GeoERA

Establishing the European Geological Surveys Research Area to deliver a Geological Service for Europe

Technical review report for project GeoConnect^{3}d

This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 731166.

INTRODUCTION

Technical review report is part of GeoERA's Monitoring and evaluation process for co-funded projects (*hereinafter: project*). The aim of a technical review is to assess the work carried out under the project over a certain period and provide recommendations. Such technical review evaluates the project reports and deliverables, the proper use of resources, the management of the project and the expected impact.

Technical review report consists of four sections, each representing one level of monitoring and/or evaluation of the project:

Level	Monitor / Reviewer	Input	Aim
1 – Monitoring of progress indicators	Monitoring and reporting officer (GeoZS)	MPPR* FPPR**	Monitoring of the effectiveness of implementation of selected projects with respect to finance, time and administration.
2 – Scientific review	Reviewers (GeoZS)	Submitted deliverables MPPR FPPR	Quality review of the deliverables and review of achieving scientific and professional goals.
3 – Review of the theme progress	Theme coordinators	MPPR FPPR	Review of achieving theme objectives.
4 – GeoERA Progress evaluation	Stakeholder Council member(s)	Sections 1 and 2 of this report Review meetings	Overall project progress and general recommendations.

*MPPR = Midterm Project Progress Report (see PI doc no 2)
**FPPR = Final Project Progress Report (see PI doc no 2)

Monitoring and evaluation process:

M0 = End of reporting period
M1 = Submitted (Final) Project progress Report (MPPR / FPPR)
M2 = 1 – Monitoring & 2 – Evaluation
M3 = 3 – Evaluation of the theme progress
M3 = (Final) Review Meeting & 4 – Progress evaluation

Each project will be reviewed twice: for first project period M1-M18 – Technical review report, and second project period M19-M36 – Final review report.
Technical review report is based on Horizon 2020 templates but adopted to GeoERA needs. Technical reviews of projects shall be carried out on a confidential basis.

GENERAL INFORMATION

ERA-NET Cofund Grant Agreement:	731166
ERA-NET Cofund acronym:	GeoERA
Call identifier:	H2020-LCE-2016-2017/H2020-LCE-2016-ERA
Project full title:	Cross-border, cross-thematic multiscale framework for combining geological models and data for resource appraisal and policy support
Project acronym:	GeoConnect^{3}d
Project reference number:	GeoE.171.009
Project topic:	GeoEnergy
Project specific topic:	GE6-Enabling subsurface management and decision support
Lead partner:	RBINS-GSB – Institut Royal des Sciences Naturelles de Belgique (Geological Survey of Belgium – Royal Belgian Institute of Natural Sciences)
Project website:	http://geoera.eu/projects/geoconnect3d6/

☐ Technical review report
☒ Final review report

Period covered	01/01/2020 – 31/10/2021
Review meeting date	02.12.2021, start at 13:30

Contributor:	Role:	Approved on:
Barbara Simić	Monitoring and reporting officer	2.12.2021
Aleksandra Trenchovska	Monitoring and reporting officer	3.12.2021
Matevž Novak	Scientific reviewer	3.12.2021
Tina Peternel	Scientific reviewer	8.12.2021
Jasna Šinigoj	Scientific reviewer	3.12.2021
Matija Krivic	Scientific reviewer	3.12.2021
Serge van Gessel	Theme coordinator	24.12.2021
Glen Burridge	GeoERA Stakeholder	31.12.2021
Harikrishnan Tulsidas	GeoERA Stakeholder	26.01.2022

1 LEVEL 1 – MONITORING OF PROGRESS INDICATORS

In this section the project is monitored "remotely" on the basis of the respective reports. This part is filled in by Monitoring and reporting officer with aim to monitor the effectiveness of implementation of the selected projects with respect to finance, time and administration, based on submited MPPR and FPPR.

	Yes	Partially (comment needed)	No
PROJECT MANAGEMENT			
Has the MPPR / FPPR report been submitted on time?	☒	See comment no. 1	☐
Have there been any changes in project partnership?	☒		☐
Has the project management been performed as required?	☒		☐
Has the collaboration between partners been effective?	☒		☐
Do you identify evidence of underperforming partners, lack of commitment or change of interest of any partners?	☒ (see comment)	See comment no. 2	☐
DELIVERABLES and MILESTONES			
Have the planned deliverables for the period been submitted on time according to timeline in Project Agreement?	☐	See comment no. 3	☒
Have the planned deliverables for the period been completed (from MPPR / FPPR, sheet 4)	☒		☐
Have any changes to deliverables occurred (type/ dissemination level)? (from MPPR / FPPR, sheet 4 and 5)	☒		☐
Have planned milestones been achieved for the reporting period? (from MPPR / FPPR, sheet 4)	☒		☐
Have the project partnership identify any difficulties achieving any of the deliverables / milestones?	☒		☐
DEVIATIONS (from MPPR / FPPR, sheet 5)			
Has the project partnership identify any deviations that will not affect projects outputs?	☒		☐
Have any deviations occur on the project, with impact on project outputs?	☐		☒
In case of deviations, have the project adopted corrective measures?	☒		☐
DISSEMINATION, COMMUNICATION			
Has the project adopted its dissemination plan?	☒		☐

Have the planned dissemination activities been completed for the reporting period? (from MPPR / FPPR, sheet 6)	☒		☐
Have the partners' disseminated project results and information adequately?	☒		☐
Is the project following dissemination plan?	☒		☐
Is the project interacting in a satisfactory manner with other GeoERA projects?	☒		☐
Is the project interacting in a satisfactory manner with national/international bodies?	☒		☐

FINANCE			
To the best of your estimate, have the resources used been utilised for achieving the project? (according to MPPR / FPPR, sheet 9)	☒		☐
To the best of your estimate, have the resources used been in a manner consisted with the principle of economy, efficiency and effectiveness?*	☒		☐
Are there any major deviations in the budget consumptions from the financial plan? (zero consumption in M18; deviation from plan exceeding 20% in M36)	☒	See comment no. 4	☐
Are there any major deviations in the Person - Months consumptions from the plan? (zero consumption in M18; deviation from plan exceeding 20% in M36)	☒		☐
Are any budget modifications for the project needed? (from MPPR / FPPR, sheet 5)	☐		☒

***The principles of economy, efficiency and effectiveness**: refers to the standard of "good housekeeping" in spending public money effectively. Economy can be understood as minimising the costs of resources used for an activity (input), having regard to the appropriate quality and can be linked to efficiency, which is the relationship between the outputs and the resources used to produce them. Effectiveness is concerned with measuring the extent to which the objectives have been achieved and the relationship between the intended impact and the actual impact of an activity. Cost effectiveness means the relationship between project costs and outcomes, expressed as costs per unit of outcome achieved.

Comments (highlighting the project progress) / deviations / recommendations:

The GeoConnect^{3}d project set objectives through which the project consortium developed a methodology for a more useful and understandable representation of geological information for policy support and subsurface management, tested the methodology on 4 case studies, and on this basis proposed general recommendations and improved methods for decision making in subsurface planning and management. This innovative bottom-up approach introduced two concepts: *a structural framework* as a means of linking existing models of different scale and resolution to clarify the meaning of geological surfaces such as faults, contacts, lineaments, unconformities, etc. in a way that makes geology understandable to stakeholders involved in subsurface management; and *geomanifestations*, both important sources of information for better geological understanding. Through work in pilot areas, the project consortium has demonstrated that its approach enables the integration of complex cross-thematic research and is useful for cross-border harmonization. The novel elements of geomanifestations and the use of semantic relationships facilitate the communication of subsurface geological features. The GeoConnect^{3}d methodology has been successful in capturing, harmonizing and disseminating geological knowledge to a wide range of stakeholders. The communication and dissemination activities of the Project lead are a good example of this. What sets this project apart from others is the effort they have put into social media to bring the project closer to the non-geological community and reach people outside Europe. Through these efforts, the project has maximized its impact in different areas, in society, in science and policy. To ensure that the project results are not kept under wraps, the partners are passing on the knowledge gained to students and ensuring that it is put into practice alongside other planned EU-funded projects.

The Covid 19 epidemic had an impact on the progress of the GeoConnect^{3}d project. In December 2020, the project was extended by 4 months, from 30.6.2021 until 31.10.2021. The postponed project activities were appropriately communicated to the GeoERA Executive board, which has reviewed and approved the changes in terms of achieving the project outcomes. A detailed list of changes is part of the project documentation in the Project plan History of changes.

The project management structure was well defined at the beginning and was efficient throughout implementation. The pandemic situation required a high degree of flexibility of the partnership and adaptability of its involvement in the project activities. To ensure the achievement of the set objectives, partners increased their efforts, resulting in higher person-months and budget expenditures. Overall, the project consortia spent ~10% more budget than planned.

A detailed and targeted communication and dissemination plan was adopted and a description of the activities with timetable was provided. The project's communication and dissemination activities followed the plan and in the end the

partnership exceeded the set objectives. The project consortia also cooperated well with other GeoERA projects, especially HIKE, VoGERA, GARAH, MUSE, 3DGEO-EU and GIP -P. The way the project used modern social media and disseminated its results is a good case scenario.

Comment no. 1: The Final Project Progress Report was submitted on time in draft form. Partners still have the opportunity to recalculate their financials by the end of the calendar year to include the final data, so minor variations can be expected. The changes will not affect the content of the project.

Comment no. 2: During the implementation of the project, the partner GEOINFORM State Research and Development Enterprise State Information Geological Fund of Ukraine finished its activities and did not participate in the second period. The partner SGL has not been responsive as it should. Project Lead partner found a way to work without these two partners so that the project results were not affected.

Comment no. 3: Due to the pandemic situation, some activities were delayed, and deliverables had to be submitted later than planned. The revised dates were communicated the Monitoring team and the GeoERA Secretariat by amending the project plan.

The deliverable changes in the project implementation period are:

Reporting period 1:
D1.4 postponed from M17 (30.11.2019) → M19 (31.1.2020)

Reporting period 2:
D2.4 postponed from M24 (30.6.2020) → M27 (30.9.2020)
D4.1 postponed from M24 (30.6.2021) → M29 (30.11.2020)
D4.4 postponed from M28 (31.10.2020) → M31 (31.1.2021)
D4.2 postponed from M30 (31.12.2020) → M33 (31.3.2021)
D5.2a postponed from M30 (31.12.2020) → M34 (30.4.2021)
D5.2b postponed from M30 (31.12.2020) → M35 (31.5.2021)
D5.2c postponed from M30 (31.12.2020) → M36 (30.6.2021)
D5.2d postponed from M30 (31.12.2020) → M37 (31.7.2021)
D3.1 postponed from M31 (30.1.2021) → M35 (31.5.2021)
D4.3 postponed from M31 (30.1.2021) → M35 (31.5.2021)
D3.2 postponed from M32 (28.2.2021) → M36 (30.6.2021)
D4.5b postponed from M34 (30.4.2021) → M38 (31.8.2021)
D1.1 postponed from M36 (30.6.2021) → M40 (31.10.2021)
D1.2v postponed from M36 (30.6.2021) → M40 (31.10.2021)
D1.5 postponed from M36 (30.6.2021) → M40 (31.10.2021)
D2.1 postponed from M36 (30.6.2021) → M40 (31.10.2021)
D3.3 postponed from M36 (30.6.2021) → M40 (31.10.2021)

D4.5a postponed from M36 (30.6.2021) → M40 (31.10.2021)
D5.3 postponed from M36 (30.6.2021) → M40 (31.10.2021)

The Deliverable D3.1 was originally foreseen as a publication of the R2R structural framework and geomanifestations model. Due to the inevitable delays due to COVID-19 pandemic, the results necessary for the development of this deliverable were fully achieved late in the project's timeline, leaving a period too limited to produce and submit the high-quality publication aspired. On the other hand, early in the project WP3 partner RBINS-GSB has dedicated special focus to geomanifestations in the form of CO2-rich groundwater springs in the AOI. This has led to a collaboration with external partners, namely the University of Liège and Spadel (private company), and the publication of a review and reassessment of available data, as well as ways forward to a model that considers subsurface interactions and the role of faults (limits in the structural framework).

Comment no. 4: Some project partners spent 20% more than their planned budget, others spent less than 80%. The partners that have exceeded their budget are BGR, GSI, MBFSZ and RBINS-GSB. Partners that spent less than their planned budget are: GSS and SGL. The consumption of man-months followed the EUR consumption.

The project has coped well with the negative external factors and has overcome its challenges in such a way that it has achieved its planned objectives and project results. For this reason, the project is rated "excellent" at level 1 and thus receives a rating of 4 - Objectives and targets fully achieved.

Overall assessment of the project:

☐ 5 - **Overachiever** (the project has achieved all objectives and goals for the period and has even exceeded expectations)
☒ 4 - **Excellent progress** (the project has fully achieved its objectives and goals for the period)
☐ 3 - **Good progress** (the project has achieved most of its objectives and goals for the period with relatively minor deviations)
☐ 2 - **Acceptable progress** (the project has achieved some of its objectives)
☐ 1 - **Unsatisfactory progress** (the project has failed to achieve critical objectives)

Summary of dissemination activities:

	SCIENTIFIC COMMUNITY	GENERAL PUBLIC	POLICY MAKERS	EUROPEAN INSTITUTION	NATIONAL INSTITUTION	REGIONAL INSTITUTION	INTERNATIONAL INSTITUTION	LOCAL INSTITUTION	PRIVATE COMPANIES	OTHER	Total number of people reach
EVENTS	20	706	25	7	290	13		4	45	172	1282
MEETINGS	122										122
ONLINE_MEDIA	1048	277719	35	10	44	10	10	10	41		278927
PUBLICATIONS	5026		5		55				10	2051	7147
Total	**6216**	**278425**	**65**	**17**	**389**	**23**	**10**	**14**	**96**	**2223**	**287478**

	ABSTRACTS	BLOG	FACEBOOK	INTERNAL PROJECT MEETING	LINKEDIN	MEETING WITH OTHER GEOERA PROJECTS	ORAL PRESENTATION	OTHER	POSTER	RESEARCHGATE	SCIENTIFIC PUBLICATION	TWITER	WEBINAR	WEBSITE	WORKSHOP	YOUTUBE	Total
EVENTS													9		2		11
MEETINGS				7		3		1									11
ONLINE_MEDIA		94	450		300					1		490		1		3	1339
PUBLICATIONS	11						10	1	7		3						32
Total	11	94	450	7	300	3	10	2	7	1	3	490	9	1	2	3	1393

Are the dissemination activities adequate?

☒ 5 - **Overachieved** (the projects dissemination activities have exceeded expectations)
☐ 4 - **Excellent** (the projects dissemination activities have fully achieved its expectations)
☐ 3 - **Good** (the projects dissemination activities are adequate)
☐ 2 - **Acceptable** (the projects dissemination activities are acceptable)
☐ 1 - **Unsatisfactory** (the project has failed to disseminate)

Cummulative financial statement:

	Person months	Total eligible costs	Reimbursement rate	GeoERA contribution	In-kind contribution
Plan	**332,87**	**1.815.958,19**	**29,7 %**	**539.339,59**	**1.276.618,60**
1st period consumption	160,79	808.379,51	29,7 %	240.088,72	568.290,80
2nd period consumption	238,63	1.196.589,60	29,7 %	355.387,11	841.202,49
TOTAL	**399,42**	**2.004.969,11**	**29,7 %**	**595.475,83**	**1.409.493,29**

Non-funded partner NRW is deducted from consumpt budget.

2 LEVEL 2 – SCIENTIFIC REVIEW

In this section the project is reviewed ”remotely” on the basis of the respective reports. This part is filled in by reviewer with aim to review the quality of the deliverables and review of achieving scientific and professional goals. Scientific review is based on submitted deliverables and reported Impact statement in MPPR/FPPR.

Impact statement (from MPPR / FPPR, sheet 8):

GeoConnect³d had the ambition to generate impact by 1) setting new standards for integrating cross-border and cross-thematic geological information, 2) providing a backbone to assess conflicts and synergies between subsurface uses through an approach that integrates data and knowledge from different geological disciplines, and 3) making it easier for the European GSOs to provide input to policy, allowing for the proper uptake of geological information in future societal planning. We believe the structural framework-geomanifestations methodology was successful to meet these goals.

Having the methodology developed and tested by multiple partners in different countries and, therefore, geological settings, resulted in a robust workflow to gather and integrate geological information that can easily be followed through guidelines (D2.4) and templates. The methodology is being adopted for the continuation of GeoERA (CSA) since it has been demonstrated to be an efficient way to work cross-borders towards harmonised outputs. The methodology has also been used to teach MSc-level students in Belgium about regional geology, with their results being incorporated to the pan-European and Roer-to-Rhine structural frameworks.

We also demonstrated that the resulting model can improve the ability to predict subsurface potential e.g. thermal anomalies in groundwater and groundwater springs within the structural framework to identify sweet spots of geothermal potential, or geomanifestations of CO2-seeps that provide information on subsurface processes involving CO2 migration and are therefore relevant to improve understanding of storage potential. Moreover, the cross-thematic character of the resulting model facilitates the assessment of potential conflicts and synergies in subsurface uses. Other results of the project such as the multiple use indicator to evaluate geothermal aquifers (D4.5a) and the traffic-light model (D4.5b) are useful tools generated at the end of the project to be promoted beyond its duration.

The scientific impact of GeoConnect³d can be estimated by the frequent presentations in international conferences (21 oral or poster presentations, most accompanied by published abstracts), as well as 2 peer-reviewed publications on the topic of groundwater-related geomanifestations as indicators of complex subsurface processes and interactions. All material is open-access. To reach beyond the scientific community of stakeholders, GeoConnect³d organised 2 interactive online workshops: a mid-term webinar series discussing the subsurface space as a cross-thematic issue (including geoheritage, groundwater and geothermal energy as sub-themes); and a

final workshop as part of the Geoscience, Policy and Society event, to showcase the structural framework-geomanifestations results and its potential applications. These events have reached a total of >250 unique participants summed, attracting the attention of geological surveys, universities/research centers, private sector and governmental institutions.

GeoConnect³d also believed that the key to highlight the importance of geology in policy is to highlight its importance to our society. To this extent, we made science communication as a core task of the project, using different media to reach the most varied possible audience. Especially social media (Twitter, Facebook) and the project blog brought the subjects of the project (geo-energy, subsurface uses and interactions, subsurface management, geodata etc.) in a more accessible language to the general public. These efforts resulted in outstanding outreach and engagement (>1,000 followers on social media, >230,000 blog post reads) and interest in the project. We believe the community we built is a strong legacy that will likely contribute to the interest of the follow-up of GeoERA.

Expected impact (from Project Agreement):

The energy transformation that is intimately linked to the growing awareness of the causes and consequences of climate change has diversified the interest in local geo-resources, including conventional and unconventional oil and gas, gas storage, thermal energy storage and geothermal energy. The fact that these resources share the same or adjacent reservoirs has led to the emergence of subsurface spatial planning as a new topic in applied geosciences. Especially where there are overlapping potential and interests in cross-border areas, a better alignment of national science and policy approaches is needed to come to an acceptable and fair use. It is clear that conflicts arising from the use of geological resources, the non-optimal use of geological resources, or overlooked synergies are issues that need to be avoided. This, however, requires a correct understanding of the potential physical effects or interactions associated with exploitation of geoenergy resources, as well as groundwater and raw materials, where these potentially influence each other. This forms the starting point of GeoConnect³d. GeoConnect³d will, through its two case studies and by developing more general evaluation schemes, act as a demonstration case for pan-European efforts in sharing and harmonizing national and regional data and building cross-border, cross-thematic geological models. The workflow for collecting, harmonizing and disclosing geological data for different applications and at different scales that will be developed within the project, can serve as a backbone for future services for applied geo-sciences in Europe, as well as for the definition and harmonization of regional, national and European policy with respect to geo-resources. What is unique about the approach is the combination of data and knowledge from different geological disciplines. This will lead to new insights in complex geological processes. Trends or processes that appear to be erratic from one perspective can, in many cases, be understood when knowledge from other fields is

taken into account. The same is true when evaluating the impact of subsurface activities, which can be misjudged when complex interactions between several processes are not considered or understood. In addition, the project will provide two large and two smaller pilots that test and optimize concepts and standards for the harmonization, management, visualization and documentation of geo-information identified at the European level. Thereby, the project contributes to the long-term ambition to integrate Europe's information and knowledge on geo-resources to support sustainable use of the subsurface in addressing Europe's societal challenges. 7 Following from above, GeoConnect³d will make substantial progress in the following pan-European challenges: • Methodologies for harmonising and integrating cross-border, cross-thematic geo-information; • Mapping and modelling strategies for resource assessment that allow cross-border, crossthematic consistency; • Methodologies to analyse the impact of resource exploitation using a cross-thematic approach; • Methodologies to analyse the interaction between subsurface activities; • Improved knowledge about complex geomanifestations; • Tools to disclose geo-information to decision makers and other end-users. As GeoConnect³d will bring together geo-research into a common context, it will improve the valorisation of ongoing and past projects on which it relies, facilitating the communication of their results. It adds value to ongoing and past national efforts in optimising the use of the underground. This includes preventing and managing potential competitive uses (e.g. interfering injection projects) and removing obstacles for further development of the subsurface. This will be demonstrated in two larger case studies, and two one-country pilots for testing the transferability of the developed methodology. By putting the method into practice in this way, direct results will be generated for 15 of the 16 countries in a challenging cross-border context (Poland is the only participant without a concrete case or pilot study, but is a leading partner for setting up the generic evaluation in WP5). At the same time, this approach will test and demonstrate the exchange of information and knowledge about geo-resources, thoroughly preparing the cross-border, cross-thematic evaluation methodologies to be scaled up to the European level. Apart from the 16 countries that will have been involved in developing and optimizing these methods (fig. 1), additional GeoERA partners will be asked to review the case studies as these are being developed and implemented. These other GSOs will reflect, using their own background and experience, on how this can foster pan-European implementation. The result will be a large group of European geoscientists that will be familiar with the GeoConnect³d workflow that will be proposed as a new template for postGeoERA projects. The data structure will allow and even facilitate future maintenance and updates, encouraging it to be used in post-project initiatives. GeoConnect³d will focus on understanding geological processes using advanced visual representations based on the annotated structural framework that allows explaining them and translating their relevance and relation to exploitation of geological resources to stakeholders from different backgrounds. This again is an aspect that will pave the way for a more consistent and scientifically based national and European planning of the subsurface.

Evaluation of deliverables

No.	Title	Status (Approve / Reject)	Comments
D1.1	Minutes of virtual (monthly) and physical (annual) meetings of the PMB	Approved	
D1.2b	First and final version of the project Data Management Plan	Approved	
D1.5	Project Final Report	Approved	Level 1 MT
D1.6c	Comulative Expenditure Report 2018,2019,2020	Approved	Level 1 MT
D2.1	Intra- and inter-thematic exchange logbook		
D2.4	Report and publication(s) on the two-step framework- geomanifestation methodology		
D3.1	Scientific publication of the annotated R2R model (submitted)	Approved	
D3.2	Minutes of the workshop on subsurface management and planning	Approved	
D3.3	Report on ways to disclose essential subsurface data and information to different stakeholders	Approved	
D4.1	Horizon and voxel 3D model, 3D fault plane surfaces of the main deformation zones in harmonisation with the stratigraphic model horizons	Approved	
D4.2	A joint report on geomanifestations with their physical, spatial- and temporal (4D) analysis, validation of the 3D structural-geological model of the Pannonian basin based on their identification and evaluation of their relevance for spatial management at pilot areas. Only interpreted data will be included	Approved	
D4.3	A scientific article on geomanifestations in the Pannonian Basin (IF paper, submitted)	Approved	
D4.4	Report on the workshop results	Approved	
D4.5a	Report on the benchmark methodology and the results of indicator calculations and evaluations	Approved	
D4.5b	Applied (traffic-light) model	Approved	
D5.1	State of the art of subsurface planning and management, and avenues for improvement	Approved	

D5.2a	Lessons learnt from Molasse Basin pilot (GeoERA: GE3-HotLime WP6/Task 6.3) - feeding into the HotLime Final Report	Approved	
D5.2b	Lessons learnt from Irish case pilot	Approved	
D5.2c	Lessons learnt from R2R case	Approved	
D5.2d	Lessons learnt from Pannonian Basin case	Approved	
D5.3	Overall conclusions and recommendations	Approved	

Has the quality as a whole been achieved according to the objectives? Has the project as a whole been making satisfactory progress?

☒ 5 - **Overachiever** (the project has achieved all objectives and goals for the period and has even exceeded expectations)

☐ 4 - **Excellent progress** (the project has fully achieved its objectives and goals for the period)

☐ 3 - **Good progress** (the project has achieved most of its objectives and goals for the period with relatively minor deviations)

☐ 2 - **Acceptable progress** (the project has achieved some of its objectives)

☐ 1 - **Unsatisfactory progress** (the project has failed to achieve critical objectives)

Comments (highlighting the project progress) / deviations / recommendations:

The final results of the project are impressive in several respects. All four case study areas have been addressed at a very high scientific level in all phases: from collection to analysis, harmonization and visualization of the data in high quality structural models. The supporting databases are extensive and well organized.

The project stands out in user-oriented presentation of the results. It has managed to overcome the high hurdle that geological data providers face in supporting the stakeholders involved in the subsurface management. The project idea itself, to use the concept of structural frameworks annotaded with the so-called geomanifestations to better understand the high complexity of 3D geological structure and its role in natural processes, is brilliant. And this idea has been very well implemented through the case studies.

The project also reflects a very good interaction with other thematically related GeoERA projects, such as HIKE, HotLime and GIP-P.

The project provided a very good and successful dissemination and exploitation of the project outputs and results. The project partners have communicated through a wide range of different research and social media, which results in reaching different audiences (from researchers to stakeholders and private companies, etc.) very well.

The project also reflects very good findings or starting points for further projects that could be implemented in different EU programmes.

The resulting GeoConnect^{3}d Webmap on the EGDI platform lacks a bit of clarity, but it is supported by a well-written user manual and enriched with a photo inventory of geomanifestations.

Reccommendations:

- At the Midterm Review Meeting, we collectively concluded that a layer, or one of the levels within the traffic light model with restrictions should be included. Natural protection or other restrictions in the interventions on the surface can affect or even prevent access to the subsurface. Such an addition would be of great assistance to decision making and subsurface spatial planning.

3 LEVEL 3 – REVIEW OF THE THEME PROGRESS

In this section the project is reviewed ”remotely” on the basis of the respective reports. This part is filled in by Theme coordinator with aim to review the achieved scientific goals in accordance with theme objectives, on the basis of Sheet 3 in MPPR / FPPR – Project contribution to GeoERA project.

Project contribution to GeoERA project (from MPPR / FPPR, sheet 3):

GeoERA objectives:
1) A more integrated and efficient management of the subsurface, and
2) More responsible and publicly accepted, exploitation and use of the subsurface.

Geo-energy objectives:
1) Establishing state-of-the-art methodologies for harmonised mapping and assessment of potential resources and capacities;
2) Improving the interoperability of geological datasets that underpin such assessments, and
3) Implementing scientific intelligence and information into the policy domain considering relevant cross-thematic links to groundwater and mineral resources.

GeoConnect³d contributions to these objectives:
The central methodology developed in GeoConnect³d is fundamentally different from state-of-the-art approaches in bringing together different types of geological information in a way that is more transparent for a diverse public, including those with limited previous knowledge about geology. The methodology entails a redefinition of the structural framework model and the introduction of geomanifestations, with semantic definitions at its core to facilitate harmonisation and standardisation across borders and themes. Furthermore, developing this methodology was not the final goal of the project. The ambition of GeoConnect³d has been to disseminate these results in order to show its potential to support the management of the subsurface for geo-energy and other uses, and to demonstrate how awareness of the opportunities and limits of the subsurface is critically important by developing several use cases.

The structural framework is therefore a direct answer to the first geo-energy objective. It has already proved successful to beyond the current state-of-the-art, e.g. by being applicable to areas that span contrasting geological units (cf. Roer-to-Rhine case study). It does this by taking an alternative approach to harmonisation by introducing global semantic models, identifying shared limits and units and introducing zoom to allow for different levels of detail, rather than attempting to reach one agreed geological model at one specific scale.

The GeoConnect³d methodology developed can also a useful tool to improve the interoperability of geological information, the second geo-energy objective. The

methodology ensures existing and new information is gathered in a structured way, clearly separated into spatial data, data attributes and semantic data, three pillars that are interlinked. This structure can be well embedded in current computer systems, and its clear structure also leaves open the option for automatisation in the future, so that information can be frequently updated and does not become obsolete.

The structural framework is also a frame of reference for other geological datasets. GeoConnect³d focusses on data that test or complement the geological models and geological understanding that they represent, and refers to such data as geomanifestations. This concept, besides inspiring geological curiosity and having great potential as a way to communicate with policy makers, is also part of the structural framework methodology and therefore brings together and discloses structured data about a variety of themes such as groundwater (as e.g. springs), mineral resources (as e.g. mineral occurrences), hazards (as e.g. earthquakes), and other subsurface processes (e.g. karstification). This is an important contribution to the third geo-energy objective, and to the first GeoERA objective.

GeoConnect³d also tackled the public awareness about subsurface exploitation and use (the second GeoERA objective) during its whole duration, with material that outlives the project. The project blog was a powerful tool in which articles with accessible language were posted frequently, and attracted the public's attention to several topics such as subsurface management, policy challenges, geothermal energy, mineral resources, geophysical methods to investigate the subsurface, among many others. These articles were widely diffused using the project's social media channels (Twitter, Facebook, LinkedIn), which all continued to attract more followers until the very last month. And, as one of the preferred blog topics, the concept of geomanifestations has been successful to attract the public's interest, linking geological wonders all around Europe with more technical discussions about e.g. subsurface processes and exploitation. GeoConnect³d also launched a YouTube channel, in which videos from public online presentations are hosted. Additionally, GeoConnect³d led two outreach initiatives aimed at a broader, non-specialised public, as part of the project's final stakeholders event together with MUSE and other external partners (Geoscience, Policy and Society): the GeoStar Challenge, to promote the understanding of past and present geological processes hidden beneath the ground by looking at their expressions reflected at the surface (also known as geomanifestations); and the virtual field trips, showing a selection of geosites that unveil and help the understanding of the potential of the subsurface. These are described in detail in Deliverable 2.1.

The ultimate goal of GeoERA was to be the first step in creating a Geological Service for Europe. In the CSA-GSE proposal, the structural framework methodology was taken up as the basis of the workpackage on geological mapping and modelling, in particular to define the geological vocabulary concepts needed at European level by the geological community, and to create the first pan-European lithotectonic map. It

will also serve to the cross-thematic pilots where applied research results will be geologically framed, which can be seen as an extension of the GeoConnect³d efforts of crossing thematic boundaries with other GeoERA projects. This proves that the structural framework methodology developed by GeoConnect³d, as well as the spirit of cross-thematic and multi-resource thinking, have passed scrutinisation and are on their way to be integrated and adopted as a new and fundamental elements of the future Geological Service for Europe.

Theme objectives:

General Theme objectives: (Excellent)
GeoConnect³d (GC3D) has devoted itself to present geological information about the subsurface in an understandable, meaningful and useful way. The project creates an important bridge between 1) data, information and 2) subsurface management and policy support tools. The connections and interactions between subsurface uses, resources and phenomena are pivotal. GC3D does not specifically assess resources, but it places existing information about these resources in a cross-thematic structural framework - geomanifestations methodology to disclose geological context and phenomena in a cross-border setting. The project demonstrates that this workflow is ready to be implemented throughout Europe with four case studies covering varied geological settings. Through many interactions with science communities and stakeholders the project shows how these endeavors can lead to improved methods for decision making for subsurface planning and management based on state-of-the-art review, and knowledge transfer.

Theme scope and approach/methods (Overachieving)
The developed and evaluated concepts can be considered as a major blue print for how geological surveys can present and deploy future geoscience information and research results in national and European policy support actions. The Structural Framework and Geomanifestation concepts are generic and applicable to a broad range of subsurface uses, resources and phenomena (including risks, conflicts of use, synergies). The structured representation supports visualization and evaluation of information at different levels of scale and detail/complexity. The results are embedded and interlinked in Semantic and LinkedData concepts which define a future direction for geoinformation in EGDI in general. Concepts are developed and tested in two cross-border pilot areas (WP3 and WP4). A third pilot area (WP5) independently tests and evaluates how the developed concepts can be transposed to other areas of Europe. The project holds both pan-EU information (low detail) and regional information (high detail).
The methodologies are applicable to the rest of Europe and currently considered for the GeoERA follow-up ”CSA Geological Services for Europe”. GC3D started with a very challenging concept, which resulted in a unique and novel approach to connect and

use geo-information for a broad range of stakeholders challenges. Together with the very extensive promotion activities, stakeholder participation and involvement of future generation geoscientists, the project has surpassed its expectations

Beyond state of art (Excellent)
The GC3D project introduced various novel and innovative concepts for visualizing and communicating geoscientific information (see above). These are applied among others to 3D models in WP4 (Pannonian Basin). The methodology is implemented and tested in cross-border pilot areas. Further expansion to pan-EU level may be done in the GeoERA follow-up "CSA Geological Services for Europe". Transposing of the concepts to other regions is demonstrated for example in the Irish Basin Area (WP5).

Project-2-Project:
There have been various interactions and collaborations with other projects (e.g. HIKE: joint development of fault data concepts, MUSE: conflicting uses and subsurface management, ...)

Has the project as a whole achieved the objectives and expected impact of the theme?

☒ 5 - **Overachiever** (the project has achieved greater impact on project theme and/or other themes than expected)
☐ 4 - **Excellent progress** (the project has fully achieved its objectives and goals towards the theme as expected)
☐ 3 - **Good progress** (the project has achieved most of its impact towards the theme for the period with relatively minor deviations)
☐ 2 - **Acceptable progress** (the project has minor impact)
☐ 1 - **Unsatisfactory progress** (the project has failed to achieve critical objectives and/or has no impact on the theme)

Comments / deviations / recommendations:

GeoConnect^{3}d developed and demonstrated novel concepts which are broadly applicable to different themes and types of geoinformation. This can be a good basis for sharing and communicating geoscience information for stakeholders and policy support.

4 LEVEL 4 – GEOERA PROGRESS EVALUATION

In this section the project is reviewed on the Review meetings, where projects present their overall progress and achievements. This section relates to particular project, broader impact of GeoERA as a whole on policies will be covered at the Final Review meeting with questionnaire and interview with Evaluator.

Based on technical review summaries provided by Sections 1 – 3 of this report, and project presentation on the (Final) Review meeting:

Has the project as a whole been making satisfactory progress according to your own understanding and expectations of the GeoERA project?

☐ 5 - **Overachiever** (the project has exceeded expectations)
☒ 4 - **Excellent progress** (as expected)
☐ 3 - **Good progress** (minor recommendations given below)
☐ 2 - **Acceptable progress** (below expectations)
☐ 1 - **Unsatisfactory progress** (the project did not meet expectations)

Overall comments for the project (overall recommendations, modifications, corrective actions, or re-tuning the objectives to optimize the impact or keep up with the State of the Art, re-focusing, or a simple praise)

Stakeholder one review:

Seeing the final results of the GeoConnect^{3}d project, the determination of the project's consortium to help unite our picture of the European subsurface is very clear, as well as their enthusiasm to pioneer new ways to disseminate and package this knowledge. Doing this while in the unprecedented conditions of a pandemic cannot have been easy.

My comments from the mid-project review would still largely seem stand and my feedback at project-ends builds on these earlier reflections and naturally forms around the hierarchy of themes the project has been addressing:

Subsurface Management
Observations:

- Getting the message across to geoscience's stakeholders that this is a pivotal concept is hugely important and hopefully GeoERA and its legacy will go some way to providing that framing in their minds.
- GeoERA's use of such a simple-to-grasp 2-word idea represents a very practical way to synthesise all the activities currently going on and planned for beneath our feet, especially for public sector stakeholders.

- It also emphasizes the fact the surface we live on is but one “special” interface and that the scale of our impact and intervention reaches for km’s deep. The kind of display shown on P.2 of the Final Evaluation report is one that should be widely disseminated and brought out at every opportunity.
- The way information is being presented within the “EGDI Viewer” is still very much a scientific style and would require reformatting if wishing to find a wider audience.
- Choosing cross-border geological features that straddle multiple countries for case studies in such EU-funded projects is a very wise approach as these areas may remain overlooked by individual national bodies otherwise as too much effort, leading to many interesting opportunities or issues to remain under-studied.
- Systematically presenting and reporting information for the full suite of potential subsurface resources in such a tool (and explaining also why absences occur, i.e. due to non-presence or simply lack of data) is useful for public awareness and re-assurance.

Thoughts for future:

- ✧ “Decision-making” is referenced repeatedly in association with Subsurface Management and this immediately suggests the need for a robust methodology
- ✧ An example would be a tool such as Decision Quality, which alongside similar approaches, is starting to be used widely in the corporate world, including by technical management in the petroleum and mining sectors.
- ✧ Very much agree with Level 1 & 2 reviewers that there is clearly a strong need and benefits to be gained from follow-up work on building practical pan-European guidelines for Subsurface Management that can be used by policymakers and technical professionals alike.
- ✧ Digital representations of specific 3D volumes, for instance beneath a city or for a region could easily form the references for the basis of control of the subsurface by the relevant authorities, much as already occurs for the supra-surface (e.g. controlled airspace) and civil protection/contingency (e.g. police/security services, disaster response).
- ✧ Can innovative “nudge” or “pull” mechanisms be encouraged and instilled among end-customers to drive support and development of central knowledge hubs for subsurface management for regional/urban planning, geohazard mitigation, sustainable resourcing, infrastructure planning, environmental protection and geotourism opportunities?

Information Benchmarking

Observations:

- The traffic-light system used for subsurface information benchmarking is very appealing and would fit well into a decision-making methodology which includes a step for debiased, reliable data sourcing

- There is a high degree of red/orange on these plots, which is suggestive of a healthy (unbiased) benchmarking. It is also noteworthy how the word “risk” is not used - this is arguably sensible, since it prevents any biased “greening” of plots, hence obscuring rather than highlighting issues.
- The use of the word “practice” on these plots is significant as this is a powerful trigger-word for demonstrating our good faith as professionals in trying to understand the local environment/subsurface and its resources/risks. It can also encouraging public awareness of holes in our collective knowledge about a site/region and be a stimulus for support for greater data acquisition, protection, collaboration/engagement.
- Wonderful to see the co-operation across numerous national borders in the case study areas; exemplar of how science could drive positive societal effects and policy.
- We know that spelling out clearly what is “Known” vs “Unknown” is critical for decision making. For non-technical audiences and/or those uncomfortable with probabilistic assessments, using the simple binary question of Do We Know This? => Yes/No avoids confusion and provides the clearest.

Thoughts for future:

- ✧ Where helpful to end-users, displaying more sophisticated “uncertainty” or “probability” maps would be worth considering in any further work, since are becoming more familiar to the public via usage in science communication (e.g. weather forecasts, flooding risk, etc)
- ✧ Would be very interesting to see attributions to each geomanifestation of the degree of local stakeholder knowledge and engagement. This would provide a useful yardstick for local authorities and researchers to judge how best to work with local communities, businesses and structure outreach.

Information Platform

Observations:

- The translation of data into meaningful information that can be deployed for geothermal or mineral exploration and made available in EGDI is the kind of pan-European mechanism that will be vital for the energy transition and resource security, especially in areas that transcend multiple national borders
- The zoomability of the Structural Framework tool is very intuitive and helpful for public engagement and setting the context and hierarchy of what you’re seeing. This is as important for hazards work as for resources.
- This project has excelled in transforming the information collected in the technical realm into stories that can be disseminated to a wider audience. It is to be hoped that the positive lessons from what has worked in this project are shared. This translation is in many ways the greatest road-block (geo)science faces at present.
- Although common practice, there is an evident risk is separating the custodianship and maintenance of a knowledge base from its content creators. The upload geomanifestations and verification of their data could be

highly automated and such a system would highly desirable if wanting public crowdsourcing of such information.

Thoughts for future:

- Building a pan-European knowledge hub of the continents geo-manifestations, which can inspire curiosity, provide educational value and demonstrate the role of the subsurface in a community's environment would a valuable tool to aim for.
- Can the basis of a geomanifestation be embedded into wider concepts and initiatives in geodiversity, conservation and cultural/natural heritage?
- Can a way be found to streamline the release and upload of national information into European central databases? The imperative of the energy transition, under the framework of the Green Deal, would seem the perfect driver and rallying-point for this and spur to action.
- Some creative marketing and communications could enable a future publicly "crowdsourced" geomanifestation knowledge hub (much in the same way Google has levered the public to populate its apps). This would be an excellent forum for raising the profile of these sites and their protection/research, but also for interacting with the public for polling, opinion-seeking, idea-testing.
- Working with regional tourism authorities, educational bodies and environmental groups to maximise the value of these sites for public awareness, the green economy, community pride and research
- Would be very beneficial for a non-technical graphical design expert to review this tool and provide it with a further degree of user-friendliness, which could include small pop-up notes explaining terminology and a sequential guide to potential workflows through the information
- As mentioned in the mid-project review, "geo-manifestations" as a concept is powerful. However, if used beyond the project it would be worth liaising with a branding expert to find a more snappy (shorter) term. Same would go for any public-facing information base, where acronyms (e.g. EGDI) should be avoided.

To avoid any potential bias issues, as picked up by the Level 1/2 reviewers, again a simple de-biasing routine from a decision quality workflow could be adopted.

Stakeholder two review:

GeoConnect^{3}d is an innovative project that is looked into the sub-surface resource potential of Europe and its optimal use. The project included cross-border harmonization of 3D geological models, structural framework models, and geo-manifestations. Optimal use of the subsurface has necessary implications for the planet's environmental and climate-friendly future. Along with utilising conventional resources such as minerals and hydrocarbons, the project looks into unconventional resources such as coal bed methane, capacities of storage of energy carriers such as natural gas, hydrogen, compressed air and heat. The storage of CO_2 holds important implications for a low carbon future. Groundwater utilization is an area which links to the nexus of Food-Water-Energy.

The project included work packages on interface and methodology such as Roer-to-Rhine cross-border, cross-thematic evaluation of geological resources and applications; Pannonian basin study involving eight counties; and case studies from Ireland and Germany (Bavaria).

Interface and methodology highlighted the structural framework model for connecting cross-border, cross-thematic, and multiscale data. The structural framework is an important aspect that endeavored to take full advantage of modern visualization technologies.

When linked to geomanifestations such as CO_2 rich springs, crude oil and mineral showings, the structural framework provides a rich context for the benefit of experts, policymakers and the general public. Geomanifestations is an excellent concept, which includes aspects of spatial data, vocabulary, a photo database and links to blog posts. The geomanifestations had archaeological, cultural and geo-parks information.

Roer-to-Rhine study looked into a cross-border, cross-thematic evaluation of geological resources and applications. This work was particularly challenging due to working across geological borders in multiple countries and regions. The tasks included assimilating regional-scale structural framework, linkage to geomanifestations and geological modelling. The team also attempted an additional study of the pan-European structural framework.

The Pannonian basin study integrated the structural framework across eight countries to provide information on sub-surface management and policy support for exploiting geo-resources. Harmonized geological-structural framework model and subsurface management of resources are linked to geomanifestations. The team commented on the traffic-light model indicating suitability for various types of subsurface use.

The tasks include knowledge transfer as a basis for pan-European recommendations, improved decision-making methods for subsurface planning and management, the applicability of advanced methods on smaller-scale pilot studies, and overall recommendations regarding subsurface planning and management. The methodologies deployed within the case studies were tested on a pilot scale in Ireland and Germany.

In summary, the whole project team is congratulated for the excellent work and achievements. This project may be considered an overachiever for demonstrating the power of geomanifestations as a perfect communication tool. Other exemplary achievements include the structural model, the benchmarking tool, traffic light system, communications products such as photo databases, fact sheets, social media. In future, the structural model could be used as a basis for 3D physical models using 3D printing technology. The project's impact includes quite ambitious targets, new

standards, and new data that provide a backbone for decision-making. The project had excellent social media outreach, published 94 blogs, had several publications and conducted several workshops. The project has significant scientific, policy and societal impact.

In general, the project has achieved more than what was expected.

Annex 1: Review meeting list of participants

Name	Role	Organisation
Joop Hasselman	GeoERA coordinator	Netherlands Organisation for Applied Scientific Research
Harikrishnan Tulsidas	GeoERA Stakeholder	UN Economic Commission for Europe
Barbara Simić	Monitoring and Reporting Officer	Geological Survey of Slovenia
Aleksandra Trenchovska	Scientific reviewer	Geological Survey of Slovenia
Jasna Šinigoj	Scientific reviewer	Geological Survey of Slovenia
Matija Krivic	Scientific reviewer	Geological Survey of Slovenia
Matevž Novak	Scientific reviewer	Geological Survey of Slovenia
Tina Peternel	Scientific reviewer	Geological Survey of Slovenia
Serge van Gessel	GeoEnergy Theme coordinator	Netherlands Organisation for Applied Scientific Research
Glen Burridge	Stakeholder council member	European Federation of Geologists
Renata Barros	Project manager	Geological Survey of Belgium
Kris Piessens	Project manager	Geological Survey of Belgium
Johan ten Veen	Project member	Netherlands Organisation for Applied Scientific Research
Johanna Van Daele	Project member	Vlaams Planbureau voor Omgeving, Departement Omgeving
Katrijn Dirix	Project member	Vlaams Instituut voor Technologisch Onderzoek
Maros Gyula	Project member	Mining and Geological Survey of Hungary
Annamaria Nador	Project member	Mining and Geological Survey of Hungary

Nina Rman	Project member	Geological Survey of Slovenia
Eva Kun	Project member	Mining and Geological Survey of Hungary
Isaline Gravaud	Project member	The French Geological Survey
Monika Konieczyńska	Project member	Polish Geological Insitute
Russel Rogers	Project member	Geological Survey of Ireland
Brian McConnell	Project member	Geological Survey of Ireland
Review done with recording of the meeting:		
Glen Burridge	GeoERA Stakeholder	European Federation of Geologists