

SpringerBriefs in Earth System Sciences

Series Editors

Gerrit Lohmann, Universität Bremen, Bremen, Germany

Lawrence A. Mysak, Department of Atmospheric and Oceanic Science, McGill University, Montreal, QC, Canada

Justus Notholt, Institute of Environmental Physics, University of Bremen, Bremen, Germany

Jorge Rabassa, Laboratorio de Geomorfología y Cuaternar, CADIC-CONICET, Ushuaia, Tierra del Fuego, Argentina

Vikram Unnithan, Department of Earth and Space Sciences, Jacobs University Bremen, Bremen, Germany

SpringerBriefs in Earth System Sciences present concise summaries of cutting-edge research and practical applications. The series focuses on interdisciplinary research linking the lithosphere, atmosphere, biosphere, cryosphere, and hydrosphere building the system earth. It publishes peer-reviewed monographs under the editorial supervision of an international advisory board with the aim to publish 8 to 12 weeks after acceptance. Featuring compact volumes of 50 to 125 pages (approx. 20,000—70,000 words), the series covers a range of content from professional to academic such as:

- A timely reports of state-of-the art analytical techniques
- bridges between new research results
- snapshots of hot and/or emerging topics
- literature reviews
- in-depth case studies

Briefs are published as part of Springer's eBook collection, with millions of users worldwide. In addition, Briefs are available for individual print and electronic purchase. Briefs are characterized by fast, global electronic dissemination, standard publishing contracts, easy-to-use manuscript preparation and formatting guidelines, and expedited production schedules.

Both solicited and unsolicited manuscripts are considered for publication in this series.

More information about this series at <https://link.springer.com/bookseries/10032>

Johanna Fink · Elisa Heim · Norbert Klitzsch

State of the Art in Deep Geothermal Energy in Europe

With Focus on Direct Heating

 Springer

Johanna Fink
Institute for Applied Geophysics
and Geothermal Energy
RWTH Aachen University
Aachen, Germany

Elisa Heim
Institute for Applied Geophysics
and Geothermal Energy
RWTH Aachen University
Aachen, Germany

Norbert Klitzsch
Institute for Applied Geophysics
and Geothermal Energy
RWTH Aachen University
Aachen, Germany

ISSN 2191-589X ISSN 2191-5903 (electronic)
SpringerBriefs in Earth System Sciences
ISBN 978-3-030-96869-4 ISBN 978-3-030-96870-0 (eBook)
<https://doi.org/10.1007/978-3-030-96870-0>

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2022

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

As the Earth continuously supplies heat, geothermal energy is a renewable energy source. Since nearly 50% of Europe's energy demand is in the heating and cooling sector (Bertani et al. 2018), it is expected that geothermal energy will play an important role in the transition to a decarbonized energy system.

Currently, geothermal energy in the European Union has an installed capacity of about 24.3 GW_{th} for heating and cooling (Kujbus et al. 2020). This is only a very small amount compared to the total geothermal potential of Europe (ETIPDG 2018; Garabetian 2019). In 2018, Europe had 280 geothermal district heating systems, spread over 24 countries with an installed capacity of 4.8 GW_{th} . However, geothermal energy is currently harvested mainly from high-enthalpy resources, i.e. from resources located in regions with favorable geothermal conditions. Because these areas are geographically limited, using geothermal energy in less favorable regions with low-to-medium enthalpy resources, is essential for unleashing the full potential of geothermal energy, as these resources account for the majority of Central Europe's total geothermal potential (Richter 2017).

This book project arose from a request made by E.ON for a literature review about the state of the art in deep geothermal energy. It relates to an EU call for the demonstration of innovative technologies to reduce greenhouse gas emissions. In this call, E.ON applied for funding for the application of deep geothermal for district heating. We believe E.ON's request reflects the growing interest in deep geothermal energy in general, and among energy companies and communities in particular. In this book, we introduce the opportunities and limitations of geothermal energy usage, particularly in geothermally less favorable regions. To this end, we review the state of the art in deep geothermal energy with focus on direct heating. The book thus provides an overview of technologies used to obtain heat from the deep underground and discusses main technical and non-technical risks associated with deep geothermal projects.

Addressing readers without a geoscientific background, we first lay the foundations of geothermal energy by explaining the heat distribution in the Earth as well as the governing geological and geophysical processes in Chap. 1. Moreover, we introduce the classification of geothermal systems to set the frame for the geothermal

potential across Europe, which we discuss subsequently in Chap. 2. After a general overview, we explain in detail the geothermal potential of three example regions (Sweden, Poland, and Hungary) with different geological conditions. Chapter 3 gives an overview of the technologies applied for harnessing heat from the subsurface. We introduce the geothermal project development process and focus on exploration, assessment, development, and operation of a geothermal reservoir. For non-favorable subsurface conditions, reservoir stimulation is required for producing heat. Therefore, we introduce methods of developing these so-called Enhanced Geothermal Systems (EGS) and give an overview of existing large-scale EGS projects in Europe. We highlight innovative technologies and assess their potential to make heat usable. Associated technical and non-technical risks and barriers are outlined in Chap. 4. Finally, we summarize the findings of our literature study and draw conclusions regarding the technological state of the art for deep geothermal energy and its potential for direct heat use in Europe.

This work was initiated and funded by E.ON. We would like to thank our colleagues Bérénice Vallier, Matthis van Wickeren, and Tobias Ganther for their support with research and writing. Additionally, we thank Thorsten Gleu for the design of some of the figures and several publishers and authors for their permission to use and reproduce images.

Aachen, Germany
October 2021

Johanna Fink
Elisa Heim
Norbert Klitzsch

References

- Bertani R, Buesig H, Buske S, Dini A, Hjelstuen M, Luchini M, Manzella A, Nybo R, Rabbel W, Serniotti L, Science TD, Team T (2018) The First Results of the DESCramBLE Project. In: PROCEEDINGS, 43rd Workshop on Geothermal Reservoir Engineering. Stanford University, Stanford, California, p 16, URL <https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2018/Bertani.pdf>. Accessed 25 Oct 2021
- ETIP-DG ETaIPoDG (2018) Strategic Research and Innovation Agenda. Tech. rep., European Technology and Innovation Platform on Deep Geothermal (ETIPDG). URL http://www.etip-dg.eu/front/wp-content/uploads/AB_AC_ETIP-DG_SRA_v3.3_web.pdf. Accessed 25 Oct 2021
- Garabetian T (2019) Report on Competitiveness of the geothermal industry. Tech. rep., European Technology and Innovation Platform on Deep Geothermal (ETIP-DG). URL <http://www.etip-dg.eu/front/wp-content/uploads/D4.6-Report-on-Competitiveness.pdf>. Accessed 25 Oct 2021
- Kujbus A, van Gelder G, Urchueguia JF, Pockel   L, Guglielmetti L, Bloemendal M, Blum P, Pasquali R, Bondu   S (2020) Strategic Research Innovation Agenda for Geothermal Technologies. Tech. rep., Geothermal Panel of European Technology Platform on Renewable Heating and Cooling. URL www.rhc-platform.org. Accessed 21 October 2021
- Richter M (2017) Summary of New Drilling Technologies. Tech. rep., International Energy Agency - Geothermal (IEA Geothermal). URL <http://iea-gia.org/wp-content/uploads/2014/10/IEA-Geothermal-Drilling-Technologies.pdf>. Accessed 25 Oct 2021

Contents

1	Introduction to Geothermal Systems	1
1.1	Introduction	1
1.2	Earth's Heat	2
1.3	Rock Types and Their Properties	3
1.4	Stress Field and Seismicity	4
1.5	Classification of Geothermal Systems	6
1.5.1	Geothermal Play Types	6
1.5.2	Geothermal Reservoir Types	8
	References	9
2	Geothermal Potential Across Europe	11
2.1	Geothermal Conditions Across Europe	11
2.2	South Sweden	13
2.3	Poland	17
2.4	Hungary	21
	References	25
3	Technologies for Deep Geothermal Energy	29
3.1	Introduction	29
3.2	Prediction and Assessment of Geothermal Resources	31
3.3	Resource Access and Development	35
3.3.1	Geothermal Drilling	36
3.4	Enhanced Geothermal Systems (EGS)	41
3.4.1	Stimulation Techniques	42
3.4.2	EGS Demonstration Projects	45
3.5	Reservoir Operation	46
Appendix 1:	Selected European Research Projects on Deep Geothermal	49
Appendix 2:	Selected Deep Geothermal Sites Across Europe with a Focus on EGS Sites	56
	References	65

- 4 Risks and Barriers** 75
 - 4.1 Introduction 75
 - 4.2 Non-technical Risks 76
 - 4.3 Technical Risks 77
 - 4.4 Environmental Risks 81
 - References 82
- 5 Summary and Conclusions** 87
 - References 89
- Index** 91