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

Technical review report for project HIKE

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:	Hazard and Impact Knowledge for Europe
Project acronym:	HIKE
Project reference number:	GeoE.171.011
Project topic:	GeoEnergy
Project specific topic:	GE4-Induced impacts and hazards
Lead partner:	TNO - Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (The Netherlands Organisation for applied scientific research)
Project website:	https://geoera.eu/projects/hike10/

☐ Technical review report
☒ Final review report

Period covered	01/01/2020 – 31/10/2021
Review meeting date	22.11.2021, start at 14:00

Contributor:	Role:	Approved on:
Barbara Simić	Monitoring and reporting officer	23.11.2021
Aleksandra Trenchovska	Monitoring and reporting officer	23.11.2021
Maja Ilić	Monitoring and reporting officer	23.11.2021
Mateja Jemec Auflič	Scientific reviewer	25.11.2021
Jernej Jež	Scientific reviewer	25.11.2021
Jasna Šinigoj	Scientific reviewer	26.11.2021
Matija Krivic	Scientific reviewer	26.11.2021
Serge van Gessel	Theme coordinator	26.12.2021
Jørgen Tulstrup	Theme coordinator	27.12.2021
Elizabeth S. Cochran	GeoERA Stakeholder	21.12.2021
Massimo Cocco	GeoERA Stakeholder	31.12.2021

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)		☒
DELIVERABLES and MILESTONES			
Have the planned deliverables for the period been submitted on time according to timeline in Project Agreement?	☐	See comment no. 2	☒
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)	☐	See comment no. 3	☒
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)	☐		☒
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 HIKE project aimed to support the state of the art in hazard and risk management through the development, demonstration, and implementation of essential subsurface data sets and assessment methodologies and to establish a knowledge exchange point where research institutes and stakeholders are guided to the information they need. HIKE has contributed three main results to support research and investigation of hazards and impacts: i) a novel information system for faults and other tectonic features, ii) four real-world case studies demonstrating advanced assessment methods, and iii) a knowledge exchange point for reports, tools, and datasets on induced subsurface hazards and impacts. The results are a springboard for the integration, harmonization and implementation of knowledge and information for responsible use of the subsurface across Europe. The challenge faced by the project was the heterogeneous data, maps or databases in the participating countries. The lack of a general fault classification did not help to solve the problem. With the development of the European Fault Database, the HIKE project has taken an important step in the assessment, publication and application of national and European fault data. In addition to the collection and publication of fault data and information, HIKE has also led to a new incentive and approach to produce and improve fault information at national and transnational levels according to common pan-European workflows and standards. The objectives of the project were ambitious. The results obtained and the discussions with the project team have clearly shown that the consortia have achieved all the objectives set and even exceeded some of them.

The Covid 19 epidemic had an impact on the course of GeoERA and its projects. In December 2020, the GeoERA project was extended by 2 months and the HIKE project by 4 months, from 30.6.2021 until 31.10.2021. The postponed project activities were appropriately communicated to the GeoERA Executive board, which reviewed and approved the changes in light 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 and efficient. The consortia demonstrated that, with regular collaboration and the help of the work package leaders, the project could overcome the main challenges and achieve more than initially expected. No underperforming partners were identified in the project that could affect the quality of the project outputs. Only one partner, GEOINFORM, discontinued its activities in the second reporting period without any impact on the project work.

The project's budget was slightly modified, with some partners reducing budgets and others increasing them. Overall, the project has spent more than originally planned, which is consistent with more work done and over-achieved objectives.

A communication and dissemination plan was adopted and a detailed description of the activities with timetable was provided. The project's communication and dissemination activities have adhered to the plan. The recommendation from the mid-term evaluation to adopt a more targeted communication strategy has been taken into account. The project outputs are complete and can be disseminated to different audiences after the completion of the project to avoid misinformation. Cooperation with other GeoERA projects, notably GeoConnecte3d, HotLime, 3DGEO-EU, VoGERA and GIP -P, was regular and contributed to a more complete database.

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: Due to the pandemic situation, some activities were postponed and deliverables were delayed to a later date. The changes in delivery dates were communicated to the Monitoring team and the GeoERA Secretariat through an amendment to the project plan.

Comment no. 3: Milestone 5 (technical workshop with other GeoERA projects) was not conducted due to Covid constraints. Instead, the project organized frequent online meetings with other projects (3DGEO-EU, HOTLIME, Geoconnected3d) to add their data to the database, explain and communicate guidelines and perform Quality Checks. Different projects have contributed to the overview of the Fault Database applications (see D2.4). Some activities, deliverables, and milestones have been delayed and partner budgets have been adjusted to achieve project outcomes.

The deliverable changes in the project implementation period are:
Reporting period 1:
D1.1 postponed from M2 (31.8.2018) to M4 (31.10.2018)
D1.4a postponed from M6 (31.12.2018) to M7 (31.01.2018)
D1.5 postponed from M6 (31.12.2018) to M7 (31.01.2018)
D1.6 postponed from M6 (31.12.2018) to M7 (31.01.2019)
D2.1a postponed M15 (30.9.2019) to M19 (31.01.2020)
D2.2a postponed from M17 (30.11.2019) to M19 (31.01.2020)
D4.2a postponed from M17 (30.11.2019) to M19 (31.01.2020)
D1.3a postponed from M18 (31.12.2019) to M19 (31.01.2020)

Reporting period 2:
D1.2 postponed from M36 (30.6.2021) to M40 (31.10.2021)
D2.2b postponed from M36 (30.6.2021) to M39 (30.9.2021)
D2.3 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D2.4 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D3.2 postponed from M36 (30.6.2021) to M39 (30.9.2021)

D3.3 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D3.4 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D3.5 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D4.1 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D4.3 postponed delayed from M36 (30.6.2021) to M39 (30.9.2021)
D5.2b postponed from M36 (30.6.2021) to M39 (30.9.2021)
D5.3 postponed from M36 (30.6.2021) to M39 (30.9.2021)
D1.3b postponed from M38 (31.8.2021) to M40 (31.10.2021)

The project has coped well with the negative external factors and has overcome its challenges in such a way that it has achieved more than was expected at the outset. For this reason, and due to the fact that it has overachieved its initial objectives, the project is rated as "overachieving" at level 1 and thus receives the highest score.

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 Target Group reach
EVENTS	40835		60	120	65					0	41080
MEETINGS	174				10						184
ONLINE_MEDIA		3508									3508
PUBLICATIONS	1540						2			20	1562
Total	**42549**	**3508**	**60**	**120**	**75**		**2**			**20**	**46334**

For some activities the number of people reached could not be assessed.

	BLOG	CONGRESS	INTERNAL PROJECT MEETING	MEETING	MEETING WITH OTHER GEOERA PROJECTS	OTHER	PITCH EVENT	SCIENTIFIC PUBLICATION	SEMINAR	WEBSITE	WORKSHOP	Total
EVENTS		3					4		1		6	14
MEETINGS			2	51	3							56
ONLINE_MEDIA	1									3		4
PUBLICATIONS						1		3				4
Total	**1**	**3**	**2**	**51**	**3**	**1**	**4**	**3**	**1**	**3**	**6**	**78**

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	**251**	**1.620.649,44**	29,7%	**481.332,32**	**1.139.317,12**
1st period consumption	103	634.905,71	29,7%	188.567,00	446.338,72
2nd period consumption	171,79	984.777,32	29,7%	292.478,80	692.298,31
TOTAL	**274,79**	**1.619.682,83**	29,7%	**481.045,80**	**1.138.637,03**

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):

Overall GeoERA Grand Challenges

1) Economy and strategic value: Hazards and impacts may significantly raise the cost of economic activities. These costs must be evaluated in the total cost and benefit equation when assessing the net economic value of resource exploitation.
• All activities in HIKE are aimed at improving the assessment of hazards and disclosure of essential information and knowledge to such assessments.
- Fault Database: assess potential seismic hazards or failing integrity of sealing formations in storage activities
- Methods and use cases: evaluate/develop methods, improve quality of hazard assessments (seismicity, seal integrity, ground motion). Exchange knowledge, methods and experiences among surveys
- Knowledge Share Point: disclose information, knowledge, data and tools on hazard assessment to stakeholders and other surveys.

2) Welfare and health: Subsurface resources (energy, groundwater, minerals) provide benefits to society. These benefits should be in balance with the potential hazards and impacts resulting from their exploitation (see “economy and strategic value).
• The results in HIKE (Fault database, Methodology development, Knowledge Share Point) deliver information and tools to better assess these hazards and support preventive measures. (see above)

3) Climate: Escape of greenhouse gases (e.g., methane emissions) and safety of CO2 storage are typical topics in hazard research.
• Two out of the four case studies in WP3 specifically address the safety of subsurface storage, taking into account the influence of faults (WP2: Fault Database)

4) Safety and environment:
• This is the main scope of HIKE. The results in HIKE (Fault database, Methodology development, Knowledge Share Point) deliver information and tools to better assess these hazards and support preventive measures (see above).

Specific HIKE impacts

1) Foundation and platform for the (future) alignment of national research on geo-energy related (induced) impact and hazard assessments across Europe.

• Activities and deliverables in WP2, WP3 and WP4 have led to concrete collaboration and knowledge-sharing among partners and partner projects. With the available developed concepts, the HIKE project needs to engage external stakeholders (applicability for use cases, align with relevant projects and science platforms). We are currently linking with national case studies, regulators as well as the EU research infrastructure EPOS.
• The HIKE project has created a first-of-its-kind European Fault Database that has collated and harmonized relevant information and knowledge on all types of geological faults. This unique product enables current and future dissemination on faults which was not available before. The Fault Database is interlinked with other (external) databases on seismic hazards (e.g., SHARE, ITHACA) and have resulted in a better integration and correlation of EU fault data.

2) Means and support to develop and improve methods to predict, prevent and mitigate hazardous and polluting effects induced by subsurface exploitation
• This is concretely done in WP3 in actual use cases. WP4 works on making these results available to the broader science community. We engage EPOS to enhance the integration outside GeoERA

3) Contribution to the reduction of economic and societal costs resulting from such effects by minimizing the risks.
• The information collected in the Fault database is resulting from billions of euro's worth in data acquisition (e.g., O/G data, decades of data acquisition and mapping in national geological survey programmes). These data are now prepared and disseminated and will reduced costs that would otherwise be spent in subsurface assessments (e.g., mapping of faults)
• The Fault database is connected to clear hazard cases. In partner countries the application of the fault database is evaluated in the context of national induced seismic hazard assessments. With a successful implementation we can better avoid such seismic risks (reduce societal costs) and make assessment more efficient (reduce assessment costs).
• In relation to the HOTLIME project: the faults in the fault database can be used to better assess geothermal resources and reduce risks of failing projects (e.g., expensive drilling)

4) Translate the achievements and results to the policy and societal domains.
• With the specification of the Knowledge Share Point HIKE identifies specific user groups. The semantics concept framework is developed to assist non-technical end-users to information that is relevant for them (assisted search).
• The knowledge generated in WP3, in particular in relation to improved methodologies for locating earthquakes will be built upon in the ACT3 project SHARP starting 1. November 2021.

• Moreover, the need for a standardized methodology for calibrating InSAR data has been considered in the implementation of the European Ground Motion Service that will be released by the European Environment Agency in the first quarter of 2022.

5) Help countries to improve their own assessment and determination of induced hazards and impacts.
• These impacts are reached with the collaboration in WP3 (methods/use cases), the knowledge SharePoint (joint framework and definition of vocabulary terms, sharing documents/tools) and the common specifications and structures of the fault database and knowledge share point. These products are aligned with other external platforms (interfaces). The knowledge on fault characterization is shared between countries in various workshops (including links to other projects)

6) Allow stakeholders and end-users to benefit from the established results and thereby avoid unnecessary data acquisition and research costs.
• HIKE has delivered the technical and scientific specifications. The joint development of the platform infrastructure is programmed between the projects and will be realized towards end of 2020 (prototyping, elaborating the final platform). In relation to EPOS it is possible to align repositories and reduce costs of double work.
• The information collected in the Fault database is resulting from billions of euro's worth in data acquisition (e.g., O/G data, decades of data acquisition and mapping in national geological survey programmes). These data are now prepared and disseminated and will reduced costs that would otherwise be spent in subsurface assessments (e.g., mapping of faults)

7) The transparency and open access to information are considered first principles and requisites for public awareness creation.
• One of the main goals for HIKE is to bring the results and achievements under the attention of external stakeholders and the public. Surveys have their own interactions with local/regional/national stakeholders and end-users. All results are open and publicly accessible through EGDI (following FAIR data principles).

Expected impact (from Project Agreement):

The successful implementation of a European Hazards and Impacts knowledge share point will provide the foundation and platform for the (future) alignment of national research on geo-energy related (induced) impact and hazard assessments across Europe. The gathering, harmonization and central dissemination of geosciences data sources, methodologies and case study results will deliver the means and support to develop and improve methods to predict, prevent and mitigate hazardous and polluting effects induced by subsurface exploitation. By supporting measures to prevent and mitigate induced hazards and impacts, the project indirectly contributes to the reduction of economic and societal costs resulting from such effects by

minimizing the risks. Through the implementation and demonstration of real and actual use cases, the project will be better able to translate the achievements and results to the policy and societal domains. The collaboration between project partners as well as between the project and other national/transnational studies is vital to establishing common agreed and broadly applicable standards and functionalities in alignment with end-user needs as well as to increasing the effective deployment of innovation capacity in the entire research area. This will help many countries to improve their own assessment and determination of induced hazards and impacts. The open-access and dissemination of information via the GeoERA Information Platform will allow stakeholders and end-users to benefit from the established results and thereby avoid unnecessary data acquisition and research costs. Last but not least, the transparency and open access to information are considered first principles and requisites for public awareness creation. By the cooperation between the identified partners, the project will establish a clear transnational focus. Through the development of generic information sources and methodologies as well as national oriented sources and use cases, the project reaches out to both national and European stakeholders and end-users. The public availability of information regarding hazards and impacts may be subject to confidentiality and other access restrictions that are imposed by national and local regulations. These restrictions cannot be resolved within the project, yet attempts will be made to include references where possible. Furthermore, it can be expected that certain use cases cannot be promoted by the project due to their political and societal sensitive nature.

Evaluation of deliverables

No.	Title	Status (Approve / Reject)	Comments
D1.2	Minutes of Meetings	Approved	/
D1.3b	Final Project Progress Report	Approved	/
D1.4c	Cumulative Expenditure Report 2020	Approved	By Level 1
D2.1a	Draft Fault Data Characterization Catalogue	Approved	/
D2.1b	Final Fault Data Characterization Catalogue	Approved	/
D2.2a	Mid-term fault data collection report	Approved	/
D2.2b	Final fault data collection report and database	Approved	/
D2.3	Final report on fault characterization and data	Approved	/
D2.4	Final report on FDB application and evaluation	Approved	/
D2.5	Fault data collected by partners embedded in the Fault database, as developed by the GIP	Approved	/

D3.2	Final case study report on improved localization of seismic events, Denmark, Netherlands, Iceland	Approved	/
D3.3	Final case study report on surface deformation assessment techniques, Po Basin area, Italy	Approved	/
D3.4	Final case study report on improved assessment of reservoir seals, Poland	Approved	/
D3.5	Final case study report on geological hazards and safety of subsurface injection, Rousse, France	Approved	/
D4.1	Final project synthesis, recommendations and best practices report	Approved	/
D4.2a	Draft scientific specifications and requirements for the hazards and impacts data share point and definitions for the Semantics Web service.	Approved	/
D4.2b	Final scientific specifications and requirements for the hazards and impacts data share point and definitions for the Semantics Web service " delivery date 30.11.2019 (M36)	Approved	/
D4.3	Final data and knowledge share point implementation and report	Approved	/
D5.2a	Draft user manual for the Fault Database and the knowledge share point	Approved	/
D5.2b	Final user manual for the Fault Database and the knowledge share point	Approved	/
D5.3	Final Project Data Management Implementation report	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:

GENERAL COMMENTS
The HIKE project compiles big amount of data and knowledge developed by national and regional geological surveys that can be used to support identification, prevention, and mitigation of induced hazards and impacts. The project partners have achieved all of the scientific objectives.

SPECIFIC COMMENTS
WP2 European Fault database
With the development of the European Fault Database, the HIKE project has taken a major step in the evaluation, publication and application of national and European fault data. The project results are not limited to the collection and publication of data and information. HIKE has also led to a new incentive and approach to establish and improve fault information at national and transnational level according to common pan-European workflows and standards.

WP3 METHOD AND CASE STUDIES
The level of knowledge varies widely across European institutions and is highly dependent on the maturity of subsurface activities and the locally existing legal frameworks for risk management. The project partners presented four case studies on induced seismicity, induced subsidence and reservoir sealing and leakage. In all case studies the relevance of the fault database created in WP2 was investigated. As part of recent climate change initiatives (Glasgow Climate Change Conference), research into methane and carbon dioxide storage options in Poland has shown that this methodology can be applied in other pilot areas which is one of the very important scientific challenges in reducing emissions.

WP4 Knowledge Share Point
The Knowledge Share Point represents a central repository and online access point for data sources, state-of-art method reports and case study outcomes relevant to an improved hazard and impact assessment.

GENERAL COMMENTS
Despite the challenging time associated with the Covid-19 epidemic, partners and collaborators of the HIKE project managed to implement all the activities you planned to do in the project. The results are good and allow further use and upgrading in the future.
Reviewers would like to highlight the broad range of the approach, namely project addresses geohazards related with faults and seismicity as natural phenomena as well as geohazards (e.g. faulting, fault sealing potential, subsidence) related with human activities.
Project website and fault database web applications are transparent and user friendly.
As can be seen from the work progress report deliverables were achieved.

As presented the results were disseminated also through some scientific publications. Project that creates a quality data and communication platform for the future.

SPECIFIC COMMENTS

WP2 European Fault database

In reports partners mentioned data heterogeneity, that many online national databases exist, and most information is dispersed and presented in heterogeneous formats. They enable that cross-border correlations can be established without the need to make these faults also geometrically consistent, which provides a solution for the fact that datasets can strongly differ between regions and countries. Reviewers see the biggest project progress that they managed to set up fault classification framework and put the results in a regional context. Actually, they learned to speak a common language. Platform is widely useful in the future since the information remains available after the end of the project. HIKE fault database is intended to provide a sustainable foundation for future fault modelling, characterization and dissemination. The collaboration among partners have increased the knowledge which has stimulated many countries to improve their fault models and information and provides the opportunity to continue its development in future research and other activities. Reviewer's advice for the future would be to attract other countries to collaborate that have not been involved in the project (e.g., UK, Spain, Croatia, Greek).

WP3 Method and Case studies

Interdisciplinary approach to study showcases has been used in terms of testing research methods, such as microseismisity measurements and monitoring, use of InSAR data, evaluation of seal integrity ect., these are methodologies relevant for the assessment of induced hazards and impacts. Study of case studies indicate directions of future work for further filling-in critical knowledge and information gaps in the area of geo-hazard identification, prediction and mitigation. For example, InSAR satellite-based methodology combined with geological and seismological data can be useful to provide constraints on modelling earthquake source mechanisms. So, project is definitely important step towards better hazard assessments.

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):

European Fault Database

The HIKE Fault Database has resulted in a first-of-its-kind platform providing access to information on geological faults covering the majority of European countries including additional non-participating countries liaised with other GeoERA projects (e.g. the Pannonian Basin Area in the GeoConnect3d project). The data has been gathered from national and regional mapping programmes, repositories and new interpretations using standardized and common agreed methods and specifications (GE4-1). These methods and specifications provide a foundation for future extensions and information improvements. The implemented Tectonic Boundary Classification is intended and expected to become a major driver for better harmonized models based on similar concepts supporting stratigraphic interpretations and correlations (GE4-2). The database provides a large extension of the current European information on seismogenic faults. With the inclusion of passive and buried faults the HIKE database provides a source for other types of fault-related research domains in a wider variety of geological settings and underground uses. So far this information was difficult to access as it only existed in local and non-harmonized archives. Both nationally and at European level this effort has resolved a major gap that became more and more apparent due to the diversification of subsurface uses, the increased attention for environmental and societal impacts and the ongoing digitalization in geosciences (GE-4). Through the implementation of HIKE Fault Database in the EGDI, the information remains available after the end of the project and the GeoERA programme while providing the opportunity to continue its development in future collaborative research activities and policy support (GE-5).

The collaboration among partner geological surveys and the developed practices in HIKE have significantly increased the knowledge base which has stimulated many countries to improve their fault models and information (GE4-2). Leading surveys with advanced fault data platforms have had an important contribution to this development. The development and implementation of the Linked Data principles and Tectonic Boundary Classification for faults is perhaps the most prominent example. This development went parallel with many other GeoERA projects which also used these principles. For this reason it has been relatively easy to exchange information and to jointly work on mutual applications (GE4-1 and GE4-5). In this context the type of information and knowledge in the database has been used as a basis for the Hazard and Impact Case Studies (GE4-3). Other foreseen applications are:

1) Investigation of natural seismic hazards (including possibilities to embed links with existing national and European information platforms)

2) Assessment of induced seismic hazards
3) Assessment of the impact of faults on potential future subsurface uses and resources (e.g.: geothermal energy, underground storage, minerals exploration, hydrocarbons and methane emissions)
4) Reconstruction of the historical geological development at large

Methods and Case studies
All case studies conducted within the HIKE project contribute to the Strategic Research Topics GE4-1, GE-2, GE-3 focusing on improvements and add-ons to the broad range of methodologies employed both in reservoirs characterisation for subsurface use planning as well as direct geo-hazard assessment and cross-cutting evaluation for more precise and reliable results. They have concentrated on seismic hazards and leakage related to human underground activities but directly connected with tectonics and faults network, being able to contribute to the FDB input on one hand and presenting opportunities how to use the data gathered in it in the future on the other. They also indicate directions of future work for further filling-in critical knowledge and information gaps in the area of geo-hazard identification, prediction and mitigation (GE4-4).
Evaluation and prediction of hazards and impacts on natural environment in Europe caused by/derived from geo-energy application is of a paramount importance both for energy security in general and for ensuring fair and even distribution of costs and benefits under the wide term of energy justice. High-quality hazard assessments in concert with state-of-the-art monitoring methods are also critical for public acceptance of future energy exploitation and climate solutions. Case studies conducted within the HIKE project show that there is a vast catalogue of methods of such assessment, implementing wide range of technologies starting from geophysical logs interpretations, on-land permanent signals monitoring and satellite measurements of various parameters combined with advanced 3D and 4D modelling. However, credibility of their results might be questioned, especially in cases of not sufficient availability or resolution of data, a lack of good reference values and a lack of possibility of cross-checking with other existing results in some way related to problems in question. In big scale activities it might be not enough to estimate an uncertainty of performed assessment, as they might appear not sufficient for proper subsurface use planning and management. An instant development and international cooperation in the field of natural and induced hazards assessment and mitigation is a clue for further safe and efficient progress of geo-energy contribution to climate neutral Europe.
The in-depth work on hazard related methodologies in relation to geo-energy has highlighted the need to assess the long-term stability and behaviour of the subsurface with higher precision than ever before. In addition to the demand for greater precision, also quantitative knowledge of the related uncertainties is required to link individual hazards to distinct locations. The determination of geo-hazards is site specific, but the methodologies involved as well as the need for common standards is an overarching matter for all of Europe.

Hazard assessments for natural seismicity are typically not linked to the seismicity of a specific fault. Instead, the analysis is carried out for a broader area. While the classical seismic hazard methodology based on a long timeline of natural seismicity is still a necessary component, it is far from sufficient for mitigation purposes. Changing the stresses on a fault by injecting or extracting fluids for e.g. harvesting geothermal energy or storing CO2 can lead to unintended seismic activity. Being able to track the microseismicity more precisely - ideally linking it to specific faults or zones in the subsurface - can serve as a first warning of fault reactivation, allowing for action to protect public safety and infrastructure. Furthermore, precise tracking of microseismicity may allow for quick intervention if there is increased risk of CO2 or other gas escape from a deep reservoir. Improving the methodology for locating earthquakes contains several components, all of which have been explored in the HIKE project:

a) more precise hypocentres which can be achieved through denser data collection, better subsurface velocity models and more advanced analysis methods

b) a deeper understanding of the uncertainties on the hypocentres which can be achieved through various statistical methods and stochastically analysis. This aids to discern if an earthquake is related to a specific fault or not

c) full waveform inversion to obtain the earthquake source mechanism can reveal if the earthquake is related to the natural seismicity in the area or to induced stresses

The long term seismological monitoring of an already utilised reservoir (e.g. for HC production) is important to assure the security in general and for potential future usage. In case of depleted HC reservoirs it is inferred that the residual stress due to the compaction can play an important role for the continued seismicity for many years after the end of exploitation. It is crucial to estimate how long it takes to relax the residual stress for the regional seismic hazard assessment. It is also important to follow up on the seismicity and reservoir state, not only for the current security but also for the potential (re)use of the reservoir such as underground gas storage or CO2 storage as required by the EU Storage Directive (2009).

Ground motion observations can vastly contribute to geo-hazards assessment not only in case of surficial landslides but also in deep subsurface applications security assessment. In general, ground motion is correlated to several natural and anthropogenic phenomena such as tectonic activity, subsidence, underground fluid exploitation or storage. All these phenomena and activities have significant implications from an economic, environmental, and social point of view. Topographical variations can have negative impacts on the hydrodynamic setting, the hydraulic and road infrastructure, the coastline setting, the biological ecosystems, and the salinization of aquifers. Therefore, an efficient monitoring of ground movements and the best possible understanding of the causes that determine them are more than ever necessary for the relevant, countless and of various kinds implications that they have on our society.

Satellite based methodologies are explored and improved to study the present-day crustal mobility and the differential uplift mostly driven by the activity of major faults.

In particular, the relative ground movements suggested by the Iso Kinematic Maps constructed from satellite measurements could give new perspectives for interpretation of present day kinematic trends. InSAR satellite-based methodology combined with geological and seismology knowledge can be useful to provide constraints on modelling earthquake source mechanisms to guide the land use and subsurface use planning, industrial layouts, urban and major infrastructure development as well as public health hazard assessment. Many challenges are related to analysing subsidence in a region naturally affected by land subsidence because of its geographical and geological features to which the effects of anthropogenic activities are added. Distinguishing the natural subsidence from the anthropogenic component requires careful analysis and measurements over extensive areas as well as detailed ground (in-situ) observations in order to validate and calibrate satellite-based data.

A sufficient sealing of subsurface reservoirs is very important with regard to resources protection (e.g. preservation of hydrocarbons plays) as well as for safety of storage utilities. Since a fault may act as a barrier for fluid flow or a migration path, appropriate recognition of its properties is extremely important for prospection of hydrocarbons and proper development planning. Sealing faults may constitute a trap forming a hydrocarbon reservoir or transform large reservoirs into smaller compartments with different reservoir pressure and fluid characteristics, hindering efficient exploitation. On the other hand, open and permeable faults may cause a loss of mud circulation leading to serious technical problems during the drilling operation (Cerveny et al., 2004; Knott, 1993) as well as environmental hazards. The fault sealing analysis is also crucial in terms of underground storage planning. To assess if a reservoir is appropriate for storage, an evaluation of its long-term confinement stability is a key point. Thus, the sealing or non-sealing properties of faults need to be evaluated considering the significant increase of fluid pressure during the CO2 or other substances injection. Proper evaluation of faults sealing potential based on shale gouge ratio is highly dependent on spatial data which allow for proper identification of fault geometry as well as geochemical data providing reliable quantitative information on clay minerals occurrence in fault-hosting rocks. Detailed information of this kind is not very common and even if exists, not easily accessible. Gathering step by step this information from existing records and further research to acquire new results especially in areas with high underground use potential or prone to seismic hazards to store them in standardised and public data base would certainly help in broader use of presented fault sealing assessment method as well as further improvement in fighting of shortages in this kind of assessment.

Each methodology tested within the HIKE project has been studied by local experts within their own country, while having regular cross-country cross-disciplinary meetings to improve the common perception of geo-hazards. The meetings have also served as a way to communicate the capabilities as well as the limitations of the individual approaches. While progress has been made within all of the fields of study, HIKE is just one important step towards better hazard assessments. Further research

is needed within each methodology, and more work is needed to ensure the impact beyond the partner institutions.

Theme objectives:

General Theme objectives: (Excellent)

HIKE's activities and deliverables were mainly aimed at the identification and assessment of hazards and impacts of geo-energy related subsurface activities. This comprises the definition, development and dissemination of a European database of faults (WP2) and development/demonstration of methodologies in case studies which address various types of hazards in a fault-related context (WP3). The project developed a knowledge SharePoint tool to exchange information and experiences on European, national and local hazard studies and tools based on semantic/vocabulary concepts/technologies.

Although HIKE's scope didn't cover the mapping and assessment of resources, the resulting data and knowledge is pivotal for identifying where subsurface resources and storage capacities can responsibly be deployed. Through the link with HotLime, the fault database delivers insight in the prospectivity and expected successful development of deep geothermal energy resources in limestone formations (i.e. faults being a proxy for achieving flow rates needed for a viable geothermal project). Through the link with GeoConnect3d, faults are linked with geomanifestations and occurrences of resources and (natural) phenomena. Through the link with 3DGEO-EU, there is better insight in how 3D fault information determines the overall distribution of geological formations and resources in cross-border regions, including potential overlaps and interactions.

Theme scope, approach and methods: (Excellent)

The HIKE FDB comprises common specifications, standards workflows and tools to generate, analyze and disseminate information on subsurface faults. These specifications , standards and tools have been developed together with all HIKE partners and several other projects (HotLime, GeoConnect3d, 3DGEO-EU). The Fault Database uses Inspire codes and added new definitions. HIKE has followed FAIR data principles and uses common tools developed in the GIP project (e.g. metadata catalogues, vocabularies and thesauri, GIS capabilities, upload functionalities, etc.). There is a common guideline to add or update information in the future. The implemented vocabularies (national) and tectonic boundary classification are used to structure and correlate fault data across borders and established links to other (external) data sources. The functionalities allow for multi-scale definition and viewing of fault data.

Hazard and impact methodologies are developed and demonstrated in real case study areas across Europe. Each study addresses a specific resource/capacity (e.g. hydrocarbons, storage, geothermal) and/or hazard aspect (seismicity, subsidence, containment and leakage)

Beyond state of art (Excellent)
The HIKE database delivers an entirely new element to the EGDI information pool. It substantially extends existing fault data repositories (e.g SHARE). During the HIKE project many partners have initiated the development of fault data (e.g mapping, attributing, classifying).

The Tectonic Boundary classification is an entirely new development for European Fault Data which is an analogue of a stratigraphic classification for geological formations. The Tectonic Boundary classification is pivotal for the correlation and interpretation of faults and fault system and understanding resource distributions, and hazards (induced/natural). Cross border fault data harmonization and correlation using Semantic concepts demonstrated in various regions. Also linking of fault data to external sources (e.g. SHARE, ITHACA).
HIKE specifically focused on State-of-the-art assessment workflows for analysis of potential geologically related surficial and subsurface effects induced by resource exploitation (e.g. subsidence, tremors, etc.). The case studies addressed uncertainty and sensitivity aspects (e.g. with the localization of seismic event, P3, deliverable D3.2).

Project-2-Project:
With the development (specifications) and population (fault data, vocabularies) of the European Fault Database, the HIKE project collaborated directly with the HotLime Project, the GeoConnect3d project, 3DGEO-EU project and the GIP-P project. Collaboration was established in technical workshops and bilateral (online) meetings. Other projects (VoGERA, GARAH) also contributed use case examples (D2.4).

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:

The project has in a very innovative way utilized the Project Vocabularies functionality of the EGDI platform to establish and document the faults and their hierarchy thereby making the results accessible via the specific HIKE Semantic Network functionality as well as through the generic EGDI search and web GIS tools. This substantially increases the accessibility and thereby the usefulness of the results.

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 evaluation:

The overall progress made by the HIKE project is impressive. The main components were the development of a European-wide fault database and hazard assessment at several case study locations.

Through involvement of many European Geological Surveys the project developed a Europe-wide fault database that is accessible through a public website. To make a functional database, a comprehensive metadata and database schema was developed to convey the resolution of the data, handle changes in fault names and slight location differences across borders, grouping of complex fault structures, and fault properties including hydrological information. The project has brought into the public sphere many existing fault data that were previously not public, or at least not in manner that could be easily shared. These data are now in a format that is easy to access and, perhaps more importantly, has sufficient metadata for appropriate use by academia, government organizations, and industry. This is an extremely valuable resource for the community.

The project also considered how to ensure the database was not a static effort, that could rapidly lose relevance. This was in part motivated by the fact that the project highlighted areas where gaps exist in available fault databases, so it was apparent

that updates would be needed as future projects were completed. The database architecture included provisions to enable easy updates to the database by individual geological surveys through uploading new fault tables with new information.

The project also included several case studies related to reservoir assessment and geohazards. Specifically, the case studies considered seismic hazard and sealing/leakage concerns for injected waste or CO2. Across the case studies there were varied datasets, limiting the use of consistent methodology. Instead, the goal was to pull together essentially a menu of approaches, depending on the available data and objectives. Despite these disparities, the teams did a nice job providing suggestions on approaches to improve the outcomes (e.g., better earthquake locations, fault databases). Hopefully the developed menu of approaches should be able to be used by future projects to speed assessments.

Overall, the project achievements were outstanding. In the future, it will be important that funding is available for maintenance of the fault database and, in particular, assessing how the fault database is used. The ambitious project timeline did not allow for much engagement with (potential and actual) users of the database. Without such engagement, the work of the project may not be as widely used and limit the overall impact of the database.

Stakeholder two evaluation:

The project has a relevant impact on GEOERA because it contributes to the sharing of data, scientific products and services dealing with seismic hazard and solid Earth sciences. The project has achieved the planned objectives contributing to the theme. There is the possibility to ensure a perspective going beyond the HIKE project and this requires some actions now supported by GEOERA.

The Methods and Use Cases are excellent applications, but they need to be included in a clear framework for data and service provision. This will be certainly done by GEOERA through the Information Platform and EGDI. A key recommendation, in my opinion, concerns making the data infrastructure interoperable now, in order to address the data management issues together with the data providers and the service developers.

The implementation of data traceability and provenance should be addressed at this stage, following a clear vision toward the operation of the infrastructure in EGDI. Strengthening the connections with EPOS and its integrated core services now might be useful and appropriate.

This might also foster the implementation of a user strategy strengthening the exploitation and the impact of HIKE beyond GEOERA.

These general considerations are motivated by the wish to strengthen the HIKE impact within GEOERA and beyond.

Overall, I consider the contributions of the HIKE project excellent for GEOERA and the data and service provision of relevance for the geological community.

Annex 1: Review meeting list of participants

Name	Role	Organisation
Joop Hasselman	GeoERA coordinator	Netherlands Organisation for Applied Scientific Research
Elisabeth S. Cochran	GeoERA Stakeholder	US Geological Survey
Massimo Cocco	GeoERA Stakeholder	National Earthquake Observatory, Italy
Barbara Simić	Monitoring and Reporting Officer	Geological Survey of Slovenia
Aleksandra Trenchovska	Monitoring and Reporting Officer	Geological Survey of Slovenia
Maja Ilić	Monitoring and Reporting Officer	Geological Survey of Slovenia
Mateja Jemec Auflič	Scientific Reviewer	Geological Survey of Slovenia
Jernej Jež	Scientific Reviewer	Geological Survey of Slovenia
Matija Krivic	Scientific Reviewer	Geological Survey of Slovenia
Jørgen Tulstrup	Information Platform Theme coordinator	Geological Survey of Denmark and Greenland
Serge van Gessel	GeoEnergy Theme coordinator and HIKE technical coordinator	Netherlands Organisation for Applied Scientific Research
Hans Doornenbal	HIKE Project manager	Netherlands Organisation for Applied Scientific Research
Rob van Ede	Hike Project member and WP2 lead	Netherlands Organisation for Applied Scientific Research
Tine Larsen	HIKE Project member and WP3 lead	Geological Survey of Denmark and Greenland
Fernanda Veloso	HIKE Project member and WP4 lead	BRGM - French Geological Survey

Esther Hintersberger	HIKE Project member and WP5 lead	Geological Survey of Austria
Valerio Comerci	HIKE Project member	Italian Institute for Environmental Protection and Research