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Finding and analysing energy research funding data: The EnArgus system

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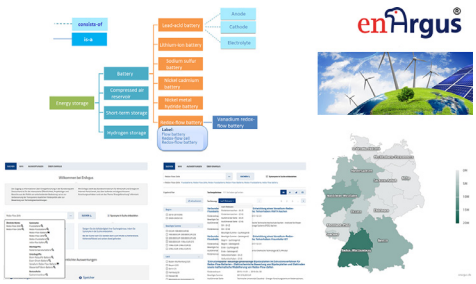
HIGHLIGHTS

- EnArgus offers info on publicly funded German energy projects of the last 40 years.
- The ontology-based and semantic search enables improved querying of energy projects.
- The EnArgus system consists of a public web-site and a restricted expert interface.
- EnArgus facilitates transparency in the subject domain and encourages imitation.
- It shows a roadmap from electronic filing, over semantic links to open data and AI.

GRAPHICAL ABSTRACT



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ABSTRACT

This paper presents the concept, a system-overview, and the evaluation of EnArgus, the central information system for energy research funding in Germany. Initiated by the German Federal Ministry for Economic Affairs and Energy (BMWi), EnArgus establishes a one-stop information system about all recent and ongoing energy research funding projects in Germany. Participants ranging from laypersons to experts were surveyed in three workshops to evaluate both the public and expert interfaces of the EnArgus system in comparison to peer systems. The results showed that the EnArgus system was predominantly evaluated positively by the various participants. It contributes to making the energy sector more transparent and offers clear advantages for professional use compared to similar systems. The system's semantic processing enables more precise hits and better coverage by including semantically related terms in search results; its intelligence makes it fail-safe, rendering it suitable for areas where poor results can have dire consequences. Reporting on an actual real-world system, the paper also provides a roadmap-view of how electronic filing of administrative project data can be semantically enhanced and opened-up to provide the basis for new ways into the data that are key for future breakthrough AI interfaces.

1. Introduction

The successful and widespread utilization of efficient and climate-friendly energy technologies is essential for achieving climate neutrality in Europe before 2050 [1]. In many countries, public funding of energy research is an important pillar towards this goal. The member governments of the International Energy Agency (IEA), for example, spent USD 20.9 billion on energy research, development, and demonstration activities in 2019 [2]. The goal of publicly funded research and development (R&D) activities of companies is that these yield positive spill-overs for the economy as a whole beyond private benefits. Without funding, companies would not contribute to the required level

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of investment that is considered optimal from a societal perspective [e.g. [3,4]].

An ever-increasing amount of publicly funded research projects makes keeping track of these projects a sine qua non condition. Among others, it is necessary to account for the spending of public funds, to identify research trends or gaps and to avoid repeated expenditures for very similar activities. On the German and European level, there are different energy information systems for such purposes. The focus of these systems and platforms varies, but there is considerable overlap between the topics covered. All systems are required to support the administrative execution of political decisions by providing, on their user interface, an unambiguous interpretation of facts based on high-quality administrative funding data.

In Germany, the main relevant sources of information on publicly funded energy research projects are the Förderkatalog (FÖKAT), the BINE Information Service, and the UFORDAT research database of the Federal Environment Agency. However, BINE Information Service was discontinued when funding ended in 2018 and UFORDAT, in contrast to EnArgus introduced in this paper, tends to focus more on topics relating to the environment sector. The strongest parallels exist between the topics of EnArgus and FÖKAT[1]. Furthermore, the project funding information system PROFI is especially relevant for internal use within the funding agencies, since PROFI[2] is intended to support the management and controlling of funding.

On the European level, the Community Research and Development Information Service [5] (CORDIS[3]) provides similar information services. Established in 1994 as the first permanently accessible website of the European Commission [5], and initially also available on CD-ROM [6], CORDIS is the primary source of results from the projects funded by the EU's framework programmes for research and innovation. With content starting from the 1990s, it covers framework programmes FP4–FP7, Horizon 2020, and beyond. CORDIS has been continuously updated over the years. It provides a public repository with all project information held by the European Commission, such as project factsheets, participants, reports, deliverables, and links to open-access publications. It can be used to assist interactions and to support cooperation amongst EU partners, as well as to study the directions, outcomes, and effects of publicly funded research and development for the advancement of knowledge and industrial development of participating EU members [7].

These information systems about past and ongoing projects provide basic support as a project catalogue, but the search functionalities, based on simple plain text matching, predefined categories or keywords have significant limitations. For example, they usually do not capture the information of all relevant activities in a field due to naming variations and would thus need additional expert knowledge and effort to generate overviews and to provide the basis for statistical analyses. And even experts can only find the information that corresponds to their level of knowledge or their expectations, which means that there is a risk that essential, up-to-date and relevant information will not be found.

The seminal idea for the development of EnArgus was to employ a domain ontology to provide a better overview and tackle many daily problems of managing funded energy research projects by semantically correlating the knowledge represented in the project proposals and reports. Funding bodies sometimes need to identify similarities in texts that go beyond typical plagiarism detection mechanism and machine learning capabilities. The EnArgus project started with the idea to automatically calculate project similarities from their text descriptions. This would allow a user to check whether a proposal has already been submitted somewhere else to avoid a project being founded twice. It would also provide an overview of the coverage of topics that need to be funded based on political decisions. The intelligent ontology-based search algorithm of EnArgus, which combines knowledge on energy-related topics, computational linguistic approaches of text processing, and modern information technology, can make the necessary expert knowledge available for automatic data processing. A system based on that combination can thus enable faster and more precise analyses on publicly funded project data, and thereby make research funding more transparent and accessible to a wider audience.

One very important data source of EnArgus is its wiki with well over 2400 editorial articles written by energy experts in the project [8]. We found that extracting information from Wikipedia [9] was not good enough for our purposes, as the quality and structure of existing articles were not consistent and many articles simply did not exist. One major task at this stage was to agree upon a core set of articles to cover the energy domain. To do so, the energy experts compared their selection with existing taxonomies and structures from literature and funding policies, e.g. reference works [10,11], funding areas by the government [12] and the German "Leistungsplansystematik", a structure of research topics used across ministries [13]. The resulting list of articles was iteratively discussed and refined between energy experts and linguists. A comprehensive writing guide was developed to facilitate the writing task and the further use of the resulting wiki articles for everyone.

In order to make expert knowledge available for automatic processing, it has to be transformed into a formal representation. Such representations are called "ontologies" after the philosophical term for the study of being [c.f. [14]]. Ontologies can represent all kinds of knowledge, but it is often problematic to translate expert knowledge into formal representations in such a way that the knowledge can be exploited by a system. This means two things: On the one hand, one has to determine precisely the kind of knowledge the system needs to process in order to improve its results. On the other hand, one has to carefully establish a process by which the subject matter experts and the information scientists communicate to agree upon the knowledge to be represented in the ontology and to agree upon what these representations look like. If the subject matter experts were only interviewed once, and could not evaluate the results, crucial knowledge might be ignored. If the information scientists represented the experts' knowledge without trying to get to its bottom, the resulting representations might trigger faulty reasoning. Ontologies are prominently applied in medical and biological domains [e.g. [15]], more domains and examples are listed in [16], but, to the best of our knowledge, the ontology built for and integrated into the EnArgus system [17] is among the biggest ontologies in the energy domain. It contains more than 4000 classes with 5000+ subclass relationships, 27 object properties, 200+ data properties, more than 2500 individuals, and more than 20,000 axioms. The smaller Open Energy Ontology OEO[4] took inspiration from the EnArgus ontology. It aims at covering the energy domain in the same generality and uses similarly expressive axioms, representing, e.g., what parts physical objects are made of. OEO follows stricter ontology engineering practices in that it is designed modularly and aligned with the Basic Formal Ontology BFO. OEO has been evaluated for its domain coverage and its usability by domain experts when annotating documents [18]. The OEMA Ontology for Energy Management Applications is of comparable size as well, but limited to the application domain of managing smart grids [19].

For us, combining knowledge on energy-related topics, computational linguistic approaches of text processing, and modern information technology means developing an intelligent data processing system that contains an integrated domain ontology and can exploit the ontologically represented knowledge for its processes. It further means that the ontological representations have been developed by a dialogue of subject matter experts and information scientists.

[1] http://www.foerderdatenbank.de/ The publicly available web interface FÖKAT (funding catalogue of the federal government) accesses data from the PROFI database.

[2] PROFI: Internal administrative funding database of the Federal Ministry of Education and Research.

[3] https://cordis.europa.eu/about/en

[4] https://openenergy-platform.org/ontology/oeo/

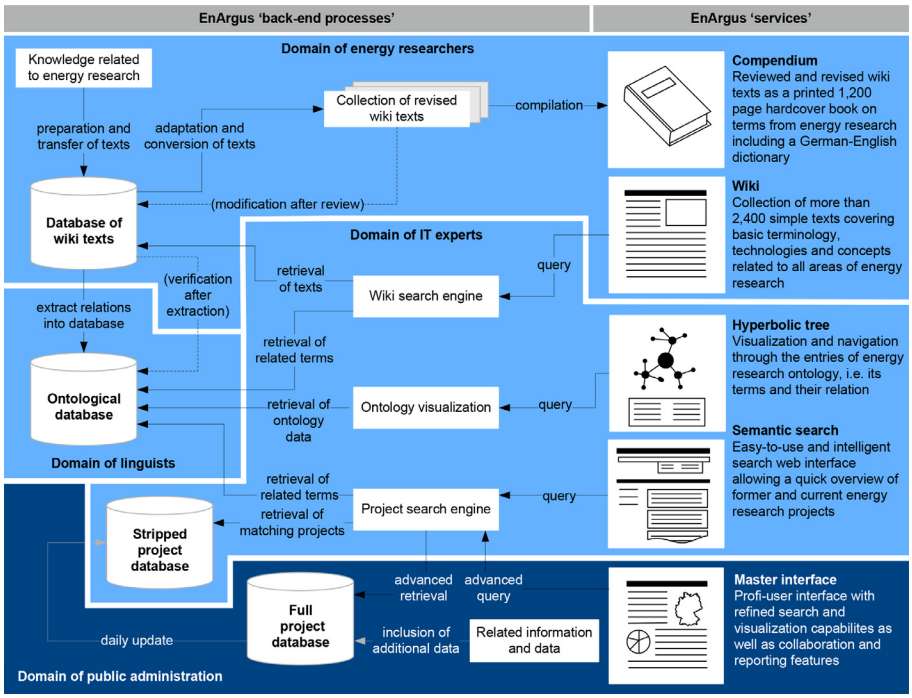

Fig. 1. Overview of the EnArgus system (source: [21]).

The resulting EnArgus system is the central information system of the German Federal government about energy funding. Its public interface[5] is one means of creating transparency about funding and can be used by anyone without registration. It is also open for automatic indexing by search engines and has been picked up by Google, meaning that if you have a fitting grant number, or you are searching for specific terms, you might end up on the EnArgus.public site sooner or later. EnArgus is now officially recommended by the German Federal Ministry of Economics and Technology (BMWi) [20 p. 137] as a tool for retrieving information about funded projects.

The aim of this paper is to further investigate the benefits of intelligent, data-driven applications for energy research. For this purpose, the centralized German energy research system 'EnArgus' [21,22] is presented and evaluated by comparing it to the established FÖKAT and PROFI systems. More specifically, this work aims to identify strengths and weaknesses of the EnArgus system and to identify potentials for improvement. For this purpose, an evaluation with different user groups was carried out. Accordingly, this paper addresses the following research questions:

1. To what extent do the participants' different levels of expertise influence the use of the public information systems EnArgus.public and FÖKAT?
2. How does EnArgus.master differ from the PROFI information system from the vantage point of its active expert users?
3. How well are EnArgus.public and EnArgus.master designed for the intended purposes from the perspective of their envisaged target groups?
   (a) What strengths do participants attribute to the respective EnArgus interface?
   (b) Which improvements are suggested?

In the remainder of this paper, an overview of EnArgus is given first, followed by a description of the methodological approach for the evaluation. Then, the evaluation results will be presented and discussed before concluding.

2. The EnArgus information system

EnArgus[6], funded by the Federal Ministry for Economic Affairs and Energy (BMWi), is the central information system for energy researchers. It enables access to archived information on state-funded energy projects and their funding documentation and provides an overview of the research landscape and its technical developments (Fig. 1). Aside from its expert platform, the information system EnArgus also serves as a communication channel to the public. The EnArgus information system offers central access to information on state-funded projects, research trends, and technologies from the domain of energy research. EnArgus.public, which is oriented towards users in policy-making, project management, and the general public, was designed and developed to empower any interested person to conduct independent research with the overarching goal of achieving greater transparency and efficiency in this sector. In 2019 alone, about 66,000 visitors from Germany used the system to search for about 2800 unique keywords (personal communication on 25 May 2020 by "Projektträger Jülich" (PTJ) to the authors).

As an extension, EnArgus.master offers an internal, access-restricted area for practitioners, ministries, and funding bodies. For enhanced collaboration, EnArgus.master is based on the BSCW shared workspace system, a groupware tool where registered users can exchange information in online workspaces. This enables a facilitated user and group administration, the authorisation of user rights, as well as the exchange of files and information within a workgroup. Although both interfaces obtain their data from the same project database, only a selected data set is disclosed to the public. Accordingly, the public interface displays only entries regarding approved projects, while the professional system also includes confidential information, such as application descriptions, technical information on funded projects, contact details, as well as interim and final reports.

Overall, the EnArgus information system is based on a funding database containing information on currently more than 28,000 publicly funded energy projects from 1968 to the present, with comprehensive coverage starting from 1977. An essential part of the EnArgus

[5] https://www.enargus.de/

[6] https://enargus.fit.fraunhofer.de/

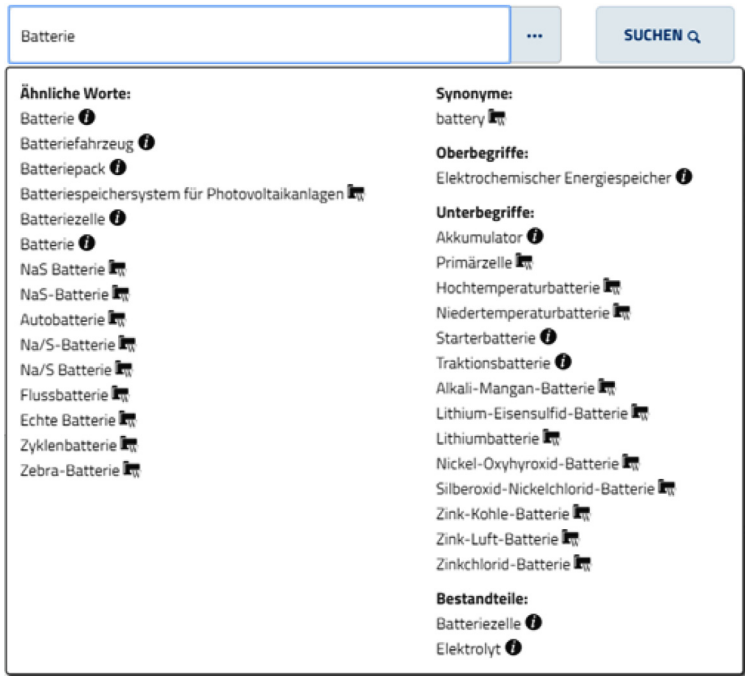

Fig. 2. The semantic search supports the user with suggestions for related search terms (left) as well as synonyms, superordinate terms, subordinate terms, and components (right, from top to bottom).

Fig. 3. Wiki entry for the search term “Batterie” (battery).

system is its semantic search, which serves to further strengthen the transparency of the funded energy research projects. With an energy research ontology that uses information semi-automatically extracted from system-internal Wiki texts, synonyms can be automatically integrated into search results; by including synonyms of the search terms, the search results of semantically related terms are also displayed in a widget (Fig. 2). This ensures that even if the choice of words for a basic term, concept or technology diverges from the actual search result, the related target is still found.

To support the respective user in their research, EnArgus incorporates its own Wiki, a hyperbolic tree, and an ontology-based search to peruse or explore the database of energy research projects.

With currently more than 2400 entries, the EnArgus Wiki serves to encompass a wide content spectrum of energy research topics (Fig. 3). In addition to an assisted search in the project database and concise introductory information texts explaining terms and technologies, the Wiki serves as a basis for the development of a domain ontology.

The ontology is generated semi-automatically from the Wiki articles composed to be both a) intelligible to the public and b) applicable for computer-aided extraction of semantic properties and relations of central information. Concretely, an automatic generation process produces results that require manual checking.

In the ontology, technical terms extracted from Wiki entries, including generalisations (hypernyms) and specialisations (hyponyms) as well as individual exemplars, are represented together with further semantic relationships (synonyms, parts etc.). An example is shown in Fig. 4. As a result, when searching for a term, related terms (hyponyms, synonyms and more) are marked and can be exploited for a semantic search [17]: e.g., if one needs a list of all projects on redox-flow batteries, one would like to get the projects that instead use the name “redox-flow cell”, too.

Below each Wiki article, an interactive hyperbolic tree is placed, which relates the searched term to its corresponding semantic environment (Fig. 5). It enables navigation through technologies, concepts, and content areas in energy research and allows a comprehensive search for thematically related terms via ontology keywords. Within the tree structure, the semantic relationships between the terms are visually represented, placing the queried term in the centre, concentrically framed by the semantically adjacent terms and concepts. At the push of a button, the user can show or hide the different levels and determine the extent of the semantic proximity. Each added level expands the picture by the concentric semantic context of the outermost terms. If the user selects one of the surrounding terms, the focus shifts to it; in parallel, the corresponding Wiki entry is displayed.

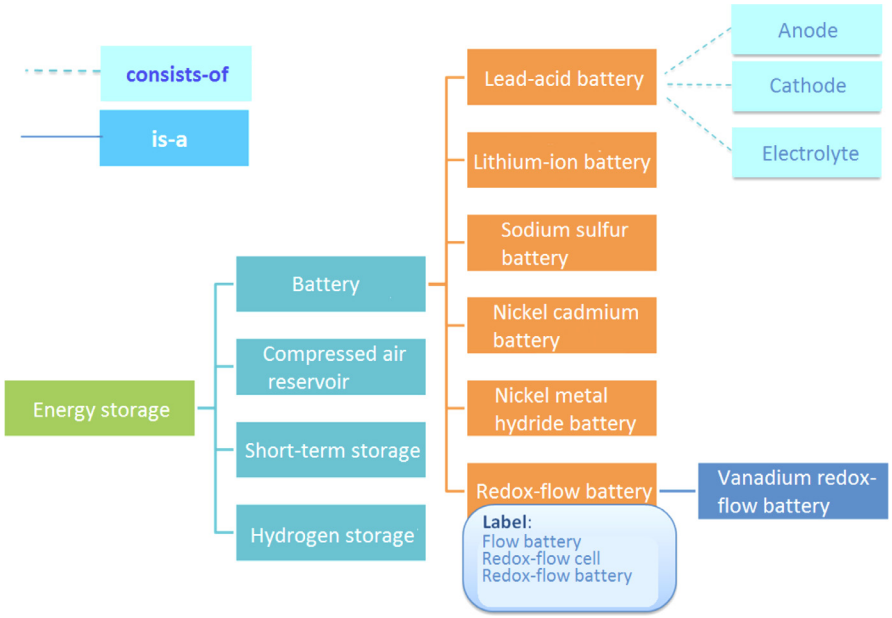

Fig. 4. Excerpt from the EnArgus ontology.

Fig. 5. Under the search term "battery", the ontology browser displays (quasi-)synonymous terms such as "accumulator" or "energy storage device" on the first level of the hyperbolic tree

On a technical level, the semantic search functionality of EnArgus ties together various data sources, including our own ontology. At its core is the project funding database PROFI which is maintained by the German Aerospace Center DLR by order of the Federal Ministry of Education and Research BMBF. Getting access to this sovereign data by us required negotiations between our funding ministry BMWi and BMBF. Once an agreement was reached, we were given restricted access to the relevant parts of the underlying database. Nightly cron jobs run queries on the Oracle database to collect the required data from different tables and output it as XML-files. These files are then processed and merged to build meta-data about projects and stored as one object per project in the object-oriented BSCW database, which is implemented in the Python programming language. Indexing of these BSCW objects with PyLucene is triggered upon their creation or update.

PyLucene is used to find results when a user enters a search term into the EnArgus interface; employing a similarity metric. In addition, the fuzzy search option is enabled for selected fields, but not on grant

Table 1
Overview of the systems examined in the EnArgus workshops.

Workshop group	Date	Number of Participants	EnArgus.public	EnArgus.master	FÖKAT	PROFI
WS1	26.10.2016	22	x		x	
WS2	07.12.2016	7	x	x		x
WS3	16.01.2017	18	x	x	x	x

numbers. The ontology is kept in a separate MySQL database. If the semantic search is enabled, the user-entered search terms are first run through the ontology database to collect further terms (near-synonyms, hyponyms, translations). These terms are then used to construct more elaborate PyLucene queries that finally allow for finding projects that are semantically linked to the search term but would have not been rated as similar otherwise. For example, searching for the German word 'Hochofen' provides the same list of projects as searching for the English term 'blast furnace'.

The semantic search enables intuitive research in the project database and provides access to extensive information on past and current state-funded energy projects. Based on the underlying data, the terms entered into the search window (Fig. 2) get interactively augmented with contextualised information about similar terms, synonyms, superordinate terms, subordinate terms, and components. Once a search has been made, the results can be further filtered, refined and sorted according to various criteria. In addition, detailed information on the individual projects can be accessed or the entire search results can be converted into diagrams and interactive maps, e.g., to identify trends in specific energy research topics at a supra-regional level.

The expert interface also includes advanced filtering and search options as well as additional administrative options allowing users to organise search results; in addition, professional users are equipped with more advanced visualization tools as well as the possibility to integrate analyses into the public homepage.

3. Methodology

3.1. Evaluation setup

In terms of general evaluation setup, EnArgus.public and EnArgus.master are processed separately due to their different target groups and main purposes. While EnArgus.public is compared to FÖKAT, EnArgus.master is compared to PROFI. The evaluation consists of both quantitative and qualitative analyses based on a combination of tasks, questionnaires, and discussions with participants from different target groups in three workshops involving 47 participants in total (Table 1). EnArgus.public was covered in all workshops, while EnArgus.master was only addressed in the second and third workshops with overall 25 participants.

The first evaluation workshop in October 2016 (WS1) was carried out with 22 students from various study programmes of the Ruhr-University Bochum. To attract a sufficient number of participants, they were compensated with 20 Euros for their participation. This group of users was chosen as a proxy to the public without specific prior knowledge of information systems on energy research. They thus are expected to have a largely unbiased perception of the system.

The second workshop took place in December 2016 (WS2) with seven experts in scientific research on "Energy in buildings and districts" that have both fundamental and applied knowledge. Due to their background, this group of participants was chosen to represent real-world professional users, performing tasks on related systems on a day-to-day basis.

The third workshop in January 2017 (WS3) was held with 18 participants from the "Projektträger Jülich" (PTJ) mainly working on operational and evaluation tasks within the funding agency. In addition to the participants of the second workshop, these participants also process the field of research on a daily basis – albeit from a different perspective. Therefore, this user group represents a daily user type that relies on the integrity, reliability, and transparency of funding information.

3.2. Evaluation design

All three workshops were held in a lecture hall or meeting room-like setting, with each participant having their own computer workstation to process the tasks. Questionnaires developed to compare the different systems were filled-in individually on paper. All tasks and questions were provided to the participants in German and translated for this publication.

The participants received a brief introduction to the EnArgus project, including the structure of Wiki articles, domain ontologies, and the corresponding search engine. An explanation of the goals and benefits of EnArgus was also provided. It should be noted that due to the gradual development process of the system and the underlying database, the briefing and assignments were slightly updated according to the actual evaluated system. After the briefing, the participants received assignments and questions on EnArgus (.public and.master) and related systems FÖKAT and PROFI.

3.2.1. Evaluation of EnArgus.public

The main part, enquiring about EnArgus, consisted of 24 tasks designed to test the performance of the system (see Appendix A: EnArgus.public task catalogue), and a set of 33 self-reported evaluation questions. For 20 of the assignments, there was a unique solution, allowing categorizing the answers as correct or incorrect within this evaluation.

To gain an understanding of the performance of the system as compared to established approaches, the participants of WS1 and WS3 also completed four additional assignments, which required completing parallel searches using both EnArgus and FÖKAT, followed by 8 evaluation questions regarding the participants' perception of FÖKAT. WS2 focused on EnArgus.public only.

After completing the EnArgus assignments, the participants were asked the evaluation questions. Using 5-point Likert scales (1: most negative; 5: most positive response), the participants were requested to answer 25 closed questions (22 of unipolar and 3 of bipolar type) about the previously gained experience working with EnArgus.public. These questions serve to gain an insight into the user perspective on the platforms, particularly addressing intelligent information retrieval using the EnArgus Wiki and the ontology browser as well as accessibility, design, and usability of EnArgus in general.

The participants were given one hour to complete the EnArgus part and 30 min to complete the FÖKAT part.

It should be mentioned that the sequence of tasks presented in WS1 entails an unintentional bias, as during the investigation of the systems EnArgus.public and FÖKAT, all participants started with the processing of the FÖKAT tasks. Preferably, half of the participants should have begun with a different system. To avoid this type of statistical bias, this approach was changed after the first workshop. Thus, when considering the results, a magnifying glass is held on this bias in an impartial manner, but at the same time, the reader is encouraged to exercise caution.

3.2.2. Evaluation of EnArgus.master

EnArgus.master was evaluated in the afternoons of two all-day workshops (WS2 and WS3). The agenda comprised a quick introduction to the BSCW system, which serves as the base system of EnArgus.master, a demonstration of the concept of the EnArgus extension, and the basic application of EnArgus, including research, analysis, and publications.

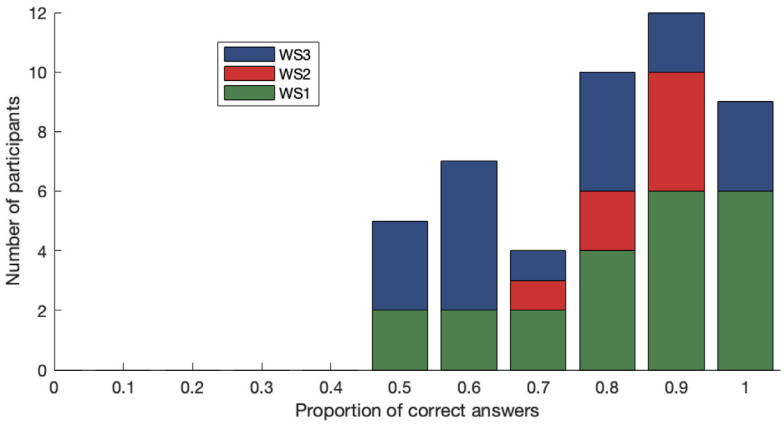

Fig. 6. Distribution of the proportion of EnArgus.public tasks correctly solved by participants of the respective three EnArgus workshops WS1, WS2, and WS3.

In WS2, the participants were given approximately one hour to freely explore the EnArgus.master system using sample questions. These included search queries by keyword, period or LPS ("Leistungsplansystematik", a federal research and development planning system, which groups federal research tasks by topic, independently of the financing department), the display of multiple search queries as a column chart, the download as an Excel file, and the creation and release of a publication of the evaluation. Following this, their comments were then recorded in a concluding group discussion. No quantitative evaluation was performed.

In WS3, following the introductory lecture, the participants performed 9 tasks and 18 evaluation questions concerning EnArgus.master. The latter is composed of 13 5-point Likert scale questions, two yes/no questions, and three free-text questions. Furthermore, they were asked to perform a comparative test with PROFI, covering the same 9 search requests as well as 15 evaluation questions. Learning from the first workshop, half of the participants started with EnArgus, the other half with PROFI. The participants had one hour to complete the questionnaire for each of the systems. During this session, the participants were able to record their comments directly on index cards. Afterwards, there was also a concluding group discussion that was logged in a protocol. Again, the analysis of the tasks is considered first, followed by the evaluation questions; then the comparison between EnArgus.master and the PROFI system is examined.

4. Evaluation results

4.1. EnArgus.public

First, the results of the EnArgus questionnaire will be presented, followed by the evaluation questions. Thereafter, the comparative findings of EnArgus and FÖKAT will be described. The complete set of questions can be found in [23].

On average participants solved 79% of the given tasks correctly (see more detail in Fig. 6).

The assignments required performing a variety of queries covering the broad functionality of EnArgus.public, such as searching for technological terms, retrieving project information, sorting and filtering entries, as well as reproducing maps and graphs. Across all workshops, most errors occurred when participants were unable to find the required functionality. This was also reflected in comments given by WS1 participants. In WS2 and WS3 a demonstration of these functions in the introductory briefing was decisive in eliminating the disorientation found among participants of WS1. The participants also reported insufficient processing time for the EnArgus assignments as a second reason why some participants did not complete all tasks.

4.1.1. Evaluation

In the unipolar rating scales, the answers are ordinally scaled, i.e., answers can be assigned to a number and arranged in ranking order. However, the scale anchors in all questionnaires were worded carefully so that equidistance of scale intervals can be assumed. Thus, we report the median and the range of responses, as well as the arithmetic mean and standard deviation as supplementary information.

The questions have been grouped as "EnArgus in general" (E1–E5 and E20–E28), Wiki-related (E7–E9), and related to the ontology browser (E13–E17). Table F.1 summarises the answers of all participants.

Considering the median of the responses given by the participants of the three workshops, it can be stated that EnArgus received an overall high rating. The entire set of unipolar evaluation questions posed across all workshops was assessed with an average of 4.09 (SD=1); of these, WS1 participants recorded an average of 4.31 (SD=0.88), WS2 participants an average of 4.13 (SD=0.87) and WS3 participants an average of 3.8 (SD=1.13). While the overall rating of the individual questions may be considered as positive, bearing in mind the moderate decline in score across the three workshops, one notable point was the generally poor rating of the questions regarding the ontology browser.

Therefore, in order to investigate the facets of EnArgus and its perception by the user more closely, the entire set of questions was examined in detail using the following categories (Fig. 7): EnArgus in general (E1–E5 and E20–E28), the Wiki (E7–E9) and the ontology browser (E13–E17).

The positive response to the EnArgus Wiki, largely expressed in the unipolar Likert questions, appears to be reflected in the bipolar-type questions of the EnArgus evaluation form as well (see Table F.2).

Whilst acknowledging that in this question type the centre of the Likert scale (here: three) represents the ideal value, and deviating values converging to the extremes one and five are regarded as undesirable extremes, all participants record a median of three among the three workshop groups examined.

Most participants consider the length of the Wiki texts to be appropriate (M=3.20; SD=0.73); this also applies to the depth and details contained in the texts (M=3.09; SD=0.8).

Concerning the representation of informative depth and level of detail given in the ontology browser, WS1 and WS3 report a median of three (WS1: M=3.23; SD=0.61 WS2: M=3.31; SD=0.79), while WS2 accounted for a median of four (M=3.67; SD=0.82). It is noticeable that all three groups, especially WS3, tended to deem the level of detail in the Wiki texts as helpful, as the range of given ratings suggests.

The following frequencies can be derived from the yes/no questions of the EnArgus evaluation (see Table F.3): In the second workshop group, 57.14% of the seven participants had already worked with EnArgus before; among the WS3 participants, ten out of 18 participants had already worked with EnArgus, which corresponds to 55.56%. This question was not addressed in the evaluation given to the students in WS1.

In the second yes/no question, 40% of all participants stated that they missed a functionality when processing the tasks with the EnArgus

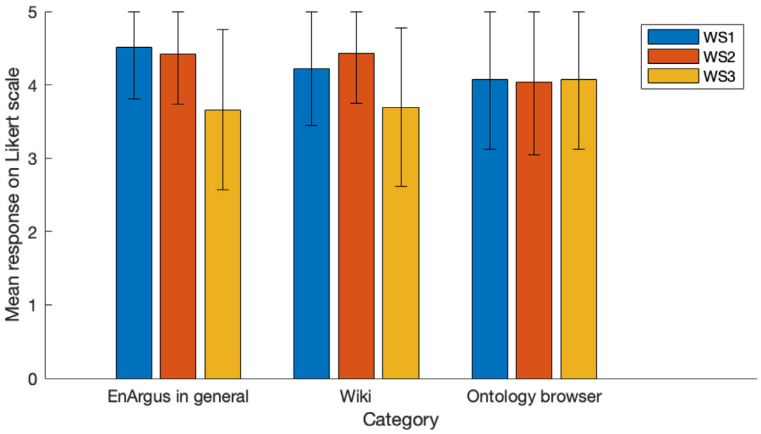

Fig. 7. Mean response on Likert scale sorted by question categories ontology browser, Wiki, and EnArgus in general; the error bar indicates the standard deviation.

Table 2
Correct and incorrect answers of the participants of WS1 from the set of four questions for the comparison of EnArgus (left) and FÖKAT (right).

EnArgus			
Question	Correct	Incorrect	Proportion
a	22	0	1.000
b	18	4	0.818
c	21	1	0.955
d	20	2	0.909
Mean	20.25	1.75	0.920

FÖKAT			
Question	Correct	Incorrect	Proportion
a	12	10	0.545
b	10	12	0.455
c	14	8	0.636
d	7	15	0.318
Mean	10.75	11.25	0.489

system. This includes almost a third of the students from WS1 (29.42%), more than two fifths of the accompanying researchers in WS2 (42.68%), and 61.11% of the WS3 participants, which accounts for more than twice the amount compared to the first workshop.

In addition to the evaluation questions described above, the questionnaire contained three questions that could be answered in commentary form. While the comments of WS1 participants indicated a better evaluation of the EnArgus system compared to FÖKAT, the comments of the more experienced users from WS2 and WS3 often focused on specific aspects of the systems. Almost all participants from WS3 expressed the wish for additional filter and search functions. With significantly fewer comments, participants from WS1 and WS2 also requested additional filters and viewing options; the latter asked for the possibility to compare, sort, and link displayed projects. Regarding the ontology browser, participants from WS1 and WS3 wished for more guidance (e.g. a user manual), as both groups reported facing difficulties using it. While in WS1 it was mainly the handling of the map and diagram view that posed obstacles, the participants in WS3 recounted that a longer familiarisation period would have been desirable. WS1 considered the wiki texts to be practical but wished for a more structured presentation of longer texts, as well as more visual illustrative material. WS3 participants stated that the Wiki can be of great benefit to laypersons, even if this benefit is comparatively small for experts. In general, based on fewer comments, WS1 considered EnArgus to be very performative, fast, and efficient, while WS3 found it slow and confusing.

4.1.2. *EnArgus.public / FÖKAT comparison*

Four tasks (*a* to *d*) from the EnArgus task form were completed by the participants of WS1 and WS3 in parallel to FÖKAT (see Appendix D: FÖKAT task catalogue).

Among the students examined in WS1, the same search queries could be correctly answered more frequently with EnArgus (Table 2). Among the 22 students, 92.05% of the four questions were answered correctly with EnArgus on average; with FÖKAT, the students were able to answer almost two of the four questions correctly, which corresponds to 48.86% correctly answered questions. On average, these are 1.75 correct questions less than with the assistance of the EnArgus system.

It remains to be emphasised, however, that these results might qualify as biased, as the sequence of tasks given to students could have produced positional effects. This methodological flaw is rooted in the circumstance that all students of WS1 were asked to answer the questions first with FÖKAT and then with EnArgus, seemingly leading to a positive distortion of the results on behalf of the latter. While the first workshop's results of the comparison of FÖKAT and EnArgus should therefore be regarded with a grain of salt, it was ensured that in the other comparative study the tasks were counterbalanced by dividing the groups into two halves, each starting with a different system.

In order to determine the statistical significance of the differences, the Wilcoxon signed-rank test is considered, as it does not make assumptions about underlying distributions and may be used with small sample sizes [cf. [24] chapter 11]; the test calculation was performed using IBM SPSS Statistics. Prerequisite is that one value of each sample can be assigned to exactly one value of the other sample. To obtain a dependent sample, the number of correct answers in FÖKAT and EnArgus are assigned to each participant. For this, a participant may receive one point for each question, i.e. a total ranging from 0 to 4 for each system. With FÖKAT, the students (WS1) scored an average of 1.95 out of 4 possible points (SD=1.68); with EnArgus an average of 3.68 points (SD=0.72) was achieved. Statistically, the results are highly significant ($w_s = 0; z = -3.550; p < 0.001$).

As shown in Table 3, the participants of the Project Management Jülich (WS3) achieved 86% correct answers with the EnArgus system and 79% correct answers with FÖKAT.

While in both systems the participants achieved consistent results on most questions, in question *b* the users delivered significantly worse results with 56% correct answers when using EnArgus. It is assumed that the users were misdirected by the interface structure of EnArgus. Instead of researching the exact time period, they adopted a rough classification

Table 3
Proportion of correct and incorrect answers of WS3 participants from the set of four questions comparing EnArgus and FÖKAT.

EnArgus			
Question	Correct	Incorrect	Proportion
a	16	2	0.89
b	10	8	0.56
c	18	0	1.00
d	18	0	1.00
Mean	15.5	2.5	0.86

FÖKAT			
Question	Correct	Incorrect	Proportion
a	14	4	0.78
b	13	5	0.72
c	16	2	0.89
d	14	4	0.78
Mean	14.25	3.75	0.79

from the facets of the system, which had to be counted as an incorrect answer. These difficulties did not occur when processing the task with FÖKAT.

As for the results of WS1, the results of the third workshop were recorded and summarised in tabular form to perform a Wilcoxon signed-rank test. With EnArgus, the participants of WS3 achieved an average score of 3.44 correctly answered questions (SD = 0.70); with FÖKAT they had been able to answer three of the four questions correctly on average (SD = 1.19).

For WS3, the observed differences are not significant ($w = 3; z = -1.710; p = 0.087$). Consequently, based on these four search queries, we cannot conclude that the participants in this user group achieve significantly better results with EnArgus or FÖKAT than in the other condition.

A comparison of the parallel evaluation questions posed in both systems clearly indicates that the EnArgus.public system was much better accepted by both WS1 and WS2 participants than its competitor FÖKAT.

Overall, EnArgus was assessed very positively (Table F.1); among all participants of both groups, the EnArgus system received in the Likert rating questions at least a median of four. FÖKAT received a significantly worse rating in comparison, in WS1 slightly worse than in WS3 (Table F.4).

While a great difference was already visible to the naked eye, the comparison was statistically examined with the Wilcoxon signed-rank test (Table F.5). This analysis explicitly shows that EnArgus was rated significantly better than FÖKAT comparison system in the entire set of evaluative questions posed in parallel.

In addition to the evaluation questions, the participants had the opportunity to comment on the funding catalogue. In the following, the comments made are described, sorted by reference and frequency:

Considering the comments submitted by WS1 participants, it is noticeable that FÖKAT is viewed predominantly negatively. Ten of the participants remarked that they had not found any useful results with FÖKAT, nine found FÖKAT too confusing, another seven too slow. Further, five participants reported the lack of functions, e.g., filters.

The participants from Project Management Jülich (WS3), whose daily work includes working with FÖKAT, also evaluated the two information systems. From a professionally motivated perspective, they are thus slightly biased and might therefore not represent an unconditional target group for the EnArgus.public interface.

Among WS3 participants, the FÖKAT system was predominantly assessed positively. Five participants compared the search function with that of EnArgus, whereby EnArgus is deemed equally good or slightly worse. Three others emphasised that there were more search and filtering possibilities in FÖKAT; further, three others positively remarked the provision of project descriptions in the form of abstracts in FÖKAT. In the remaining ten comments, which were categorically incomparable due to their reference to the specifics of the FÖKAT system, not only a high level of expertise in working with FÖKAT can be derived, but also a positive assessment of the system by the expert users from WS3.

4.2. EnArgus.master

This section presents the results of the EnArgus.master evaluation collected in the course of WS2 and WS3. First, the results of the performance tasks and evaluation questionnaires of the EnArgus.master interface collected in WS3 are presented. Afterwards, the results of the comparison to the PROFI system will be described. The input and results produced during the group discussions of WS2 and WS3 will be included as part of the discussion in chapter 5.

4.2.1. Questionnaire

Considering the results of the tasks for the EnArgus.master and PROFI systems among the participants of the third workshop, no meaningful quantitative evaluation could be conducted. Irrespective of whether the search results were correct or incorrect, the participants responded only to 42% of the tasks in total. Further, the answers given were neither consistent with EnArgus.master nor with PROFI. The questions posed in the EnArgus.master evaluation were made especially difficult and were previously agreed with an expert and declared feasible. The complete EnArgus.master questionnaire is attached to this document (see Appendix C: EnArgus.master task catalogue).

The inclusion of more complex questions and the comparatively high rate of unanswered or incorrectly answered questions is also consistent with the ensuing comments of the participants, which often expressed their perception that the questions were particularly difficult and that there was insufficient processing time provided. In addition, it was mentioned that the PROFI system often could not be reached due to connection problems.

4.2.2. Evaluation

Although it was not possible to quantify the answers, as no useful data set was produced, all participants interacted with the systems, which is why the available evaluations can still be interpreted. Nevertheless, it should be noted that due to the short processing time given, a relatively large number of responses are missing in the evaluation forms. Regarding the EnArgus.master evaluation, a total of 30 questions remained unanswered; in the PROFI evaluation nine questions were left unanswered.

As in the evaluation of EnArgus.public, the Likert intervals are assumed to be equidistant, with the medians and ranges serving to characterise the data set and the standard deviation as an additive reference.

As shown in Table F.6, the ratings of all Likert questions resulted in an overall median of three. The question about whether participants like working with EnArgus received the lowest rating of two. For the remaining questions, one third received a median of three and two thirds even higher. Given the nature of the questions, the results suggest that they perceive EnArgus.master as a potential future benefit and as an approach to making energy research results transparent, but one that involves a learning process.

The yes/no questions on the evaluation questionnaire provide the following information (Table F.7): None of the participants from the

Table 4
Median of responses to EnArgus.master and PROFI evaluation questions among the participants of WS3.

	Question	EnArgus	PROFI
E3	Did you like working with EnArgus.master/PROFI?	2	2
E4	Would you consider EnArgus/PROFI a sensible approach to making the funding of energy research more transparent?	4	1
E5	Would you recommend EnArgus.master/PROFI?	3	2
E6	Would you be interested in using EnArgus.master/PROFI in the future?	4	3
E8	Did you, as a novice, consider EnArgus.master/PROFI easy to understand?	3	2
E9	Did you find EnArgus.master/PROFI easy to use?	3	2
E10	Is the functionality of EnArgus.master/PROFI sufficient for your purposes?	4	3
E12	Did you find the display of the search results informative?	4	2
E13	How do you evaluate the evaluation possibilities (research) with EnArgus.master in general?	4	1.5
E16	Were you satisfied with the speed of the search engine?	3.5	1
	Total	3	2

Project Management Jülich (WS3) had previously worked with the EnArgus.master system. One third of this group reported missing functionalities within the system, one third negated the lack of functionalities, and one third did not respond to the question.

The remaining questions asked for missing functionalities, problems and further remarks. All resulting comments on the evaluation sheet, on the index cards, and from the subsequent discussion were collected: With 15 out of 18 occurrences, almost twice as often as any remark, it was noted that the respective participants would like to have a manual to clarify ambiguities from the beginning. Eight people expressed the short time available for processing the tasks. The same number of participants expressed the desire for more options to sort and filter the given search results, including running projects, funding amount, LPS, PTJ unit, ZE, executing unit. Five participants struggled with the meaning of the abbreviation “ZE” (grant recipient, German: “Zuwendungsempfänger” instead of payment recipient: “Zahlungsempfänger”), which hitherto they encountered differently.

4.2.3. EnArgus.master / PROFI comparison

As mentioned before, due to the many unanswered questions in the task part, a statistical performance comparison between EnArgus and PROFI would not be very meaningful. However, the self-reported evaluations of the two systems can be compared: For this, 15 evaluation questions were asked exactly in parallel to EnArgus.master and PROFI, ten of which were scaled questions.

Considering the average means of the evaluation questions of EnArgus.master and PROFI, as shown in Table 4, it can be observed that EnArgus.master is better received by the WS3 participants in general.

In sum, while EnArgus reported a median of three in the Likert questions, the PROFI system received a median of two. PROFI received a median of one in the question of whether the system contributes to a more transparent promotion of energy research; the same score applies to the speed of the search engine. The individual benefit of the system in the participants’ everyday work was best appreciated with a median of three. The question of whether there was any interest in future use of the system received the same median rating.

Statistical significance is tested using the Wilcoxon signed-rank test; all results of the 10 comparisons (each question separately) are presented in Table F.8:

The results of the analysis showed that five of the ten comparisons were significant (E10 and E12) or very significant (E4, E13 and E16). This means that EnArgus.master was rated significantly better than PROFI in the marked five questions. In the other five questions, EnArgus.master did slightly better, but the difference is too small and therefore not meaningful. In comparison to the PROFI system, EnArgus is therefore regarded as a significantly better approach to making the funding of energy research more transparent. In this context, however, the different nature of the systems must be taken into account. It should be noted that the mere comparison is to be regarded as invalid since the PROFI system was not developed for the purpose of enhancing transparency in this domain. While the comparison and its statistical significance should be disregarded in this evaluation, a positive trend regarding the transparency of the EnArgus system can be inferred from the high rating given by the WS3 expert users. Furthermore, EnArgus.master is evaluated significantly better than the comparison system in terms of the adequacy of the system for the purposes of the participants, the information content projected by the search display, the evaluation options, as well as the speed of the search engine.

5. Discussion

The aim of the evaluation was to examine the EnArgus information system regarding its quality, utility, and applicability. Based on the results of the respective evaluation areas, the findings regarding the strengths and weaknesses of the EnArgus system compared to the systems FÖKAT and PROFI are discussed below. In the subsequent part, the genesis of EnArgus and the use of ontology-based information systems

is discussed and compared to the wider background of the current AI research landscape.

5.1. A synoptic view of the systems

To what extent do the participants' different levels of expertise influence the use of the public information systems EnArgus.public and FÖKAT?

Regarding the results of the tasks to be solved with the EnArgus.public system, it can be observed that all three workshop groups achieved similarly good results despite their different levels of expertise. In the same vein, the results of the EnArgus.public evaluation indicated that the system was largely well-received in all three workshops (see Table F.1). In particular, the user group of students representing the public in this study assessed the system as very positive overall. The evaluation by the accompanying researchers, as well as the participants of the Project Management Jülich, both with obviously higher demands, was slightly lower than the very positive evaluation by the students, but the system is also perceived as positive in their eyes.

Among the participants of the first workshop, significantly fewer questions could be answered correctly with the FÖKAT system (see Table 2). This is reflected in their self-reported assessment of the FÖKAT system, which is significantly worse than that of EnArgus. Due to a built-in bias, in which all participants in WS1 first assessed FÖKAT and then EnArgus, it might be assumed that EnArgus received a more favourable assessment as a result. However, the highly divergent evaluations leave hardly any doubt as to which system is the preferred one. In line with this assumption, the participants of WS1 expressed their sympathy with EnArgus in the free comments and assessed FÖKAT predominantly negatively.

In WS3, the evaluation of EnArgus was significantly better than that of FÖKAT, however, through their daily work with FÖKAT the participants were able to correctly answer as many search queries as with EnArgus.public (see Table 3). A more critical approach is also recognisable in the comments made on FÖKAT. Although they solved the tasks slightly more successfully with the EnArgus system, which was also reflected in the predominantly positive evaluations, many comments clearly indicated that the participants of the Project Management Jülich felt a pronounced acceptance for working with the FÖKAT system. While few participants of WS3 considered the systems to be of equal (or almost equal) value, many participants highlighted positive aspects of FÖKAT, as well as negative impressions of the EnArgus.public system. A closer look at the comments reveals, however, that a large part of the comments on FÖKAT positively emphasised idiosyncratic functionalities of the system; many comments on EnArgus on the other hand showed that there was still a need for explanation in some facets of the system and about half of the WS3 participants wished for more training time. Since all participants have already worked with FÖKAT, but about half of them only with the EnArgus.public interface, it can be interpreted that part of the criticism might be due to the participants' already high familiarity with the comparative system. Especially since it often touches upon the absence of seemingly idiosyncratic system processes and functionalities. This may indicate that a short-term readjustment to a new platform might be difficult, which is confirmed in the numerous commentaries calling for a manual and more time to familiarise with the system. During the tests of EnArgus.public, it seems that especially time frame and documentation of the system proved to be a bottleneck. Although the comparison in the third workshop setting did not reach significance, we can expect EnArgus.public to be easier to use overall.

Based on the overall positive results in task outcomes and evaluation questions, a positive picture can be drawn for EnArgus.public. As opposed to WS3 participants, the student participants were not familiar with either of the tested systems. Against this background, EnArgus was generally very well-received, especially by users with no previous knowledge. This could indicate an easy overall familiarisation with the system so that it can be regarded as more suitable for the general public in comparison to FÖKAT.

How does EnArgus.master differ from the PROFI information system from the vantage point of its active expert users?

During the EnArgus.master examination, a large part of the participants did not answer many questions both in the task and in the evaluation questions. This precluded a counting of the correct answers among the tasks due to a lack of significance; the evaluation questions, however, were considered. The evaluation of EnArgus.master, conducted in the third workshop, tended to reflect a positive assessment of the expert platform on the part of the participants, albeit with strongly diverging views overall (see Table F.6). Among the evaluation areas, the presentation of search results in map and diagram form was particularly well-received; certain limitations were noted in the ontology browser.

In all 10 comparative questions, the EnArgus.master interface received more positive results than PROFI; in 5 out of 10, its results were statistically significantly better (see Table 4, Table F.8). From a qualitative point of view, it appears that the existing information systems FÖKAT and PROFI can only contribute to creating transparency in energy research to a very limited extent, or "by design", not at all. This represents a major advantage of EnArgus.

In the second workshop, no quantitatively evaluable tests regarding the EnArgus.master system were conducted. Instead, after an introduction to the EnArgus.master interface, as well as a one-hour work session on the basis of a set of sample questions and the prompt to take notes on index cards, a discussion was conducted in which the following topics and aspects were addressed:

WS2 participants expressed a desire to update the search filter after each setting. However, this was deemed impractical, since entering several filter settings would cause the page to update each time an adjustment was made.

In addition to the questions that arose from the participants' notes when working with EnArgus.master, further focal points were discussed, including the following topics and aspects:

For accompanying researchers, connections between technologies are interesting (e.g. which terms/technologies frequently appear in connection with the term "heat"). So far, technology relationships are predefined in EnArgus and can only provide similarities to other projects. The resulting proposal was to implement the creation of word clusters and correlations for topics and concepts as functions.

In addition, a conflict was discovered in the semantic search. Usually, when searching (for topics), suggestions are displayed that update with each character and support the user in finding the desired search term by providing different spellings and semantically related terms. However, if there are no suggestions from the ontology, the words "no suggestions" will appear. From the user's point of view, this could be a misleading formulation, since topics can still be found while searching. It was therefore suggested to simply leave this field blank to avoid misinterpretations.

What strengths do participants attribute to the respective EnArgus interface? Which suggestions for improvement are mentioned?

The tasks posed in the EnArgus.master evaluation were reported to be very difficult; in particular, the participants agreed that the questions asked were not typical PROFI requests or that the tasks could not have been solved in PROFI either (which was not the case). Overall, the functionality of EnArgus was considered to be higher than that of the PROFI system, but with limitations. It was pointed out that EnArgus is only helpful if it contains the same data as PROFI (the entire data set must be available). This is also reflected in the number of results of EnArgus.public and EnArgus.master, which varies according to the underlying database. Further, there are weaknesses on the part of EnArgus regarding the underlying PTJ basic data, e.g., LPS has not listed Bosch's fuel cell projects because they involve electromobility.

Since EnArgus.public only uses a scaled-down version project database, it may occur that certain data is not visible. For example,

while the complete project database also contains information about private photovoltaic systems, they cannot be displayed in EnArgus for data protection reasons.

With regard to the user interface, several participants have compared EnArgus.master and EnArgus.public and, in some cases, voiced criticism of their differences. It was noted that the normal search function in EnArgus.master is considered useful; however, the search in EnArgus.public was reported to be slightly more intuitive. The EnArgus.public search, it was agreed, provides a quick and user-friendly overview; the search in the EnArgus.master search is regarded as rather complex. Therefore, it was stated that a combined input field, as is found in the EnArgus.public search, could also be offered on the expert platform. The evaluation function was generally perceived as very good; although it is faster than in the comparison system, it is still relatively slow.

The participants were slightly dissatisfied with the day's planning, as they would have liked more time to familiarise themselves with EnArgus system. Although EnArgus.master is uncharted territory for the attendees, and they discovered that it requires a higher training effort (compared to the public interface), the interest of the participants in the further procedure in the EnArgus system remained.

The comments submitted in the evaluation naturally contributed to scrutinizing the approach from the user's point of view, presenting their respective workflows in detail and to pointing out possible improvement potentials. This included a clearer approach to working with the ontology browser, as well as suggestions for possible prospects for filter options, visual representations, and system processes that could enhance the work experience through more intuitive and efficient navigation. Further, the creation of a manual is highly desired. To this end, two flyers were created; one describing the project itself and one containing a short manual [23].

According to the free comments, PROFI is much more frequently criticised as cumbersome and slow. Some users are downright frustrated with PROFI, and consider it the source of many daily problems and errors. Others say that although the program is not very user-friendly, it is still useful enough for everyday use. Visualized evaluations are not available in PROFI, nor is the search for constituents. The same applies to an ontological search or to work-relevant sorting functions. All these points are addressed by EnArgus.master; the interest of the test users seemed to be accordingly high.

Regarding the usability of the system, a distinction must be made between EnArgus.public and EnArgus.master. Due to the significantly larger scope of functions and the "more professional" target group, EnArgus.master is rated as a useful tool and more positive than the PROFI system. At the time of the evaluation, however, it was perceived less positively than EnArgus.public and various other requirements were formulated.

In the light of these findings, it can be assumed that the expert platform EnArgus.master has great application potential in specialist areas. Especially, considering that all WS3 participants have already worked with PROFI but never with EnArgus.master, it can be assumed for the EnArgus expert interface that the overall functionalities of the system were convincing despite difficulties during their first application.

5.2. Approaches to AI research

This paper showed that ontology-based, semantic information systems like EnArgus are already very useful as they are. They provide information to the public that was previously locked in databases. We would thus see a benefit to providing more transparency in funding if such systems were adopted by more ministries and state departments everywhere in Europe and beyond. They organise and augment administrative information to make it searchable and useable. Opening up such data to make them FAIR (Findable, Accessible, Interoperable, Reuseable) [25] is key to enabling their decentralized use in AI. EnArgus does all this for data on energy research and respective projects. By design, EnArgus provides all of its 2400+ wiki-texts about the energy domain under a permissive Creative Commons licence (CC BY-SA 3.0 DE), similar to the ministry website.

The headless core EnArgus service has a REST API for providing data to the user-interfaces, which is currently being used for a major "mobile-first" redesign of the public interface. As part of this, the originally German-only EnArgus system and its wiki-texts are now available in five languages by employing the DeepL neural machine translation API.

Naturally, many more ideas existed throughout the development process and even since the very beginning. The possibility to release the ontology and make it available as open data was also discussed. But this was given a lower priority in favour of concentrating our efforts on first finishing the system itself. We still see the release of the EnArgus ontology as future work, probably as part of the website relaunch. Other seminal ideas turned into prototypes for practical reasons. The EnArgus project built a function that calculates for a given project description the N projects in the database that have the most similar descriptions. This allows a user to check whether a proposal has already been submitted somewhere else to avoid a project being founded twice. However, for this to be put into practice certain legal problems around data-protection and security certification (e.g. ISO 15408) remain to be solved as future work. Another common issue is the continuation of development efforts to avoid "bit-rot", both in software and (ontology) data. There are several lessons to be learned here. Many project websites go offline some time after the project ended. This was avoided in EnArgus by transferring operation to another legal entity (PTJ) and can be seen as good practice. But this comes with small problems on the side, e.g. the purchase of required licences and service agreements, or even just the URL, can be complicated. The bigger issue is the work required to keep the software and ontology up to date. The aforementioned European system CORDIS can be seen as good practice in this regard, as it has been continuously developed since 1994.

In a public meeting of the German Federal Parliament AI committee of inquiry in 2019, Auer outlined that AI breakthroughs have always been enabled by the availability of big and easily accessible datasets [9,26]. There is a need for explainable AI and responsible data science. Hence, AI should not act as a black box but must remain traceable, reliable, fair, and non-discriminating. Such AI approaches require data to be linked to provenance metadata and background knowledge, in other words, to knowledge graphs [27] built from linked, open data [28] that is freed from data-silos. Concretely, making the EnArgus ontology more interoperable and re-useable could be achieved by modularization and by aligning it with standards, like the Open Energy Ontology mentioned in Section 1 did. Given that the primary application scenario is information retrieval, it seems particularly promising to align the EnArgus ontology with the W3C Simple Knowledge Organization System SKOS[7]. SKOS provides standard terminology for hierarchically classifying concepts and giving them multilingual labels that facilitate both human communication and search. It is supported by collaborative authoring and curation tools such as VocBench [29], which is officially recommended by the European Union for centralising the management of controlled vocabularies and metadata used by public administrations to support interoperability, or the commercial PoolParty[8] [30]. Beyond SKOS, using linguistic ontologies such as the Lemon Lexicon Model for Ontologies[9] and language resources such as WordNet[10], or GermaNet[11] for German, promises to address the issue of clustering words and correlating topics pointed out in the evaluation (cf. Section 5.2) [31]. Benefits

[7] https://www.w3.org/2004/02/skos/
[8] https://www.poolparty.biz/skos-and-skos-xl/
[9] https://lemon-model.net/
[10] https://wordnet.princeton.edu/
[11] https://uni-tuebingen.de/en/faculties/faculty-of-humanities/departments/modern-languages/department-of-linguistics/chairs/general-and-computational-linguistics/ressources/lexica/germanet/

of reusing such standards include the potential to take advantage of tools based on related ontologies and datasets, such as the SKOS-based AIDA (Academia/Industry DynAmics) Knowledge Graph for analysing the dynamics of emerging research and development topics, and the respective involvement of academia and industry [32].

Data exchange should be made easy, maybe even mandatory, to avoid redundancy and to practice privacy by design. However, it is also important to take data sovereignty into account, for example by empowering the data owner to decide who shall be using their data subject to which conditions. For the semantic web to further flourish there must be persistent identifiers, something the academic community and funded projects in general, but also EnArgus specifically, do not always keep in mind and follow. There is much work to be done to provide the groundwork for a symbiosis of energy and AI.

These are all complex challenges. Part of the European answer is the Federated Data Infrastructure GAIA-X[12], whose "Energy" domain group has so far defined seven publicly featured use cases, including the utilisation of data from critical infrastructures or municipal grids for new business models, and avoided grid collapse by AI-driven redispatching[13] [33]. Reaching a common understanding of data is key and requires formal representations for machines, and discussion between humans. McCarthy coined the term Artificial Intelligence (AI) in 1955 and since then it has grown into a popular discipline in computer science and beyond [34]. Sometimes forgotten in AI, Engelbart famously advocated for the use of technology for augmenting the human intellect, or in short: intelligence augmentation (IA) [35]. We see a big chance in linking human and artificial intelligence to balance humans and technology for a human-centred vision of AI and IA [36].

6. Conclusion

In the evaluation described in the present study, the three EnArgus workshops in 2016/2017 provided valuable insights into both the current state of the EnArgus interfaces, as well as the target state. It was equally rewarding to apply quantitative and qualitative research methods where appropriate and to listen carefully to experts and laypersons alike when given opinions about the requirements of the systems in terms of functionality and usability.

Overall, a positive conclusion can be drawn from the evaluation of EnArgus' interfaces: EnArgus.public and EnArgus.master. This especially applies to the public interface, which was predominantly assessed positively by all three workshop groups: the explicit acceptance and positive reception of the system among all workshop groups projects a recognisable benefit of the system for the general public, and contributes to the process of making funding documentation and research needs in the energy sector more transparent.

Considering the expert platform EnArgus.master, a positive resonance and increased interest can be observed in the evaluations of the specialist workshop groups. This was also reflected in the workshop discussions. In addition, the valuable insights of the evaluation and constructive contributions of the experts in the discussions provided numerous clues for improvements and optimisations to the EnArgus system.

Although there is still room for improvement, this study already shows that the EnArgus.master system, in combination with an up-to-date database, is in no way inferior to comparable systems, and is even preferred in many respects.

Furthermore, the positive feedback across different subject levels shows that EnArgus satisfies the requirements for an intelligent information system; by including an ontology-based search improving the search results by semantically related search terms, the statistical probability of getting the targeted results is increased, which enables an even more precise search for funded research projects. In addition, the internal wiki and, after some familiarisation, the hyperbolic tree proved to be important components to make the subject matter more tangible for everyone.

In summary, we believe that the integrated EnArgus concept and solution provides a valuable contribution towards the provision of a comprehensive information retrieval system, that fosters both the reuse of existing project information as well as identifying gaps for new research initiatives. The EnArgus system has been handed over to the PTJ for continuous operation after the conclusions of the development process. Since then, efforts mainly focused on operation and maintenance, yet very recently, a more responsive redesign of the user-interface for mobile devices and automated translations have been added, making it accessible to a wider, international audience.

Our approach to leveraging domain knowledge by using a custom-built domain ontology made from custom Wiki-articles can be applied to other domains. Much like with open-source software, it would be beneficial to open up the data of EnArgus, as well as its ontology, for further use and development. While both steps would have been relatively easy, we simply have not done them in the project in order to stay focussed on finishing the system first, and also to avoid hi-jacking, i.e., a semantically unfaithful redefinition of EnArgus' ontology terms by third parties [37]. They would be a welcome next step, though. It would also be conceivable to apply the EnArgus system structure to other research areas[14]. Once the complex, real-world legal and data-access problems that EnArgus tackled are solved with forthcoming sovereign data-exchange infrastructures like GAIA-X, we should see a range of new applications building upon these datasets to provide the next breakthrough of AI that is traceable, reliable, fair, and non-discriminating.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendices

The following questionnaires and evaluation forms, which were employed during the three EnArgus workshops to evaluate the EnArgus information system, were translated into English; the participants received the questionnaires in German.

[12] https://www.data-infrastructure.eu/

[13] https://www.data-infrastructure.eu/#id1854484

[14] https://www.fraunhofer-innovisions.de/semantische-medienanalyse/energiewissen-fuer-alle/

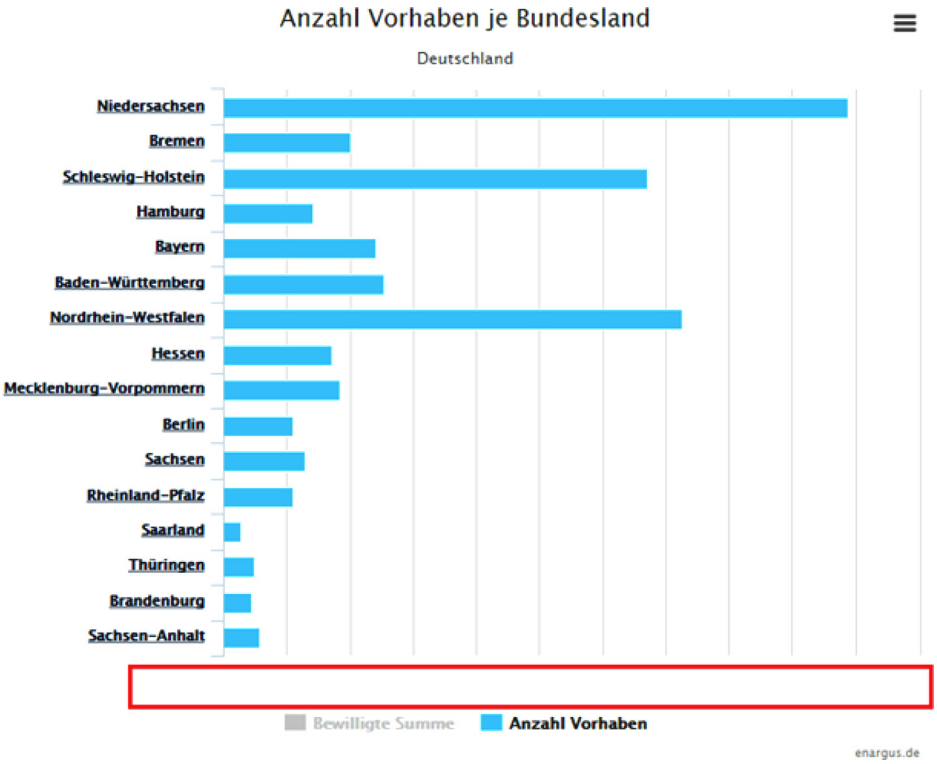

Fig. A1. Visualisation of funding data: Number of projects per federal state.

Appendix A. EnArgus.public task catalogue

Web address: http://www.enargus.de

Topic 1: What did we research yesterday, what are we dealing with today?

In the past, the Ruhr-University has been engaged in R&D for pre-stressed concrete reactor pressure vessels.

a. How many projects on this topic have been conducted at the Ruhr-University?
b. In which period of time was the R&D on this topic conducted?
c. Which institute conducted this research?
d. What is the institute currently working on?

Topic 2: Solar energy will be an important source of renewable energy in the future - What is the Ruhr-Universität Bochum working on?

e. With which projects is/was Ruhr-Universität Bochum active in the R&D sector of solar energy?
f. I would like to work in the field of solar energy research in the future - preferably in NRW - Which companies/institutions are particularly active here?

Topic 3: Wind turbines

g. How many research projects on wind turbines can be found in Germany if you search for the term without synonyms and if you allow synonyms when searching?
h. Which synonyms are also included?
i. How many projects can be found in the respective federal states if you perform the above search with synonyms? Reproduce the diagram below and complete the X-axis labels.
4. What was the distribution of the approved sums for the respective federal states? Reproduce the map below and enter the axis labels (4 values).
5. Which two types of wind turbines can be distinguished?
   1.
   2.
6. Search for the term “tower” in the “Ontology Browser” and draw the ontology for the first term level.
7. What do the colours of the connecting lines in the “Ontology Browser” mean?
   Pink:
   Light green:
   Blue:
8. Given is a search for “wind energy” (incl. synonyms).
   i. Which federal state received the highest total amount of funding in the period from 1990 to 2019?
   ii. Which amount was granted?
   iii. Which federal state has the most projects in the same period?
   iv. How many projects have there been?

Topic 4: Research volume

o. What was the research project with the highest approved sum that was conducted in Bochum?
p. What was the research project with the highest approved sum that was conducted at the Ruhr University in Bochum after the year 2000?
q. How high was the approved project sum?
r. The project “Design of natural and biomimetic systems for light-driven hydrogen production from molecular to mass fermentation systems” is a collaborative project. Which other partners were involved in the project?

Topic 5: Miscellaneous

s. EnArgus information about Li-Ion batteries: My laptop battery is marked with the abbreviation Li-Ion. What information does EnArgus provide about this technology?
t. Excursion into the animal kingdom 1: Energy research also seems to have connections to the animal kingdom. But what is actually hidden behind the abbreviation “ZEBRA”?
u. Excursion into the animal kingdom 2: Energy research also seems to have links to the animal kingdom. But what is actually hidden behind the abbreviation “Molch”?

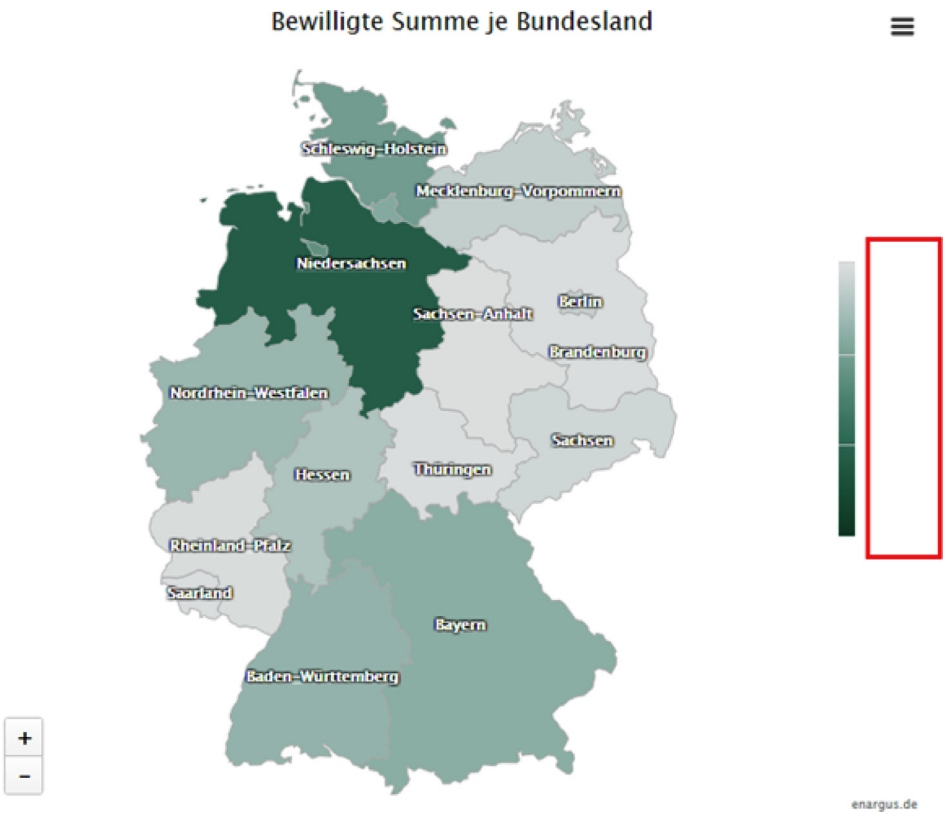

Fig. A2. Visualisation of funding data: Number of projects per federal state.

Table B1
Four EnArgus questions that were omitted from the set of questions used in the evaluation.

	EnArgus question	Exclusion criteria
e	With which projects is/was the Ruhr-University Bochum active in the solar energy R&D sector?	• Only one project can be found under the keyword "solar energy" • Search output of "solar" and "solar energy" deviates significantly. • select filter "Bochum" • sort by "Exporting agency"
f	I would like to work in the field of solar energy research in the future - preferably in NRW - which companies/institutions are particularly active in this field?	• It is unclear whether the solution should be accepted if there is at least one match with the institute list in the sample solution • Search output of "solar" and "solar energy" deviates significantly.
l	Search for the term "Turm" (English: "tower") in the ontology browser and draw the ontology for the first term level.	• It is unclear whether the task is only considered solved when the tower is in the middle, the first term level has been defined, and all surrounding terms have been entered according to the sample solution
r	The project "Design of natural and biometric systems for light-driven hydrogen production from molecular to mass fermentation systems" is a collaborative project. Which other partners were involved in the project?	• It is unclear whether the task can only be considered solved when all other project partners have been found

Appendix B. EnArgus.public questions omitted from task catalogue

Appendix C. EnArgus.master task catalogue

Web address: https://ptj.fit.fraunhofer.de/ (then click on EnArgus.master)

Topic 1: Wind energy research projects

a. Find the wind energy research project that has received the highest grant.
b. Also take inflation into account.
c. How many wind energy research projects were funded before 1990?

Topic 2: Bosch fuel cell projects

d. Find the Bosch Group's fuel cell projects since 2000.
e. Which Bosch affiliates conduct research mainly in the field of Fuel cells?
f. Which Bosch locations are primarily involved in research? Both in general and specifically regarding fuel cells?

Topic 3: Constituencies

g. Find current projects in the constituency of the Federal Minister of Economics (constituency 49 "Salzgitter – Wolfenbüttel").
h. Which projects from the support measure "Schaufenster intelligente Energie - Digitale Agenda für die Energiewende" (SINTEG, English: "Smart Energy Showcases - Digital Agenda for the Energy Transition") are supported in the Minister's constituency?
i. Which large commercial enterprises receive funding in the Minister's constituency?

Appendix D. FÖKAT task catalogue

Web address: http://foerderportal.bund.de/

What did we research yesterday, what are we dealing with today? In the past, the Ruhr-University has been engaged in R&D for pre-stressed concrete reactor pressure vessels.

a. How many projects on this topic have been conducted at the Ruhr-University?
b. In which period of time was the R&D on this topic conducted?
c. Which institute conducted this research?
d. What is the institute currently working on?

Appendix E. PROFI task catalogue

Topic 1: Wind energy research projects

a. Find the wind energy research project that has received the highest grant.
b. Also take inflation into account.
c. How many wind energy research projects were funded before 1990?

Topic 2: Bosch fuel cell projects

d. Find the Bosch Group's fuel cell projects since 2000.
e. Which Bosch affiliates conduct research mainly in the field of Fuel cells?
f. Which Bosch locations are primarily involved in research? Both in general and specifically regarding fuel cells?

Topic 3: Constituencies

g. Find current projects in the constituency of the Federal Minister of Economics (constituency 49 "Salzgitter – Wolfenbüttel").
h. Which projects from the support measure "Schaufenster intelligente Energie - Digitale Agenda für die Energiewende" (SINTEG, English: "Smart Energy Showcases - Digital Agenda for the Energy Transition") are supported in the Minister's constituency?
i. Which large commercial enterprises receive funding in the Minister's constituency?

Appendix F. Tables

F1. Table F.1

Table F1
Range and median of responses to EnArgus unipolar-type questions among the three workshop groups' participants (mdn = median; min = lowest reported response; max = highest reported response; r = range of participant responses on the ordinal grading scale; M = mean; SD = standard deviation).

	Question	Worksho	mdn	min	max	r	M	SD
E1	Did you like working with EnArgus?	WS1	4	2	5	3	4.32	0.78
		WS2	4	2	5	3	3.86	1.07
		WS3	4	2	5	3	3.67	0.91
E2	Did you find the implementation in the information system including search engine and wiki helpful?	WS1	5	4	5	1	4.82	0.39
		WS2	5	4	5	1	4.57	0.53
		WS3	4	2	5	3	3.89	1.02
E3	Would you consider EnArgus a sensible approach to making the funding of energy research more transparent?	WS1	5	3	5	2	4.68	0.57
		WS2	4	3	5	2	4.14	0.9
		WS3	4	1	5	4	4.06	1.16
E4	Would you recommend EnArgus?	WS1	5	4	5	1	4.77	0.43
		WS2	5	4	5	1	4.57	0.53
		WS3	5	2	5	3	4.44	0.86
E5	Would you be interested in using EnArgus in the future?	WS1	4	2	5	3	4.18	0.85
		WS2	4	2	5	3	4.14	1.07
		WS3	5	3	5	2	4.39	0.78
E7	Do you find the wiki texts useful?	WS1	5	3	5	2	4.55	0.67
		WS2	4	4	5	1	4.43	0.53
		WS3	4	2	5	3	4.00	1.06
E8	Are the wiki texts easy to understand?	WS1	5	4	5	1	4.64	0.49
		WS2	5	4	5	1	4.71	0.49
		WS3	5	4	5	1	4.63	0.50
E9	Do the wiki texts help working with EnArgus?	WS1	4	2	5	3	4.09	0.75
		WS2	4	3	5	2	4.14	0.9
		WS3	4	1	5	4	3.50	1.03
E13	Do you find the ontology browser useful?	WS1	4	2	5	3	3.50	1.01
		WS2	4	2	5	3	3.86	1.07
		WS3	3	1	5	4	3.24	1.15
E14	Is the ontology browser easy to use?	WS1	4	2	5	3	4.00	1.02
		WS2	4	2	5	3	3.86	1.21
		WS3	3	1	5	4	2.81	1.22
E15	Is the functionality of the ontology browser easy to understand?	WS1	4	2	5	3	3.68	1.13
		WS2	3	2	5	3	3.43	0.98
		WS3	2	1	4	3	2.25	0.93
E16	Does the ontology browser help you work with EnArgus?	WS1	3	2	5	3	3.36	1.22
		WS2	4	1	4	3	3.14	1.21
		WS3	2.5	1	5	4	2.81	1.28
E17	How do you rate the visualisation of the ontology browser?	WS1	4	2	5	3	3.77	1.07
		WS2	4	3	5	2	4.14	0.9
		WS3	3	1	5	4	2.88	1.17
E20	Did you, as a "novice", consider EnArgus easy to understand?	WS1	5	3	5	2	4.59	0.59
		WS2	4	3	5	2	4.00	0.58
		WS3	4	3	5	2	4.12	0.60
E21	Did you find EnArgus.public easy to use?	WS1	5	4	5	1	4.73	0.46
		WS2	4	3	5	2	4.29	0.76
		WS3	4	2	5	3	4.17	0.92
E22	Is the functionality of EnArgus.public adequate for the general public?	WS1	5	2	5	3	4.59	0.73
		WS2	4	4	5	1	4.14	0.38
		WS3	4	2	5	3	4.00	1.03
E23	Did you find the suggestions of alternative search terms in ontology helpful?	WS1	4	2	5	3	4.05	0.84
		WS2	4	3	5	2	4.00	1
		WS3	4.5	2	5	3	4.06	1.16
E24	Did you find the display of the search results informative?	WS1	4.5	3	5	2	4.45	0.60
		WS2	4	4	5	1	4.29	0.49
		WS3	4	2	5	3	3.94	0.94
E25	How do you rate the evaluation options (research) with EnArgus in general?	WS1	5	3	5	2	4.59	0.59
		WS2	4	4	5	1	4.14	0.38
		WS3	4	2	5	3	3.89	0.96
E26	Did you find the presentation of search results in map form helpful?	WS1	4.5	2	5	3	4,36	0.79
		WS2	5	3	5	2	4.57	0.79
		WS3	4	2	5	3	4.11	1.08
E27	Did you find the presentation of search results in form of a diagram helpful?	WS1	5	2	5	3	4.64	0.79
		WS2	5	3	5	2	4.71	0.49
		WS3	4.5	3	5	2	4.33	0.77
E28	Were you satisfied with the speed of the search engine?	WS1	5	2	5	3	4.36	0.85
		WS2	4	2	5	3	3.71	1.11
		WS3	4	2	5	3	3.94	0.94

F2. Table F.2

Table F2
Range and median of responses to EnArgus bipolar-type questions among the three workshop groups' participants ("3" represents the ideal value)

	Question	Worksho	mdn	min	max	r	M	SD
E10	How do you rate the length of the wiki texts?	WS1	3	2	5	3	3.41	0.73
		WS2	3	3	4	1	3.14	0.38
		WS3	3	1	4	3	2.93	0.80
E11	Do you find the depth and detail of the texts appropriate?	WS1	3	2	5	3	3.17	0.73
		WS2	3	2	4	2	2.86	0.69
		WS3	3	1	5	4	3.07	0.96
E12	Do you find the depth and detail of the information presented appropriate?	WS1	3	2	5	3	3.23	0.61
		WS2	4	3	5	2	3.67	0.82
		WS3	3	2	5	3	3.31	0.79

F3. Table F.3

Table F3
Yes/No questions posed in the EnArgus evaluation questions across all three workshops.

Question		Frequency of response	
		Yes	No
Have you worked with EnArgus before?	WS1	-	-
	WS2	4	3
	WS3	10	8
Did you miss any functionality?	WS1	5	1
	WS2	3	4
	WS3	11	7

F4. Table F.4

Table F4
Range and median of responses to FÖKAT evaluation questions among WS1 and WS3 participants (mdn = median; min = lowest reported response; max = highest reported response; r = range of participant responses on the ordinal grading scale; M = mean; SD = standard deviation).

	EnArgus-Question	Worksho	mdn	min	max	r	M	SD
F1	Did you like working with FÖKAT?	WS1	1	1	3	2	1.55	0.74
		WS3	2	1	4	3	2.39	0.98
F2	Did you, as a novice, consider FÖKAT easy to understand?	WS1	2	1	5	4	2.14	1.13
		WS3	2	1	4	3	2.18	1.01
F3	Did you find FÖKAT easy to use?	WS1	2	1	5	4	2.36	1.13
		WS3	2	1	4	3	2.28	0.75
F4	Did you find the display of the search results informative?	WS1	3	1	5	4	2.91	1.48
		WS3	3	1	5	4	2.94	0.97
F5	Would you recommend FÖKAT?	WS1	2	1	5	4	2.41	1.26
		WS3	3	1	4	3	2.56	0.92
F6	Would you be interested in using FÖKAT in the future?	WS1	2	1	5	4	2.05	1.21
		WS3	2	1	5	4	2.39	1.09

F5. Table F.5

Table F5
Statistical analysis of the comparative questions posed for EnArgus and FÖKAT among the participants of WS1 and WS3 (p-values ≤.05 are significant, p-values ≤.01 are very significant, p-values ≤.001 are highly significant).

Question	Workshop	W_s	z	p
Did you like working with FÖKAT / EnArgus?	WS1	0	−4.146	<.001
	WS3	0	−3.228	<.001
Did you, as a "novice", consider FÖKAT / EnArgus easy to understand	WS1	0	−4.053	<.001
	WS3	0	−3.325	<.001
Did you find the FÖKAT / EnArgus easy to use?	WS1	0	−3.949	<.001
	WS3	0	−3.349	<.001
Did you find the display of the search results informative?	WS1	10	−3.342	<.001
	WS3	2	−2.684	<.007
Would you recommend FÖKAT / EnArgus?	WS1	0	−4.050	<.001
	WS3	1	−3.467	<.001
Would you be interested in using FÖKAT / EnArgus in the future?	WS1	0	−3.596	<.001
	WS3	0	−3.335	<.001

F6. Table F.6

Table F6
Range and median of responses to EnArgus.master evaluation questions among the participants of WS3 (mdn = median; min = lowest reported response; max = highest reported response; M = mean; SD = standard deviation).

	Question	mdn	min	max	M	SD	No response
E3	Did you like working with EnArgus.master?	2	1	5	2.5	1.29	0
E4	Would you consider EnArgus a sensible approach to making the funding of energy research more transparent?	4	2	5	3.44	1.15	2
E5	Would you recommend EnArgus.master?	3	2	5	3.22	1.06	0
E6	Would you be interested in using the EnArgus.master in the future?	4	2	5	3.67	1.24	0
E8	Did you, as a novice, consider EnArgus.master easy to understand?	3	1	5	2.65	1.06	1
E9	Did you find the EnArgus.master easy to use?	3	1	5	2.71	1.26	1
E10	Is the functionality of EnArgus.master sufficient for your purposes?	4	2	5	4	0.96	4
E11	Did you find the suggestions of alternative search terms from ontology helpful?	3	1	5	3.25	1.36	6
E12	Did you find the display of the search results informative?	4	1	5	3.27	1.28	3
E13	How do you evaluate the evaluation possibilities (research) with EnArgus.master in general?	4	1	5	3.73	1.39	3
E14	Did you find the presentation of search results in map form helpful?	4	3	5	3.83	0.72	6
E15	Did you find the presentation of search results in form of a diagram helpful?	4	3	5	3.93	0.73	4
E16	Were you satisfied with the speed of the search engine?	3.5	1	5	3	1.53	0

F7. Table F.7

Table F7
Frequency of responses of yes/no responses EnArgus.master evaluation questionnaire among WS3 participants.

	Question	Frequency of response		
		Yes	No	No response
E1	Have you ever worked with EnArgus.master?	0	18	0
E17	Have you missed any functionality?	6	6	6

F8. Table F.8

Table F8
Test statistics (z) and p-values in comparison of EnArgus.master and PROFI evaluation questions (p-values ≤.05 are significant, p-values ≤.01 are very significant, p-values ≤.001 are highly significant).

Comparison	z	p
E3	-0.203	0.839
E4	-2.831	0.005
E5	-1.440	0.150
E6	-1.799	0.072
E8	-0.550	0.582
E9	-0.359	0.719
E10	-2.157	0.031
E12	-2.266	0.023
E13	-2.676	0.007
E16	-2.697	0.007

References

[1] Commission E. Communication from the commission. A clean planet for all. A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Tech. Rep. 773 final; 2018. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773.

[2] IEA. Energy technology RD&D budgets 2020: overview – analysis. 2020. The estimated total public energy RD&D budget for IEA member governments reached $20.9 billion in 2019; https://www.iea.org/reports/energy-technology-rdd-budgets-2020.

[3] Brezis ES. Focal randomisation: an optimal mechanism for the evaluation of R&D projects. Sci Public Policy 2007;34(10):691–8. doi:10.3152/030234207X265394. Publisher: Oxford Academic

[4] Roper S, Hewitt-Dundas N, Love JH. An ex ante evaluation framework for the regional benefits of publicly supported R&D projects. Res Policy 2004;33(3):487–509. doi:10.1016/j.respol.2003.10.002.

[5] Commission E.. About CORDIS: innovate with EU research results. 1994. https://cordis.europa.eu/about/en.

[6] Petrakis EGM, Tzeras K. Similarity searching in the CORDIS text database. Softw: Pract Exp 2000;30(13):1447–64. doi:10.1002/1097-024X(20001110)30:13<1447::AID-SPE344>3.0.CO;2-C.

[7] Feldman MP, Lichtenberg FR. The impact and organization of p-funded research and development in the European community. In: Encaoua D, Hall BH, Laisney F, Mairesse J, editors. The economics and econometrics of innovation. Boston, MA: Springer US; 2000. p. 177–200. ISBN 978-1-4757-3194-1. doi:10.1007/978-1-4757-3194-1_7.

[8] Energiekompendium: Ein Nachschlagewerk für Grundbegriffe, Konzepte und Technologien.. Hirzel S, editor. 2nd Edition. Fraunhofer IRB Verlag; 2019. https://www.baufachinformation.de/energiekompendium/buecher/252709. ISBN 978-3-7388-0425-6.

[9] Auer S, Bizer C, Kobilarov G, Lehmann J, Cyganiak R, Ives Z. DBpedia: a nucleus for a web of open data. In: Aberer K, Choi K-S, Noy N, Allemang D, Lee K-I, Nixon L, Golbeck J, Mika P, Maynard D, Mizoguchi R, Schreiber G, Cudré-Mauroux P, editors. The semantic web. Berlin, Heidelberg: Springer; 2007. p. 722–35. ISBN 978-3-540-76298-0. doi:10.1007/978-3-540-76298-0_52.

[10] VDI-Lexikon Energietechnik. Schaefer H, editor. Düsseldorf: VDI-Verlag; 1994.

[11] German Federal Government. Energie-lexikon. 2016. https://www.bundesregierung.de/Webs/Breg/DE/Themen/Energiewende/EnergieLexikon/_node.html.

[12] Federal Ministry of Economics and Technology (BMWi). 6th energy research programme of the federal government "research for an environmentally sound, reliable and affordable energy supply". 2011. https://www.bmwi.de/Redaktion/EN/Publikationen/research-for-an-environmentally-sound-reliable-and-affordable-energy-supply.html.

[13] Federal Ministry of Education and Research (BMBF), Daten und Fakten zum deutschen Forschungs und Innovationssystem: Bundesbericht Forschung und Innovation 2016 - Ergädnzungsband I, Tech. rep. 2016. https://www.bmbf.de/upload_filestore/pub/Bufi_2016_Ergaenzungsband_1.pdf

[14] Handbook on ontologies. Staab S, Studer R, editors. 2. Berlin Heidelberg: Springer-Verlag; 2009. ISBN 978-3-540-70999-2. doi:10.1007/978-3-540-92673-3.

[15] Smith B, Ceusters W, Klagges B, Köhler J, Kumar A, Lomax J, Mungall C, Neuhaus F, Rector AL, Rosse C. Relations in biomedical ontologies. Genome Biol 2005;6(5):R46. doi:10.1186/gb-2005-6-5-r46.

[16] Bartussek W, Bense H, Hoppe T, Humm BG, Reibold A, Schade U, Siegel M, Walsh P. Introduction to semantic applications. In: Hoppe T, Humm B, Reibold A, editors. Semantic applications. Springer Vieweg; 2018. p. 1–12. doi:10.1007/978-3-662-55433-3_1.

[17] Schade U, Bense H, Dembach M, Sikorski L. Semantische Suche im Bereich der Energieforschungsförderung. In: Ege B, Humm B, Reibold A, editors. Corporate Semantic Web. Springer; 2015. p. 71–85. ISBN 978-3-642-54886-4.

[18] Glauer M., Booshehri M., Emele L., Flügel S., Förster H., Frey J., Frey U., Hastings J., Hofmann C., Hoyer-Klick C., Hülk L., Kleinau A., Knossala K., Kotzur L., Kuckertz P., Mossakowski T., Neuhaus F., Robinius M., Stappel M., Stolten D.. The open energy ontology; 2020. https://openreview.net/forum?id=ofZ5BBg2lSe.

[19] Cuenca J, Larrinaga F, Curry E. A unified semantic ontology for energy management applications. In: Web stream processing and ontology modularity, contextuality and evolution workshops, vol. 1936. CEUR-WS.org; 2017. p. 86–97.

[20] Federal Ministry of Economics and Technology (BMWi), Innovation durch Forschung: Erneuerbare Energien und Energieeffizienz: Projekte und Ergebnisse der forschungsförderung 2017, Annual Report, Berlin. 2017. https://www.bmwi.de/Redaktion/DE/Publikationen/Energie/innovation-durch-forschung-2017.html

[21] Hirzel S, Oppermann L, Krassowski J, Sikorski L, Rauscher T, Seier M, Wagner H-J, Frietsch O, Koch T, Flamme S, Pöstges A, Frick J, Schreiner M, Beier C, Heiwolt K, Ruland R, Plötz P, Rohde C, Teufel B. What's going on in energy efficiency research?

A platform to enhance the transparency of energy research funding in Germany; 2017. Presqu'ile de Giens, France
[22] Oppermann L, Hinrichs E, Schade U, Koch T, Rettweiler M, Ohrem F, Plötz P, Beier C, Prinz W. EnArgus: zentrales informationssystem energieforschungsförderung; 2015. p. 1717–30. Cottbus
[23] Oppermann L., Hirzel S., Krassowski J., Heiwolt K., Ruland R., Koch T.. EnArgus 2.0 - Zentrales Informationssystem Energieforschungsförderung. Schlussbericht Verbundvorhaben "01142005/1" - BMWI II C 6; Laufzeit: Juli 2013 - Juni 2017. 2017. https://www.tib.eu/de/suchen/id/TIBKAT%3A1012771555/.
[24] Larson R, Farber B. Elementary statistics: picturing the world. 5th edition. Boston: Prentice Hall; 2012.
[25] Beyan O, Wuchner A, Eisengräber-Pabst D, Quix C, Zaschke C, Schumacher O. Research data in the Fraunhofer digital project. Creating a FAIR research data infrastructure and culture. In: Workshop on research objects, RO 2018. Proceedings. online resource; 2018. p. 8. http://publica.fraunhofer.de/dokumente/N-534423.html.
[26] Auer S.. Enquete-kommission künstliche intelligenz – gesellschaftliche verantwortung und wirtschaftliche, soziale und ökologische Potenziale". 2019. https://www.bundestag.de/dokumente/textarchiv/2019/kw11-pa-enquete-ki-627120.
[27] Lecue F. On the role of knowledge graphs in explainable AI. Semant Web 2020;11(1):41–51.
[28] Berners-Lee T. 5 Star Open Data. 2012. http://5stardata.info/.
[29] Stellato A, Fiorelli M, Turbati A, Lorenzetti T, van Gemert W, Dechandon D, Laaboudi-Spoiden C, Gerencsér A, Waniart A, Costetchi E, Keizer J. VocBench 3: a collaborative semantic web editor for ontologies, thesauri and lexicons. Semant Web 2020;11(5):855–81. doi:10.3233/SW-200370. Publisher: IOS Press
[30] Schandl T, Blumauer A. PoolParty: SKOS thesaurus management utilizing linked data. In: Aroyo L, Antoniou G, Hyvönen E, ten Teije A, Stuckenschmidt H, Cabral L, Tudorache T, editors. The semantic web: research and applications. Berlin, Heidelberg: Springer; 2010. p. 421–5. ISBN 978-3-642-13489-0. doi:10.1007/978-3-642-13489-0_36.
[31] McCrae JP, Fellbaum C, Cimiano P. Publishing and linking wordNet using lemon and RDF. In: Proceedings of the 3 rd workshop on linked data in linguistics; 2014.
[32] Angioni S, Salatino AA, Osborne F, Reforgiato Recupero D, Motta E. Integrating knowledge graphs for analysing academia and industry dynamics. ADBIS, TPDL and EDA 2020 common workshops and doctoral consortium. Springer; 2020.
[33] GAIA-X: a pitch towards Europe. Status report on user ecosystems and requirements. 2020. https://www.bmwi.de/Redaktion/EN/Publikationen/gaia-x-a-pitch-towards-europe.html.
[34] McCarthy J, Hayes PJ. Some philosophical problems from the standpoint of artificial intelligence. In: Readings in artificial intelligence. Elsevier; 1981. p. 431–50.
[35] Engelbart D.. Augmenting human intellect: a conceptual framework. 1962. http://www.dougengelbart.org/pubs/augment-3906.html.
[36] Oppermann L, Boden A, Hofmann B, Prinz W, Decker S. Beyond HCI and CSCW: challenges and useful practices towards a human-centred vision of AI and IA. In: Proceedings of the halfway to the future symposium 2019 (HTTF 2019). Nottingham, England: ACM; 2019.
[37] Hogan A, Harth A, Passant A, Decker S, Polleres A. Weaving the pedantic web. Linked data on the web, vol 628. CEUR-WSorg; 2010.