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Findability of geothermal energy websites in seven EU countries and Iceland

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A B S T R A C T

Obtaining information on scientific topics and access to websites with multidimensional data is a crucial part of any geothermal project development. Using the Internet to publish information according to the FAIR principles (Findability, Accessibility, Interoperability and Reusability) on topics that are not yet well known to stakeholders could improve not only general knowledge but also public acceptance for increased use of geothermal in the future. This research lists 90 geothermal websites from eight countries: nine in Austria, 13 in Croatia, eight in Hungary, 17 in Italy, seven in Germany, 16 in Iceland, 13 in the Netherlands and seven in Slovenia, and classifies them based on findability and content criteria. It is an issue that only 41 % of these national-relevant websites are easy to find using a browser and keywords, while for the rest an expert advice is needed. The user-impression by searching these websites was checked, for example, on language, graphical presentation, type of information, content, and references. It was expected that Iceland, Italy and Germany, as the countries with the largest geothermal utilization, have the most information available. Iceland has the most findable and quality websites, while Italy has the most listed websites but only a few are easy to find. Germany is not ranked as high as expected. The Netherlands and Croatia do not stand out but have few very good websites. Hungary and Austria show similar results while Slovenia needs most improvements.

1. Introduction

In today's internet-dominated world, the accessibility of information on websites is crucial. The internet has becoming more interactive with the development of Web 2.0, allowing users to create content rather than just consume it. With the help of applications, social media and web tools, individuals can now create, transform and share information in a wider, social environment (Allen, 2012). This shift has opened up new avenues for knowledge creation, but also new opportunities for citizens to connect with their particular interests.

In this digital world, awareness of geothermal energy is increasing and geothermal is a popular topic on many renewable energy websites, scientific projects and achievements. Several research papers (Angelis-Dimakis et al., 2011; Azraff Bin Rozmi et al., 2019; Kazmi et al., 2021; Sharpton et al., 2020; Zaunbrecher et al., 2018) suggest that public acceptance of renewable energy resources and the availability of public data on sustainable energy is a crucial part of their further development. However, not all online data is supported by good data management. Therefore, this research addresses this issue following the FAIR principles (Findability, Accessibility, Interoperability, and Reusability) introduced in 2016 (Wilkinson et al. 2016; Zastempowski, 2023).

The problems associated with the excessive use of fossil fuels and the

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Abbreviation

AT	Austria
DE	Germany
HR	Croatia
HU	Hungary
IS	Iceland
IT	Italy
NL	The Netherlands
SI	Slovenia
FAIR	Findability, Accessibility, Interoperability, and Reusability
WGC	World Geothermal Congress

Units

MW_{el}	Megawatt electric
MW_{th}	Megawatt thermal
TJ/yr	Terajoules per year

associated emissions are one of the greatest challenges of this century (Zastempowski, 2023). The energy crisis that developed from the Russian-Ukrainian war has emphasised the importance of renewable energy in diversifying energy sources, where geothermal energy can play an important role. It is not only sustainable and reliable, but also provides an independent and cost-effective source of energy (Soltani et al., 2021). It is therefore crucial for the future development of renewable energy, including geothermal, to provide access to important geoscientific and economic data and to provide non-experts with basic knowledge in the form of interpreted geoscientific data. Alongside, understanding the process of development of public perception on geothermal energy is useful (Turnšek and Kokot, 2025).

In the global overview of the direct use of geothermal energy in 2020 (Lund and Toth, 2021), 88 countries report an increase in direct use compared to previous years. An estimate of the installed thermal capacity for geothermal heating was 107,727 MW_{th} at the end of 2019, which corresponds to an annual growth rate of 8.7 %. According to the statistics for the WGC2020 (Huttrer, 2021) and the WGC2015 (Bertani, 2016), China shows the greatest absolute increase in geothermal power generation (not per capita or area). With respect to installed capacities for the direct utilisation of deep geothermal energy in Europe 2012–2021 (Sanner et al., 2022), Turkey is in the first place. In terms of area or population, however, smaller countries dominate, especially the Nordic countries. Most of the thermal energy (58.8 %) was used for ground source heat pumps, while 18.0 % was used for bathing and swimming (including balneology), 16.0 % for space heating (of which 91.0 % for district heating), 3,5 % for greenhouse heating, 1.6 % for industrial applications, 1.3 % for aquaculture and racecourse heating, 0.4 % for agricultural drying, 0.2 % for snow melting and cooling and 0.2 % for other applications (Lund and Toth, 2021).

There are some good examples of geothermal websites that are known worldwide. In the U.S., a web tool called USGIN – U.S. Geoscience Information Network (USGIN, 2023) aims to collect and share all geoscience data from across the country, including geothermal data. This is an example of a unified system at the national level that is available to the public.

In European countries, there are many websites created as part of projects funded by various funding mechanisms (e.g. Horizon, European Economic Area, Interreg, etc.), which often results in them ceasing to function after a few years due to poor maintenance or domain expiry. On the other hand, websites maintained by organisations, public authorities, educational and research institutions and national service providers are usually long-lasting and are updated more frequently. European Geological Data Infrastructure (EGDI) managed by EuroGeoSurveys is one of geoscientific repositories that plans to overcome this barrier in the following years. However, the websites are not always easy to find, as presented here. A group of seven EU countries and Iceland were selected for this study. Slovenia encouraged it as it is one of the 41 full members of the European Cooperation in Science and Technology, leading the project INFO-GEOTHERMAL, funded by the European Economic Area programme between 2022 and 2024. The project aimed to foster the use of thermal water through the publication of available information, and was focused on Slovenia and its neighbouring countries: Austria, Croatia, Hungary and Italy, as well as the project partner Iceland. In addition, Germany and the Netherlands were selected for comparison as one of the fastest growing geothermal markets in the EU (Lund and Toth, 2021).

This research gathers and analyses websites in eight countries, for the first time: Slovenia, Austria, Germany, Croatia, Hungary, Iceland, Italy and the Netherlands. The hypothesis is that the countries with the highest installed capacity of geothermal energy have the largest amount of findable and publicly available websites. We assume that more websites are a consequence of more mature market with more installations and higher capacity. The research focuses on the discoverability of websites, which are listed in supplementary materials, and the availability of data for a non-professional stakeholder interested in geothermal energy. It focuses on: (1) identifying the findable and coherent national websites with geothermal content, (2) assessing their information types (e.g. text, graphics, spatial data, …) and (3) evaluating their accessibility in other languages, and academic integrity in terms of referencing. This overview is advised to be used for knowledge and best-practice transfer to improve the reader's websites and not as an exhaustive national list of such websites.

Websites of EU and international projects and organisations (e.g. the European Geological Data Infrastructure, ThinkGeoEnergy, International Geothermal Association, European Geothermal Energy Council…) were explicitly excluded from the study, as the focus was on the websites that are relevant and maintained at a national level.

2. Geothermal energy utilization in eight selected countries

The total installed capacity and utilisation types are reported based on classifications used for Country reports for European Geothermal Congresses as instructed by Burkhard Sanner and colleagues since 2013. The six categories are discussed in this paper. Electricity production denotes its production from thermal water and steam. District heating is defined as the use of one or more production fields of thermal water as sources of heat to supply thermal energy through a network to multiple buildings or sites, for the use of space or process heating or cooling, including associated domestic hot water supply. If greenhouses, spas or any other category is among the consumers supplied from such a network, it should be counted as district heating and not within the category of the individual consumer (e.g. Balneology or Greenhouse heating). In case heat pumps are applied in any part of such a network, they also should be reported as district heating and not as geothermal heat pumps. Geothermal heat for buildings stands for sites using thermal water at individual buildings which are not connected to a network (expression individual space heating was often used in the past). On the opposite, ground-source heat pumps (GSHP) do not use thermal water but shallow geothermal sources which provide low-temperature water to heat pumps to produce energy.

Data from 2021 was available for six EU countries, from 2020 for Iceland (Huttrer, 2021), and from 2019 for the Netherlands (Provoost and Agterberg, 2022) (Table 1). Minor uses such as cooling, fish farming, snowmelt and industrial processes were not included in this assessment. The reader should check the methodology to understand differences among various types, if needed.

The main geothermal use is direct use of which the total installed capacity was 14,605 MW_{th} (Table 1). The ranking of investigated countries by installed capacity is: (1) Germany (5337 MW_{th}), (2) Iceland (2471 MW_{th}), (3) Italy (2223 MW_{th}), (4) the Netherlands (1833 MW_{th}),

Table 1
Installed capacity of different types of geothermal energy use by country in 2021, except for Iceland (2020) and The Netherlands (2019).

Country	Year	Electricity production [MW_{el}]	District heating [MW_{th}]	Ground-source heat pumps [MW_{th}]	Greenhouse heating [MW_{th}]	Balneology [MW_{th}]	Geothermal heat for buildings [MW_{th}]	SUM [MW_{th}] (without electricity production)	References
AT	**2021**	1.20	75.10	1120.00	18.80	43.10	9.80	1267	Goldbrunner and Goetzl, 2022
HR	**2021**	16.50	42.30	no data	6.84	18.31	14.10	82	Živković et al., 2022
HU	**2021**	2.30	235.29	80.00	429.50	263.00	86.11	1094	Nádor et al., 2022
IT	**2021**	915.80	164.00	907.14	147.00	387.00	618.00	2223	Della Vedova et al., 2022
DE	**2021**	47.60	345.80	4930.00	no data	56.80	4.28	5337	Weber et al., 2022
IS	**2020/2021**	755.00	1990.00	1.20	145.00	335.00		2471	Ragnarsson et al., 2022
NL	**2019**	0	3.15	1600.00	230.00	no data		1833	Provoost et al., 2022
SI	**2021**	0	49.58	237.75	6.34	3.22	1.56	298	Rajver et al., 2022
	TOTAL WITH ELECTRICITY	**1738**	**2905**	**8876**	**983**	**1106**	**734**	**16,342**	
	%	**11**	**18**	**54**	**6**	**7**	**4**	100	

(5) Austria (1267 MW_{th}), (6) Hungary (1094 MW_{th}), (7) Slovenia (298 MW_{th}), (8) Croatia (82 MW_{th}) (Fig. 1). If geothermal heat pumps and electricity are excluded from this comparison, Iceland (2470 MW_{th}) is in first place, followed by Italy (1316 MW_{th}), Hungary (1014 MW_{th}) and Germany (407 MW_{th}) in third and fourth place.

The electricity production sums to 1738 MW_{el}. The most is produced in Italy (916 MW_{el}), followed by Iceland (755 MW_{th}), significantly less in Germany (48 MW_{th}) and Croatia (17 MW_{th}), while Hungary and Austria have the lowest production.

A comparison of the percentage share of utilisation types within the countries (Table 2) shows that the most important utilisation types are district heating in Iceland (81 %) and Croatia (52 %), geothermal heat pumps in Germany (92 %), Austria (88 %), the Netherlands (87 %), Slovenia (80 %) and Italy (41 %), and greenhouse heating (39 %) in Hungary.

A comparison of total installed capacity by category in the eight countries (Table 3) shows that the largest use of geothermal energy for district heating is in Iceland (68.5 %), geothermal heat pumps in Germany (55.5 %), greenhouse heating in Hungary (43.7 %), balneology (35.0 %) and geothermal heat for buildings (84.2 %) in Italy. Austria, Slovenia, the Netherlands and Croatia do not have outstanding total installed capacities in the individual categories. With the exception of geothermal heat pumps and electricity, as they have a slightly different market approach, the majority of capacity for direct use in Austria, Germany and Slovenia is used for district heating, in the Netherlands for greenhouse heating, in Croatia, Hungary and Iceland for balneology and

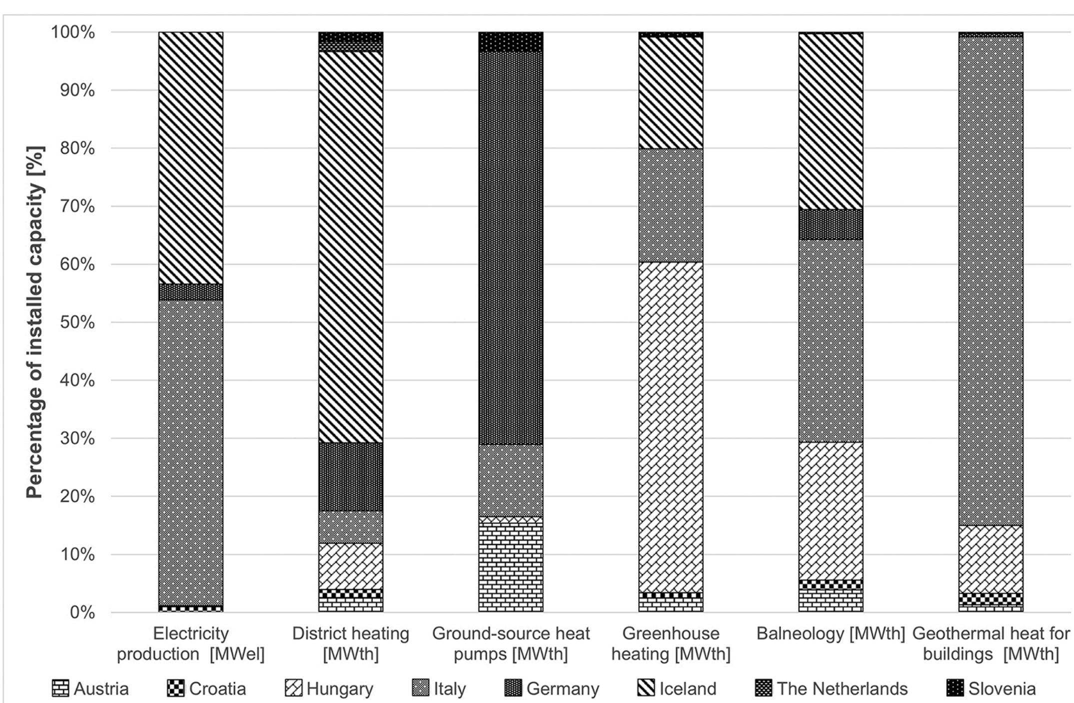

Fig. 1. 100 % stacked bar chart by types of the installed capacity of used geothermal energy by eight selected countries.

Table 2
Distribution of the dominant type of geothermal energy installed capacity in each country. The predominant type of direct use in a country, without electricity, is bolded. Row total is 100 %.

Country	Electricity production	District heating [%]	Ground-source heat pumps [%]	Greenhouse heating [%]	Balneology [%]	Geothermal heat for buildings [%]
AT	MINIMAL	6 %	**88 %**	2 %	3 %	1 %
HR	NOTICEABLE	**52 %**	0 %	8 %	23 %	17 %
HU	MINIMAL	22 %	7 %	**39 %**	24 %	8 %
IT	MAXIMUM	7 %	**41 %**	7 %	17 %	28 %
DE	MINIMAL	7 %	**92 %**	0 %	1 %	0 %
IS	A LOT	**81 %**	0 %	6 %	13 %	0 %
NL	NO	0 %	**87 %**	13 %	0 %	0 %
SI	NO	16 %	**80 %**	2 %	1 %	1 %

Table 3
Distribution of countries according to shares within each category of use. The dominant one in the country is bolded. The total in the column is 100 %.

Country	Electricity production [%]	District heating [%]	Ground-source heat pumps [%]	Greenhouse heating [%]	Balneology [%]	Geothermal heat for buildings [%]
AT	0.1	2.6	12.6	1.9	3.9	1.4
HR	1.0	1.5	0.0	0.7	1.6	1.9
HU	0.1	8.1	0.9	**43.7**	23.8	11.7
IT	**52.7**	5.6	10.2	15.0	**35.0**	**84.2**
DE	2.7	11.9	**55.6**	0.0	5.1	0.6
IS	43.4	**68.5**	0.0	14.7	30.3	0.0
NL	0.0	0.1	18.0	23.4	0.0	0.0
SI	0.0	1.7	2.7	0.6	0.3	0.2

in Italy for geothermal heat for buildings.

At least in some countries, the installed capacity is expected to increase significantly soon due to the rapid development of geothermal energy utilization (Goldbrunner and Goetzl, 2022).

2.1. Ground source heat pumps

Geothermal ground source heat pumps provided around 58.8 % of thermal energy in 62 selected countries worldwide in 2020 (Lund and Toth, 2021). Germany (Fig. 1) had the conspicuously highest installed capacity (4930 MW_{th}), which is due to a large growth potential for shallow and medium-deep geothermal resources, especially for new buildings or through the use of high-temperature heat pumps (Sanner et al., 2022; Weber et al., 2022). Data on this category was not available for Croatia.

2.2. District heating

District heating is a widely used technology in Europe with >6000 different systems installed. This technology is considered to be a good replacement for conventional heat sources, also for improving overall energy efficiency (Sayegh et al., 2018). In 2020, it accounted for around 14.5 % of the thermal energy used worldwide (Lund and Toth, 2021).

Iceland (Fig. 1), with an installed capacity of 1990 MW_{th}, is the leader in the use of district heating among the countries analysed. Its use dates back to 1930. Today, Reykjavík Energy is by far the largest geothermal district heating supplier in Iceland, supplying around 65 % of the Icelandic population (Ragnarsson et al., 2022). Cascade use is applied in many Iceland systems where waste heat from electricity production is used for district heating.

2.3. Greenhouse heating

The distribution of thermal energy in 2020 showed that around 3.5 % was used to heat greenhouses worldwide (Lund and Toth, 2021).

Hungary (Fig. 1) is the leader in the installation of greenhouse heating systems among the countries analysed. With a capacity of 429.5 MW_{th}, classified as geothermal heat in agriculture and industry (Nádor et al., 2022), this type of utilisation has experienced significant growth.

2.4. Balneology

Approximately 18.0 % of global thermal energy distribution in 2020 was used for balneology (Lund and Toth, 2021).

Italy (Fig. 1) had the highest capacity among the countries considered in 2021 (387 MW_{th}). The use of geothermal energy in Italy dates back to the Roman era (Della Vedova et al., 2022).

2.5. Geothermal heat for buildings

The individual use of geothermal energy has increased over the last two decades. It is part of individual space heating, which excludes district heating, geothermal heat pumps and greenhouse heating (Lund and Toth, 2021).

Italy (Fig. 1) has by far the largest capacity (618 MW_{th}) among the countries analysed, which corresponds to around 28 % of the total installed capacity including electricity in 2021. In terms of numbers, it is in third place, after electricity and geothermal heat pumps (Della Vedova et al., 2022).

2.6. Electricity production

The total electricity generation capacity in the selected countries amounts to 1738 MW_{el}, with Italy having the highest capacity (916 MW_{el}), which corresponds to 53 % of the total (Fig. 1) (Della Vedova et al., 2022). Iceland (data from 2019) follows with 43 %, while in other countries it is more symbolic. There is no geothermal power generation in the Netherlands and Slovenia to date (Della Vedova et al., 2022; Provoost and Agterberg, 2022; Rajver et al., 2022) while Croatia built its first geothermal power plant in 2018 (Živković et al., 2022).

3. Methodology

This research targets geothermal websites covering national areas, therefore, no unique project-related websites are included. It was conducted in three steps. First, the Google Chrome search engine was used by entering five keywords and the name of the country as described in Tab 3.1 on a personal computer of the Geological Survey of Slovenia, which was purchased in October 2022 and with no previous search history on this topic. Second, this list was supplemented with websites

Table 4
Scoring table for the findability criterion. Only one can be selected.

No.	Findability
1	website is findable only indirectly through other websites, contacting local experts, or as a targeted search
2	website is findable by using keywords in native language
3	website is findable by using keywords in English

suggested by the experts from all countries. Third, this list was evaluated as described in chapters 3.1–3.6.

The websites that were found using keywords are labelled “F”. The websites that were listed based on expert judgement and a targeted search are labelled “N”.

Six predefined criteria (see Tabs 3.1–3.6) were used to analyse the findability, content, language options, graphical presentation, academic integrity as references and their nature for each of the listed websites.

The results were categorised according to findability criteria. The websites within the same findability category (Table 4) were ranked in descending order of total score. If the websites in the same findability category received the same score, they were listed according to the descending type of information. If all criteria were the same, they were listed in alphabetical order.

The main objective was to obtain quantitative assessments for comparing the websites. Therefore, a descriptive form was avoided and classes that allow categorisation according to the chosen criteria were created. Higher score indicates better practise in the findability and presentation of the data.

The list of 90 websites with evaluation is available in supplementary material.

3.1. Findability

The degree of findability was determined by entering the keywords “geothermal”, “geothermal energy”, “geothermal association”, “geological survey” and “geothermal database” with the name of the country (e.g. Austria) into the Google Chrome search engine. The keywords were initially used in English. Later, when nothing relevant was found, the same keywords were used in the native language of the selected country. In some cases, online dictionaries and translators such as PONS online translator, Google Translate and DeepL Translate were also used.

It was expected that searching with the keywords in the native language would yield a broader list of websites. However, before compiling the final list, the geothermal experts from all countries suggested additional websites that were not found using this search method. As can be seen in Table 4, the subsequently added websites from the expert judgement were given the lowest score for the findability criterion, namely one out of three (possible). Higher scores mean better findability. These websites were also labelled “N” in Annexes 1 and 2 instead of “F” for websites with two or three points.

Findability as F in FAIR principles strongly depends on machine-readable metadata for automatic discovery of datasets and services. The presented analysis did not search for or evaluate the structured metadata, but much simpler approach was applied (Table 4) without artificial intelligence (AI) tools.

3.2. Content

The available information was categorised into five groups:

- Information – basic information about the organisation, its work, achievements, etc.
- Contact – emails, mobile phone numbers, addresses of contact persons in the organisation/company.
- News – new project and research results (including published articles), further plans in the field of geothermal energy, upcoming events, reports and news about past events, conferences, summer schools, and seminars.
- Up to date – the date of the last published news or information of any kind had to be from at least 2022. Otherwise, the website was considered out of date.
- Social media – all available links leading to the official social media profiles (e.g. Facebook, Instagram, LinkedIn, Twitter, YouTube).

Websites found without any content on geothermal energy (e.g. basic definitions, information on the geothermal potential of an analysed country and its use at national level, etc.) were automatically excluded from further analysis. The defined classes are listed in Table 5. Only one selection can be made for each category. More points (1) mean better content.

3.3. Language options

As the world is increasingly multilingual, it was expected that most of the information is available in English. This category was divided according to the following definitions:

Table 5
Scoring table for the content criterion. Only one can be selected within the categories.

	Content
No.	***Information***
0	no basic information about the organisation
1	basic information about the organisation is available
No.	***Contact of the organisation/company***
0	no contact in any form (email, phone, address, etc.)
1	contact is available in some form (email, phone, address, etc.)
No.	***News***
0	no news available
1	news available (links to publications and articles, published events, etc.)
No.	***Up to date***
0	news and other information available were published before 2022
1	news and other information available were published in and after 2022
No.	***Social media***
0	no links to official profiles on social media (Facebook, Instagram, LinkedIn, Twitter, YouTube) available
1	at least some links to official profiles on social media (Facebook, Instagram, LinkedIn, Twitter, YouTube) are available

Table 6
Scoring table for the language criterion. Only one can be selected within the categories.

	Language
No.	***Categories***
0	only official language
1	less content in English and/or other than official languages
2	less content in official language
3	no difference between languages
No.	***Other***
n	number of other languages (with an abbreviation of their name in a separate column in Annex 2)

Table 7
Scoring table for the graphical display criterion. Only one can be selected.

No.	Graphical display
1	difficult to use and navigate and low interactivity (information is indirect and poorly accessible) with none to very few tabs and sub-tabs and none to very few images
2	rather easy to use and with some interactivity (some of the information is directly accessible) with few tabs and sub-tabs (insufficient for some of the content), few images shown
3	easy to use and with good interactivity (most of the information is directly accessible, sometimes website offers extra interactive tools – e.g., UserWay), many images that support the text

Table 8
Scoring table for the academic integrity criterion. Only one can be selected within the categories.

	Academic integrity
No.	***References***
0	no references for both text and images
1	references only for text or images
2	references for both, text and images
No.	***Responsible person***
0	no contact (email, phone, address, etc.) is available
1	contact is available in some form (email, phone, address, etc.)
No.	***Extra links***
0	no extra links are available
1	extra links to original data are available

- Official – the predominant official language spoken in the country being analysed.
- English – English language.
- Other – any languages that were not previously listed (e.g. if the organisation operates in multiple countries).

It was checked whether or not the content was identical in all languages. The four listed possibilities are given in Table 6. Other languages used were listed separately in Annex 2 and added to the final score.

3.4. Graphical display

Graphical representation is the category most prone to subjectivity. Therefore, four themes were combined to categorise the websites (Table 7):

- Ease of use – first impression of the website, directness of available data.
- Tabs and sub-tabs – number of tabs, meaningful division of the website content into thematic sections.
- Interactivity – enabling a two-way flow of information between the website and the user, responding to the user's input (e.g. encouraging social sharing, suggesting relevant links, enabling conversation, publishing user-generated content, etc.).
- Images – visualisation of the text (e.g., photos, charts, sketches, etc.) – images with an aesthetic purpose and not fully related to the topic were excluded.

Some of the websites offer special interactive tools, such as UserWay or a virtual chat with a robot or employee, which combines both ease of use and interactivity. UserWay defines itself as an AI-supported technology for website accessibility that offers numerous functions for people with disabilities (e.g. motor disabilities, blind people, colour-blind people, dyslexics, visually impaired people, epileptics, etc.).

3.5. Academic integrity

Three aspects of academic integrity were considered and evaluated in Table 8:

- References – imply if the content (text and images) is accompanied by an acknowledgment of the source, or not. This is one of the general criteria for findability evaluation (as F in FAIR principles).
- Responsible person – sometimes, especially when no reference is available, a contact of the responsible person is added, with a possibility of gaining more verified information about the content.
- Extra links – when the content is the result of a previously published information, it is accompanied by additional links to original data, such as official publications or other websites.

Table 9
Scoring table for the type of information criterion. Only one can be selected.

No.	Type of information
1	1D – text, tables, chemical analysis, etc.
2	2D – maps, graphs, photos, sketches, and schemes
3	3D – profile sections, borehole logs, 3D model

3.6. Type of information

The categorisation of information by their dimension was made as shown in Table 9. It was made according to the proposal of He et. al. (2020), where 3D does not only mean 3D spectral models, but also a 2D profile, which can be a product of 3D seismic data, for example (He et al., 2020)7. Higher dimension information was favoured and therefore scored higher as it provides spatial data and more visualisation that can be used for more detailed geothermal exploration.

In this stage of research, there was no criteria set regarding the simplicity of data access. In future this could be tested, for example: is it free, free with registration or available only with payment.

3.7. Comments

Additional comments could be added in website ranking tables in Annex 2 to emphasise the advantages and disadvantages of the websites. For example, in this section the aesthetics, access to the web portals, content, difficulties in accessing certain information, etc. were highlighted.

3.8. Summary evaluation

After evaluating the individual websites in the selected countries, an overview of the results was compiled. First, a sum of the points obtained per website and then per country was calculated. A neutral approach in which all criteria are considered equally without weighting them was taken.

Second, a list of websites was created for each country (Annex 1). The websites were listed according to the criterion of findability (Annex 2). Finally, an analysis was created in which the following ratios were compared: (1) sum of websites labelled “F” and “N” per country, (2) sum of scores and total number of websites found, (3) sum of scores and installed capacity per country, and (4) number of websites per country with 3 points for findability and total number of websites per country.

4. Results and discussion

A total of 90 websites was identified from eight countries (Annexes 1 and 2): 17 websites for Italy, 16 for Iceland, 13 for the Netherlands and 13 for Croatia, nine for Austria, eight for Hungary, seven for Germany and Slovenia, each. By clicking on the website title in Annex 1, a direct link to the website is activated. The websites are listed with the full name in the official language and, if available, also in English. At the end, the official abbreviation of the host institution is added in brackets. It this is not available, no abbreviations are added. The evaluation of the listed websites according to the proposed methodology can be found in Annex 2.

Although a correlation between installed capacity and total score was expected in this analysis, the countries with the highest installed capacity did not necessarily receive the highest score, such as Germany in seventh place (Fig. 2). Due to the method used, some important websites (e.g. Orkustofnun, Skemman and GRÓ in Iceland) were placed further down in the rankings as no weighting was applied.

4.1. Findability and type of information as the key criteria

The relationship between the installed capacity (Table 1) and the total scores received (Table 10) is not always such that the countries with the largest installed capacity receive the highest score.

When comparing the total number of F (two or three points) and N (one point) websites in each country, Iceland ranks first due to the largest number of findable websites (Table 10), with the website Orkustofnun in first place, which offers an extensive geothermal database. Iceland also leads in total scores and ranks second overall in the total number of websites. The website of the Icelandic geological survey (ÍSOR) was easy to find (listed as F2 in Annexes 1 and 2).

Although the number of findable websites in the Netherlands is not particularly high, it should be noted that the country offers a wide range of websites with large open access datasets (namely, at least, NLOG, ThermoGIS, DINOloket and WarmteAtlas). This is due to their adapted legal system, which facilitates access to data (e.g. in the Netherlands, the Mining Act was amended in 2004 and since then it is mandatory to publish all data after five years). Their geological survey (TNO) has an easily findable website (listed as F1 in Annexes 1 and 2).

Croatia has a comparable number of findable websites as the Netherlands. The Croatian geological survey’s (HGI) website is not very easy to find (listed as F5 in Annexes 1 and 2). Even more difficult to find was the site of the Austrian geological survey (Geosphere) which is listed only as N3 in Annexes 1 and 2.

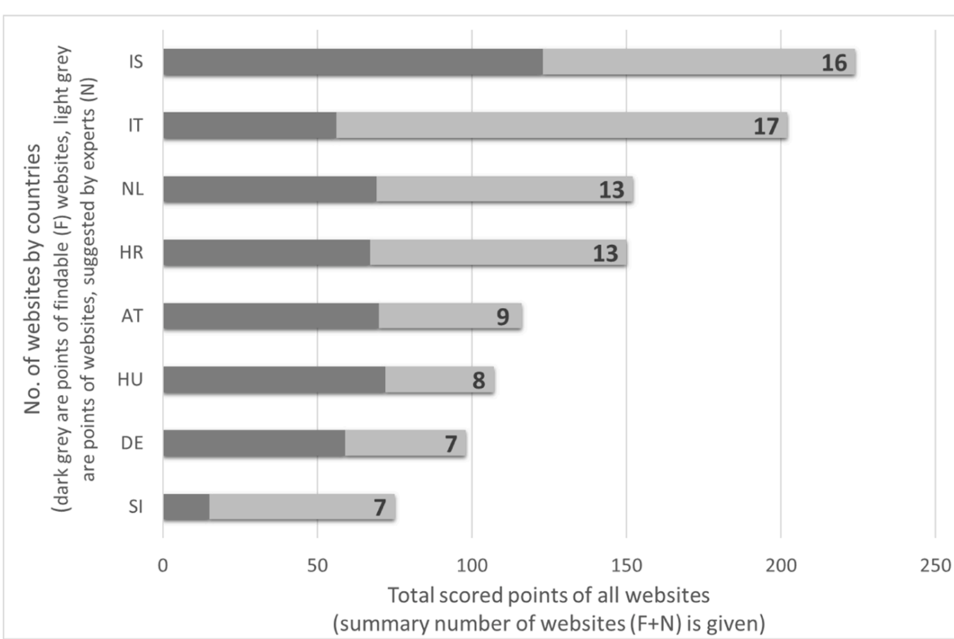

Fig. 2. Calculated scores for each country.

Table 10
Scoring results of websites by country according to accessibility (categories F and N) and the sum of all points.

Country	No. of Findability 3 (= F)	No. of Findability 2 (= F)	No. of websites F	Total points of websites F	No. of Findability 1 (= N)	Total points of websites N	No. of websites	Total points
SI	1	0	1	15	6	60	7	**75**
DE	3	1	4	59	3	39	7	**98**
HU	3	2	5	72	3	35	8	**107**
AT	3	2	5	70	4	46	9	**116**
HR	1	4	5	67	8	83	13	**150**
NL	5	0	5	69	8	83	13	**152**
IT	3	1	4	56	13	146	17	**202**
IS	6	2	8	123	8	101	16	**224**
TOTAL	**25**	**12**	**37**	**531**	**53**	**593**	**90**	**1124**

Table 11
Scoring results of websites by country regarding the range of all points in the scored content of the page.

Country	No. of websites	Total Points	Min points per website	Max points per website	Total points/ No. of websites	Points F/ No. of websites F	No. of websites F / No. of websites	No. points content F websites	No. points content N websites	Total points content	No. points content F websites / Total
SI	7	**75**	6	15	10.7	15.0	14 %	4	11	15	27 %
DE	7	**98**	7	17	14.0	14.8	57 %	15	7	22	68 %
HU	8	**107**	9	18	13.4	14.4	63 %	15	11	26	58 %
AT	9	**116**	9	17	12.9	14.0	56 %	19	14	33	58 %
HR	13	**150**	6	16	11.5	13.4	38 %	18	25	43	42 %
NL	13	**152**	9	16	11.7	13.8	38 %	18	21	39	46 %
IT	17	**202**	7	18	11.9	14.0	24 %	12	45	57	21 %
IS	16	**224**	9	17	14.0	15.4	50 %	31	26	57	54 %
TOTAL	**90**	**1124**	**6**	**18**	**12.5**	**30.4**	**41 %**	**132**	**160**	**292**	**45 %**

Table 12
Scoring and ratios by country for multilingual and graphical display.

Country	No. of websites	Total Points	Language - No. with 0 points	Language F - No. with 0 points	Language - No. with 3 points	Language F - No. with 3 points	Language - No. with 0 points/No. of websites	Graphical display - No. with 3 points	Graphical display - No. with 3 points / No. of websites
SI	7	**75**	2	0	3	0	29 %	4	57 %
DE	7	**98**	1	0	3	1	14 %	5	71 %
HU	8	**107**	5	3	2	2	63 %	7	88 %
AT	9	**116**	5	1	2	2	56 %	9	100 %
HR	13	**150**	3	1	5	2	23 %	9	69 %
NL	13	**152**	0	0	1	1	0 %	11	85 %
IT	17	**202**	11	2	4	2	65 %	17	100 %
IS	16	**224**	0	0	9	5	0 %	16	100 %
TOTAL	**90**	**1124**	**27**	**7**	**29**	**15**	**30 %**	**78**	**87 %**

In Germany, on the other hand, there is no standardised data for the whole country, although it has the highest total installed capacity (excluding electricity generation). Germany is second to last in the ranking of the number of findable websites and total score, and shares the last place with Slovenia in terms of the total number of websites listed. This is a consequence of the separate federal system for 16 federal states with their own geological surveys, which prevents the creation of a standardised German geothermal database. As a result, most of the data is only available in physical form in different locations and is very difficult to access from abroad. These surveys collaborate through the State Geological Surveys of Germany (BVG) and work alongside the Federal Institute for Geosciences and Natural Resources (BGR; listed as F2 in Annexes 1 and 2) for national-level projects.

On the other hand, the F/N ratio has shown that Hungary has the highest percentage of findable websites. It also ranks second in the overall score of the F-websites but is ranked sixth in the total score of all websites. The website of its survey (MBFSZ/SZTFH) was rather difficult to find (listed as N1 in Annexes 1 and 2).

Slovenia has a very poor performance, the lowest number of findable websites and the lowest F/N ratio. Its easiest found website is managed by the geological survey (GeoZS) (listed as F1 in Annexes 1 and 2).

For Italy, no website managed by their geological survey (ISPRA) was listed in this paper.

Individual websites from Hungary and Italy received the highest scores, followed by Austria, Iceland and Germany (Table 11). The highest ratio of total score to number of websites is observed for Iceland and Germany, followed by Hungary, Austria, Italy, the Netherlands, Croatia and Slovenia. If only findable (F) websites are considered, the highest ratio of total score to the number of these websites is observed for Iceland and Slovenia, followed by Germany, Hungary, Italy and Austria. The highest percentage of findable websites of all those listed is reported for Hungary, followed by Germany, Austria and Iceland. In Hungary, the same company manages three websites with different findability (F4, F5, N2 in Annex 1 and 2).

4.2. *Content and language*

These two criteria were found to be strongly linked, similar to findability and type of information. Most countries have a sufficient number of websites with the same content in English, in the official language and in other available languages (Table 12). In Iceland, however, most websites are equally available in English and Icelandic or are

Table 13
Scoring and ratios by country for academic integrity.

Country	No. of websites	Integrity References - No. of websites with 0 points	Integrity References - No. of websites with 2 points	Integrity References - share of pages with cited references	Integrity Responsible person - No. of websites with 0 points	Integrity Responsible person - page share with the contact for the content in question	Integrity Extra links - No. of websites with 0 points	Integrity Extra links - share of pages with extra links
SI	7	5	1	29 %	5	29 %	4	43 %
DE	7	3	2	57 %	4	43 %	0	100 %
HU	8	5	1	38 %	6	25 %	0	100 %
AT	9	6	1	33 %	6	33 %	4	56 %
HR	13	13	0	0 %	13	0 %	2	85 %
NL	13	12	1	8 %	10	23 %	4	69 %
IT	17	14	1	18 %	16	6 %	4	76 %
IS	16	14	0	13 %	14	13 %	6	63 %
TOTAL	**90**	**72**	**7**	**20 %**	**74**	**18 %**	**24**	**73 %**

only in English (93 % of all Icelandic websites found). Furthermore, Iceland and the Netherlands are the only two countries where no websites were found in the official language only (zero points). In Germany, too, more than 86 % of websites are in English. In Hungary, however, there are only two websites that are equally presented in English and Hungarian (13 %), while the others have less content in English. Italy, on the other hand, has the largest proportion of websites available only in the official language (65 % of all Italian websites found). Italy also has a low F/N ratio as it was generally impossible to find the website with the English search terms, and in most cases also with the Italian search terms.

Content available in English also led to better findability. All findable websites in Germany, Iceland, the Netherlands and Slovenia are also in English, but this is not necessarily the case in other countries. Some of the websites (Annex 2) were also available in other languages: Danish, French, Norwegian, Polish, Portuguese, Romanian and Spanish, depending on the organisation's activities in other countries.

4.3. Graphical display

The vast majority of websites is quite easy to use and has good interactivity (three points) (Table 12). In Slovenia, this criterion, along with findability, plays the biggest role on the official website of the Geological Survey of Slovenia (Annex 2), where it is not difficult to find the "Geothermal energy". However, when searching for spatial data of any kind, the user must be well informed about the name and designation of the data and its location on the website. Therefore, the eGeologija portal was not found without expert judgement, although it is the most important geological database in Slovenia. A better practice was shown in Austria, where the federal research institute GeoSphere has established a separate research data repository Tethys, which is directly available on the official website.

4.4. Academic integrity

This criterion is very important to determine the accuracy and reliability of the information on the websites. The average scores show that much can be improved (Table 13). Only 20 % of websites has references properly included, German, Hungarian, Austrian and Slovenian sites can serve as good examples. On average, only 18 % of websites has responsible person listed for a specific topic, German do act as best cases. External links are very common, 73 % of websites have them, and again, Germany and Hungary have most often listed them. The most outstanding websites are Geotermikus energia Magyarországon, GeotIS and GeoThopica (Annexes 1, 2). However, according to the established methodology, they were categorised as "N" as they were not easily findable.

4.5. Type of information

Most (67 %) of the websites found contained 2D information with maps, schemes and similar (Table 14). This is informative but not enough for more demanding users. Some websites (e.g. Tethys, AZU, OGRe, BGR, Orkustofnun, NLOG and GDN) also contain various 3D information. This is mainly due to relevant legislation and/or the clear ownership of the data. In percentages, Germany and Hungary have most 3D data available but looking at the number of sites, the Netherlands has the same absolute number of such websites (summing only to two for each country). Croatia has the most websites with text only (only 1D). Some data (e.g. AZU) is only available by creating a user account or contacting a responsible employee, which makes access to the information easier to control.

Various practices exist with respect to data access. At Austrian GeoSphere, maps are available, but for a fee. Borehole data collected on one map are available in Hungary (MBFSZ / SZTFH) and Iceland (Orkustofnun), the latter also has publicly available profiles (older are scanned with handwritten lithology in Icelandic, newer borehole data are already translated into English). All data is digitized on the Dutch NLOG. The Italian GeoThopica website tries to provide similar experience and several Dutch websites also have to be mentioned (TNO, DINOloket). Croatia (AZU) and Hungary (MBFSZ / SZTFH) have databases, but they are not publicly available - both require registration and, in most cases, a fee to access the content. In Croatia, users who need data for scientific purposes have free access.

Table 14
Scoring and ratios by country based on 1D to 3D type of information.

Country	No. of websites	No. websites with 1D type of information	No. websites with 2D type of information	No. websites with 3D type of information	Share of websites with 1D type of information	Share of websites with 2D type of information	Share of websites with 3D type of information
SI	7	1	6	0	14 %	86 %	0 %
DE	7	0	5	2	0 %	71 %	29 %
HU	8	0	6	2	0 %	75 %	25 %
AT	9	3	5	1	33 %	56 %	11 %
HR	13	7	5	1	54 %	38 %	8 %
NL	13	5	6	2	38 %	46 %	15 %
IT	17	2	15	0	12 %	88 %	0 %
IS	16	3	12	1	19 %	75 %	6 %
TOTAL	**90**	**21**	**60**	**9**	**23 %**	**67 %**	**10 %**

4.6. Additional analysis

The results from Annex 2 were additionally analysed by comparing the total number of websites found, the installed capacity per country and the number of websites per country with the three points obtained for findability. The comparison (Fig. 2) showed that the total scores and the total number of websites is highest in Iceland and Italy, while Slovenia has the lowest ratio. The ratio of total scores to installed capacity is highest in Croatia, where the installed capacity is also the lowest compared to the other countries (82 MW_{th}). The number of three points in the discoverability category compared to the total scores is highest in the Netherlands, followed by Germany, Hungary, Iceland and Austria. The other countries have a ratio of below 2 %.

4.7. Reproducibility of results

Using only one search engine (Google Chrome) on only one computing device bought in October 2022 can cause a potential bias. To evaluate the reproducibility, two additional searches were done by the same approach. The first one was from Budapest in November 2023 with a focus on Hungarian websites. As partly expected, it did not find all the same websites. For example, it persistently showed website of the Hungarian Geothermal Association which is hosted on the website of the International Geothermal Association, but as such the latter was not within the focus of this research. On the contrary, it did not find any of the F5 website listed in Appendices. The second test was done on a new laptop in the same office of Geological Survey of Slovenia as the first time and at about the same time as test in Budapest, for all eight countries. Now, better findability was observed for 10 % of listed sites in four countries. One site per country (N1 in Hungary, F4 in Germany), three in Iceland (N1, N7, N8) and four in Croatia (F2 to F5) got at least one score more for findability as within the original herein presented research.

5. Conclusion

The internet is a fundamental tool for education and capacity building of all stakeholders, including in the field of geothermal energy. Consequently, FAIR principles and discoverable information are key to social engagement and public acceptance of geothermal projects.

This analysis of 90 websites from eight countries has shown that the findability of geothermal websites is still problematic for most of them when using traditional browsing approach. Most websites are moderate to very difficult to find via selected keywords “geothermal”, “geothermal energy”, “geothermal association”, “geological survey” and “geothermal database”. If other words were used, for example, "data", "data centre", "map viewer" or "information system", different sites would probably be found. Therefore, the list is not exhaustive but it reflects the applied research methodology. With rapid development of AI technology analysis as an engine for searching data and knowledge on geothermal resources the findability of geothermal websites should increase, however, overcoming highlighted weaknesses can improve their findability in any case.

Three types of content were found by used search engine. First, this approach did not target scientific papers and other publications or presentations, so they are not listed. Second, company websites were included if they had sufficient general geothermal information and about geothermal project developments. Third, most focus was on country-wide or country-relevant geothermal information (but not strictly databases) which are most often but not exclusively provided by geological surveys, authorities or associations.

This research did not confirm the main hypothesis; which stated that the countries with the highest installed geothermal capacity have the largest amount of publicly available data. It is evident that findability is strongly influenced by the legislative process and leaves Germany behind Iceland, Italy, the Netherlands, Croatia, Austria and Hungary, although its installed capacity is much higher, mainly because of the huge geothermal ground source heat pump market. Nevertheless, it is shown that the amount of 2D data is extensive and some countries, such as Germany, Hungary and the Netherlands, which have also good examples of 3D datasets. It was confirmed that many websites with relevant information on geothermal energy are only findable by contacting the experts, and that the used method has placed some important websites (e.g. Orkustofnun, Skemman, GRÓ, DINOloket, WarmteAtlas, Tethys, eGeologija, etc.) further down the rankings due to low findability scores using the presented methodology.

These results can serve as a starting point for adjustment of geothermal websites, its content and design according to FAIR principles. Which weaknesses can be improved is evident for each evaluated website based on assigned points in Annex 2. All data providers and academia should be aware that no matter how good the content is, if the website cannot be found, the information will not be disseminated and used as widely as desired.

CRediT authorship contribution statement

M. Macut: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation. **D.F. Bruhn:** Writing – review & editing. **J.M. Chicco:** Writing – review & editing. **G. Götzl:** Writing – review & editing. **T. Marković:** Writing – review & editing. **A. Nádor:** Writing – review & editing. **J.A. Newson:** Writing – review & editing. **P.G. Ramsak:** Writing – review & editing. **N. Rman:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.geothermics.2025.103252.

Data availability

All data used is included in the article by using links to websites in annex 1.

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