipping into the same extent and masking for the project area
- changing grid values into integer type by rounding
- checking and repairing altitude (z coordinate) topology errors
- exporting to geotiff format for continue processing by GRASS GIS.

Production of voxels in GRASS GIS
Geotiff rasters created at the preparation process discussed above were imported into a mapset (set of data layers) in GRASS GIS.
5 voxel models were interpolated from the series of subsurface and resource grids by the ***r.vol.dem*** tool filling the voxel space in between them.
Raw voxels were combined by two different methods for joint assessment:
- composite coding version: creating a voxel with only 1 five-digit variable by GRASS GIS 3D map calculator tool
- multivariable voxel version: merging the 5 voxels into one with 5 different variables

Output GRASS GIS 3D rasters were converted into the common netCDF format for easier handling:
multiCode.nc

- variable *multiCode@trafficLight*: 5-digit code elements are the following

geological surface [1,2,3,4,5,6]	hydrocarbons mining [0,2]	geothermal mining [0,2]	heat (30/50°C isotherm) [0,1,2]	thermal well [0,1,2]

geological surface
- 1: Base
- 2: Rift initiation
- 3: Rift climax
- 4: Base slope
- 5: Top slope
- 6: Surface

hydrocarbons mining
- 0: reserved
- 2: free

geothermal mining
- 0: reserved
- 2: free

isotherm 30-50 °C
- 0: free under the heat level of 50 °C
- 1: conditionally free between heat level 30 °C and 50 °C
- 2: reserved over heat level 30 °C

thermal well
- 0: free
- 1: conditionally free at the buffer area of filtered section
- 2: reserved filtered sections of wells

multiVar.nc
- variable *geologicalSurface@trafficLight*: [1,2,3,4,5,6]
- variable *miningHydrocarbon@trafficLight*: [0,2]
- variable *miningGeoterm@trafficLight*: [0,2]
- variable *isotherm30v50@trafficLight*: [0,1,2]
- variable *thermalWell@trafficLight*: [0,1,2]

NetCDF voxel files can be displayed and analyzed (creating sections and slices) by ArcGIS Pro using the Add Multidimensional Voxel Layer dialog box.

3. 2D TLM model of the Zala-Mura Basin

The Mura-Zala Basin area was evaluated in Slovenia, Croatia, and Hungary in a plain view (Fig. 66). The main target reservoir here is a regional and transboundary geothermal aquifer in the Upper Pannonian sandy formations, named also transboundary thermal groundwater body (TTGWB) Mura-Zala. It is most often tapped between depths of 500 to 2000 m and interpretation was done with it in the focus.

However, three other geopotentials are also used here. Drinking water reservoirs are much shallower, usually tapped in Quaternary sediments between few tens to 200 m deep. They do not actively hydraulically interact with geothermal reservoirs as there is a few-hundred meters thick sequence of sandy and clayey materials between them. Still, if waste thermal water would be emitted to infiltrate into their catchment areas, close to the narrowest water protection zone, there could have been some effects on the quality of drinking water.

Then, local geothermal aquifers exist also below TTGWB, in deeper and older Miocene formations or in pre-Neogene carbonate rocks in the basement. These are geologically mostly separated reservoirs. In between, hydrocarbon reservoirs are tapped in thinner and less productive (for water) older Miocene formations in all three countries at depths of several kilometres. At several sites thermal water and hydrocarbon production wells are quite close-by, even though they tap hydraulically separated reservoirs with few-hundred meters sequence of low permeable marlstones and siltstones in between.

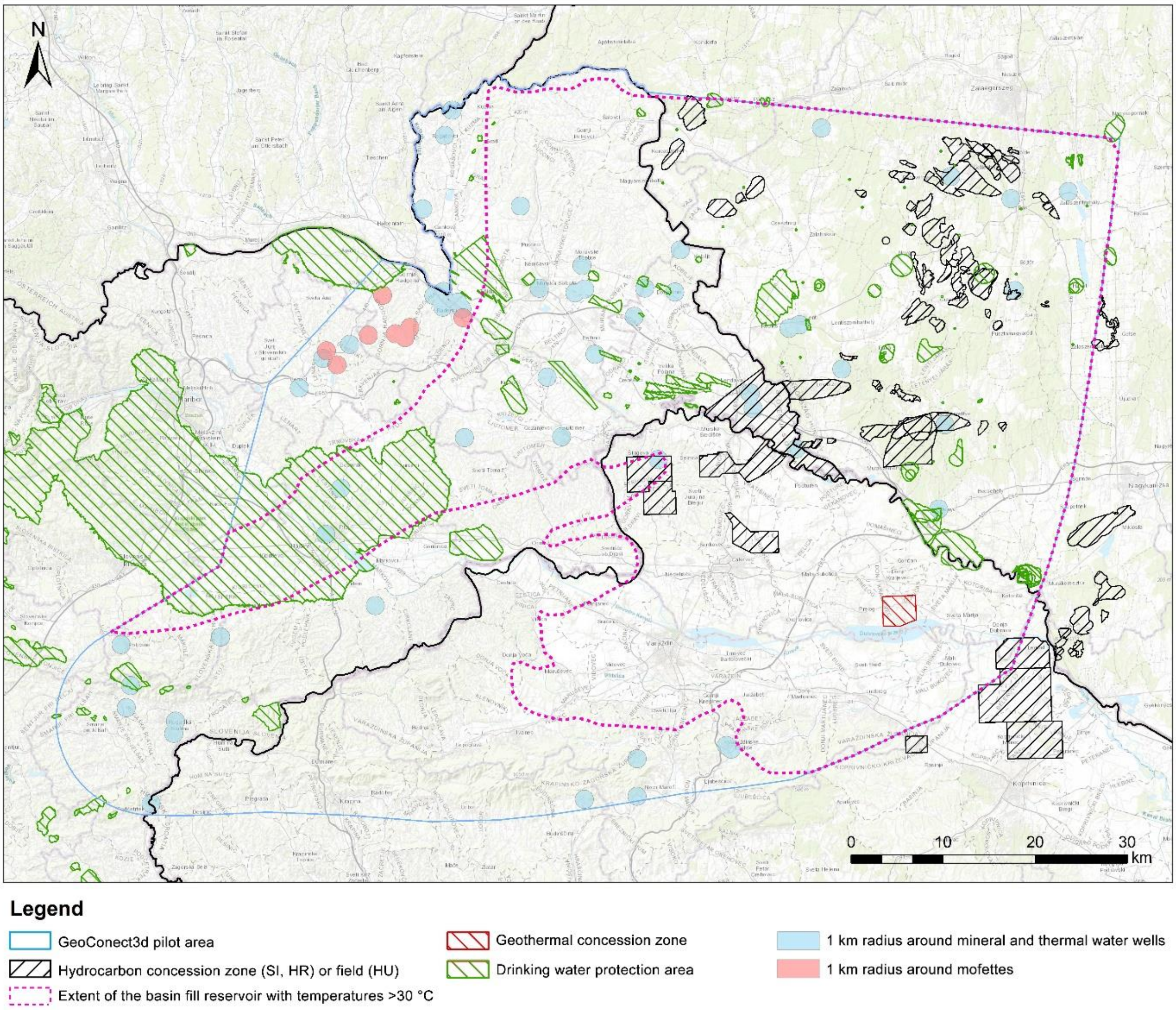


Fig. 6: Extent of identified reservoirs and uses in the Mura-Zala Basin pilot area

A/ Criteria of potentials coming from the geology of the area

The colouring of the potentials is done so that the existing geothermal potential of the transboundary thermal groundwater body (TTGWB) Mura-Zala (violet dashed line in Fig. 66) is marked with green and no potential (or where only local geothermal aquifers exist) with red. Yellow is used only at the drinking water protection areas (as the use of space might be subjected to stricter regulations as otherwhere). The geological and hydrogeologic criteria used is the followings.

Green: The area of the basin fill sediments which compose the transboundary thermal groundwater body (TTGWB) Mura-Zala and have more than 30 °C (delineation is taken from DRGIP portal https://www.darlinge.eu/mapviewer/index.html). All other area, even if sediments do exist, are coloured in red.

B/ Criteria of geospace usages of the area

Another group of the model parameters are the bodies of usages. We applied selected radiuses from mineral and thermal water wells and mofettes, surfaces from concession areas of oil and gas reservoirs and geothermal concession areas, and of water protection areas (their full extent, not differentiating among the zones). The used criteria in this scenario are the following (Fig. 7):

- CH concession blocks (inside red)
- Geothermal concession blocks (inside red)
- 1 km radius around a mineral or thermal water well and a mofette (inside red)
- water protection area (inside yellow).

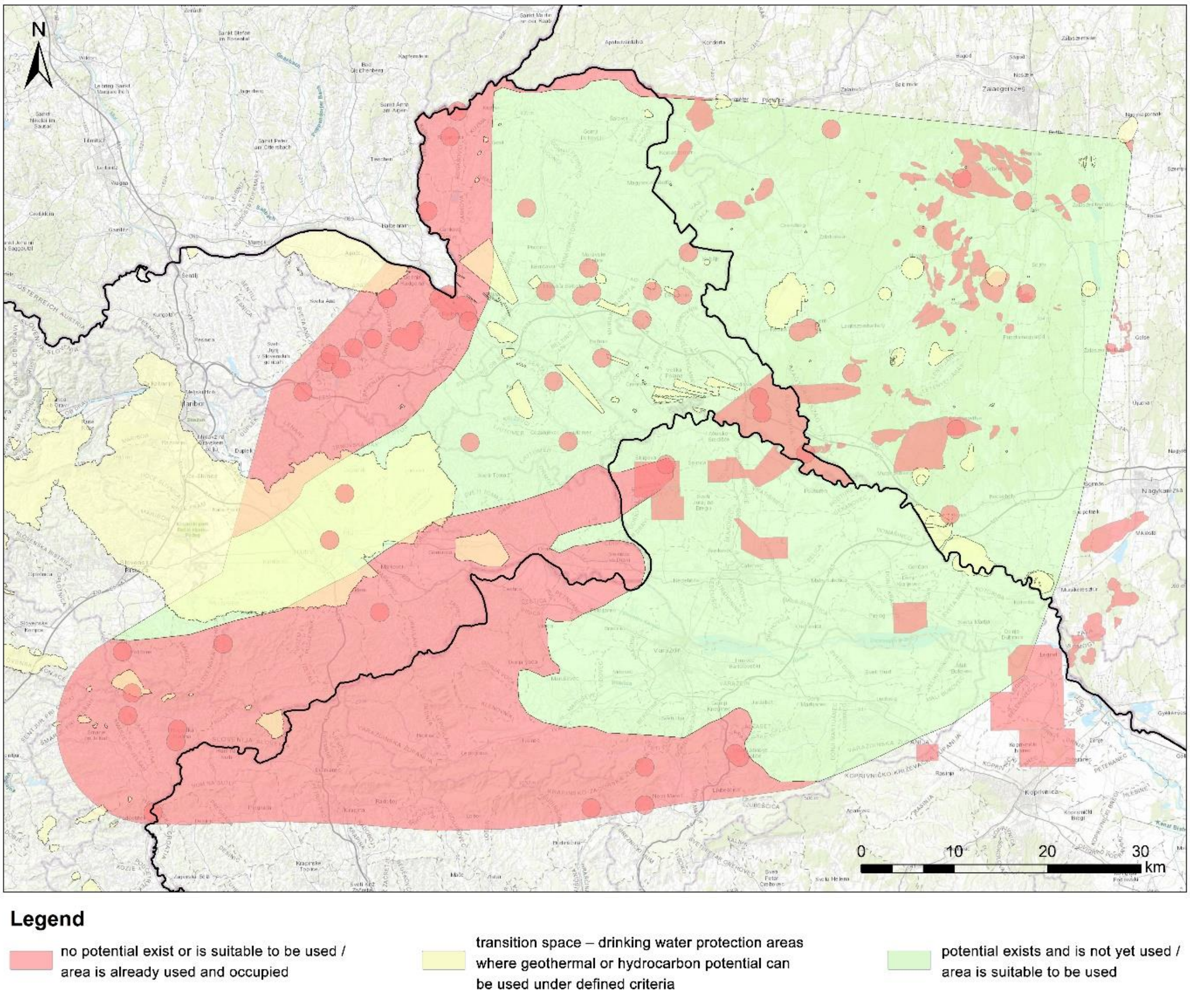


Fig. 7: Geospace usage in the Mura-Zala Basin pilot area with less strict classification where the water protection areas are not taken as classifying space as not-suitable for geothermal use

C/ Colouring of the model

The criteria divided geospace into two parts, i) a potentially suitable and not yet used areas (green) and ii) areas without potential or not suitable or already used/occupied (red). After this colouring we combined all criteria. The colour combination gives final two colours: only green stays green and if any other overlapping is noticed then three shades of red colour are used (one red is light pink, two are red and three are dark red).

The yellow colour is not interpreted the same way as for Hungary, as a geological transition space, but here it stands for the water protection area where restrictions on land use may apply. So, two approaches can be:

i) Yellow stays yellow as in Fig. 7 and it is clear that this area is not strictly forbidden for development or

ii) Yellows is coloured in red (Fig.8) and the area is taken as where spatial restrictions apply.

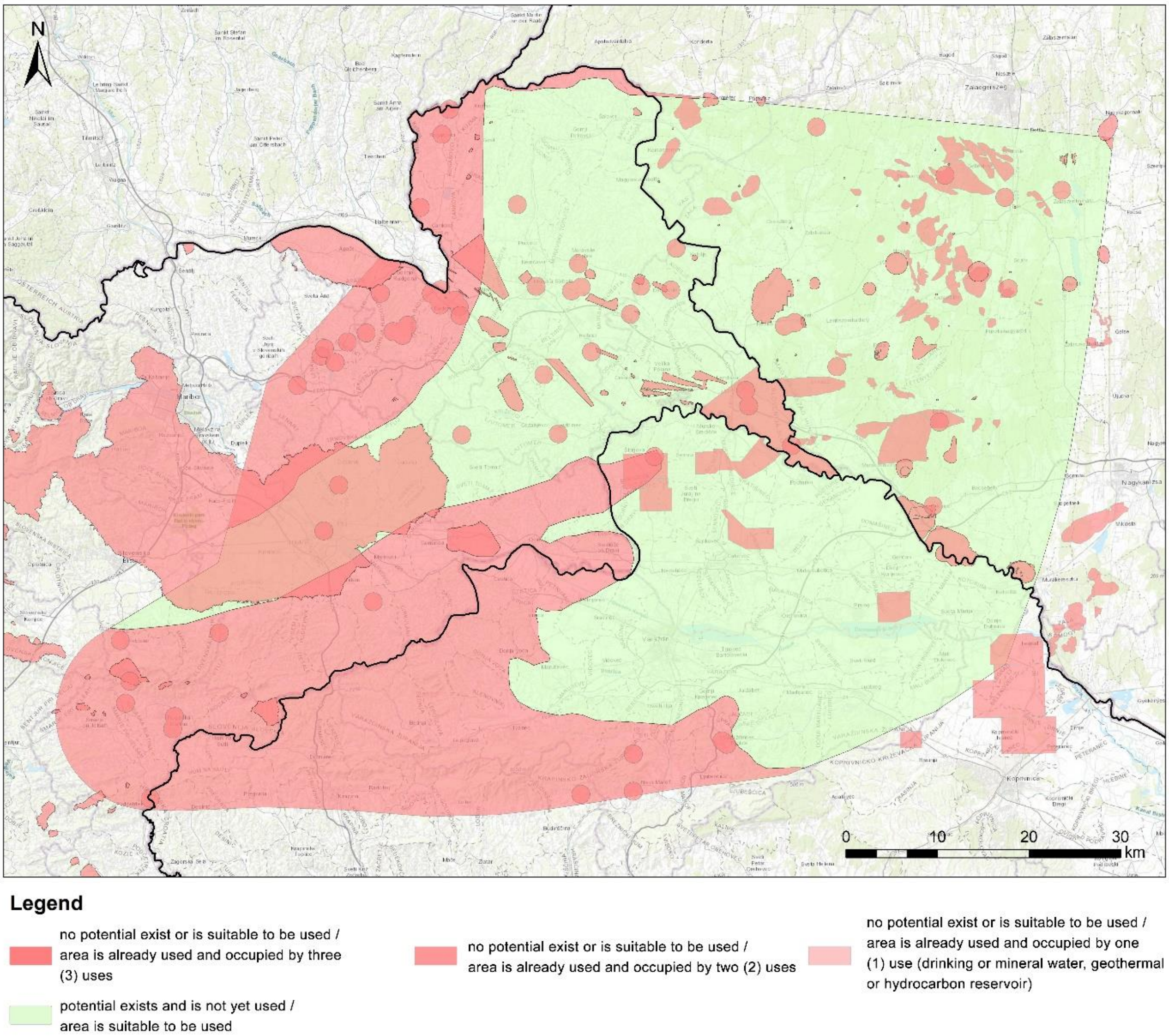


Fig.8: Geospace usage in the Mura-Zala Basin pilot area with more strict classification where the water protection areas classify space as not-suitable for geothermal use in the whole protected catchment area

D/ Data specification

The list of used information is the following:

- extent of the basin fill sediments which compose the transboundary thermal groundwater body (TTGWB) Mura-Zala and have more than 30 °C: delineation is taken from DRGIP portal https://www.darlinge.eu/mapviewer/index.html
- mineral waters and mofettes: point data taken from NOVAK et al. (2016) and as used for geomanifestation report
- thermal waters: point data taken from RMAN et al. (2020 and as used for geomanifestation report
- geothermal concession zone: provided by the Croatian Agency for hydrocarbons (Agencija za ugljikovodike),
- hydrocarbon concession zones: provided by the Croatian agency for hydrocarbons (Agencija za ugljikovodike) and taken from the map of concession areas in Slovenia in 2019 in 1 : 500 000 (https://www.geo-zs.si/PDF/PeriodicnePublikacije/Karta_koncesije_2019.pdf), plus in Hungary rom KOVÁCS (ed) (2018)
- drinking water protection areas: provided by Croatian agency for waters (Hrvatske vode), and taken from Slovenian portal Atlas Okolja (http://gis.arso.gov.si/atlasokolja/profile.aspx?id=Atlas_Okolja_AXL@Arso), and from vizeink.hu (Hungary)

E/ Evaluation of the model for the Mura-Zala Basin

Applying this approach, we have found some benefits, but also uncertainty issues. The approach enables fast regional impression on where future development of geothermal potential is possible and where areas of overlapping subsurface uses (may) occur, or there is no large regional potential, so it is very suitable for regional planning. However, when analysing such areas of multiple use, there is not sufficient level of details given in 3D space at the moment to differentiate whether this is a real issue (as resources also geologically overlap) or just a „plain view" issue (as resources are totally separated by thick geological layers and cannot interfere) and overlapping of red colours is misleading. However, this can very rarely be interpreted without more geological knowledge, so this traffic light still can serve as a first indicator of possible issues which then have to be investigated locally in more details. For the area of the Mura-Zala basin, the approach points out that there is still huge geothermal potential undeveloped as more than half of the pilot area is marked in green colour.

Regarding the geology there are some issues on accuracy of delineation of the observed reservoirs. For example, only extend of the Upper Pannonian basin fill – transboundary geothermal aquifer Mura-Zala is well defined in 3D as it was investigated in details by many previous projects, e.g. T-JAM, TRANSENERGY, DARLINGe, where data is also published on portals. All other local aquifers or the ones in the pre-Neogene (carbonate) basement rocks are not so well defined in space, so they could not be shown and coloured. The discrepancy is evident in the SW and S part of the pilot area, in Croatia and Slovenia, both, as the whole area is marked in red as being without potential, but at the same time production wells and their radiuses are also coloured. So here the model is not very accurate. The second issue is the extent of hydrocarbon or geothermal reservoirs/fields is a geological structure which are not always overlapping with the management delineation of an official concession zone. This is evident from comparing such areas between Slovenia and Croatia (given are concession zones), and Hungary (where fields extent is reported). However, only this information was available to us at this moment.

Regarding the point datasets (wells), we used the whole set of point well data from the geomanifestation list. But this included also sites where either wells do not exist anymore (e.g. deepest Slovenian well in Ljutomer) or are not exploited (e.g. mofettes and thermal wells without concessions), so some of „red” coloured space is actually not „already used” in reality.

Moreover, there can be a debate on the importance of accounting for the drinking water protection areas when evaluating conflicts of use affecting geothermal. At the moment, we are fonder of the approach where the water protection area is coloured in yellow and not in red. The reasons are that: I) the drinking and thermal water aquifers usually do not interfere hydraulically (very rarely they actually do as in the case of the transboundary carbonate aquifer between Slovenia and Croatia in SW part of the pilot area) so the effect on quantity is not really expected, ii) such areas usually set special land use requirements which in the narrowest protection zone can even forbid drilling of geothermal wells, iii) geothermal use can affect drinking water resources mostly in case that more mineralized and warm waste thermal water is infiltrated in the shallow aquifer, potentially affecting the quality of drinking water. So, the yellow colour would point out that there is something to be checked prior to development of geothermal site in that area but it is not forbidding or seriously limiting the development.

4. References

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