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Ontology-Driven Exploration of Energy Research Funding Data for Open and Intelligent Access

Thomas Jensen[1*], Freya Nielsen[1], Mette Sørensen[2], Noah Williams[3]

Abstract

This article outlines the theoretical framework, system architecture, and assessment of EnArgus, the primary database for energy research financing in Germany. Commissioned by the German Federal Ministry for Economic Affairs and Energy (BMWi), the platform serves as a comprehensive, centralized resource detailing all current and recently completed publicly funded energy research projects nationwide. Participants, ranging from general users to domain specialists, attended three assessment workshops to compare the system's public and professional interfaces with analogous platforms. Findings indicated that the diverse user base generally offered favorable appraisals of the EnArgus framework. The platform enhances visibility in the energy field and delivers distinct benefits for specialized applications compared to comparable databases. By incorporating conceptually associated terminology into search queries, the platform's semantic engine ensures superior accuracy and broader scope; furthermore, its intelligent design enhances reliability, making it appropriate for critical domains where inadequate information retrieval could yield severe repercussions. By detailing a fully operational platform, this study also presents a strategic outline for enriching digital administrative records with semantics and making them open, thereby laying the groundwork for novel data exploration methods crucial to next-generation artificial intelligence applications.

Keywords Energiewende, Information system, Wiki, Ontology, Databases, Evaluation

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Introduction

To attain climate neutrality across Europe by 2050, the effective and broad deployment of sustainable, high-efficiency energy technologies is critical [1]. Government financing for energy-related research serves as a fundamental component of this objective in numerous nations. For instance, in 2019, the participating states of the International Energy Agency (IEA) allocated USD 20.9 billion toward energy research, development, and demonstration initiatives [2]. The primary objective behind state-sponsored corporate research and development (R&D) is to generate beneficial economic externalities that extend well beyond individual corporate gains. In the absence of such financial support, private enterprises would fail to reach the investment thresholds deemed ideal from a broader societal standpoint [3, 4].

The continually expanding volume of state-financed research initiatives renders systematic tracking of these initiatives an absolute necessity. Such monitoring is essential to ensure accountability for public expenditures, pinpoint emerging research trajectories or deficiencies, and prevent redundant funding for nearly identical projects. Various energy-focused information platforms exist at both the national German and broader European levels to fulfill these functions. While these

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databases have distinct primary focuses, their subject matter frequently intersects. Each platform must facilitate the bureaucratic implementation of policy choices by presenting a clear, unequivocal representation of information via their interfaces, grounded in robust administrative financial records.

Within Germany, the primary databases detailing government-backed energy research include the Förderkatalog (FÖKAT), the BINE Information Service, and the Federal Environment Agency's UFORDAT system. Nevertheless, the BINE Information Service ceased operations following a termination of its financing in 2018, while UFORDAT concentrates heavily on environmental issues, distinguishing it from the EnArgus platform detailed herein. The most significant thematic overlaps occur between FÖKAT1 and EnArgus. Additionally, the PROFI project database is particularly important for the internal operations of financing institutions, as PROFI2 was specifically designed to support the administration and oversight of monetary allocations.

At the European tier, analogous data services are delivered by the Community Research and Development Information Service [5] (CORDIS3). Launched in 1994 as the European Commission's inaugural permanent website [5], and originally distributed via CD-ROM [6], CORDIS functions as the principal archive for outcomes generated by the EU's research and innovation framework initiatives. Archiving records dating back to the 1990s, the platform encompasses framework programs ranging from FP4 through FP7, Horizon 2020, and subsequent endeavors. Over time, CORDIS has undergone consistent modernization. It serves as an open-access archive housing comprehensive records of European Commission projects, including participant details, technical reports, deliverables, summaries, and links to open-access literature. The platform facilitates engagement and collaborative efforts among European partners while also serving as a tool for analyzing the trajectories, deliverables, and broader impacts of state-sponsored R&D on the scientific and industrial progress of EU member states [7].

While these databases of current and historical initiatives serve as project registries, their search capabilities—which rely on basic keyword matching, standardized classifications, or plain text—pose substantial constraints. Specifically, due to terminological inconsistencies, these systems frequently fail to retrieve all pertinent endeavors within a given domain, requiring supplementary specialist expertise and labor to compile comprehensive summaries and prepare data for statistical analysis. Furthermore, even domain specialists are restricted to uncovering data that aligns with their preexisting hypotheses or knowledge base, introducing the persistent danger that critical, contemporary, and highly applicable insights remain undiscovered.

The foundational concept driving the creation of EnArgus was to use a domain-specific ontology to generate superior systematic overviews and resolve routine challenges in administering financed energy research by drawing semantic connections between information in funding applications and progress reports. Financial sponsors frequently require the ability to detect textual correlations that exceed those of standard machine learning algorithms and conventional plagiarism scanners. The initial premise of the EnArgus initiative was to autonomously compute the degree of similarity between projects solely from their narrative descriptions. This capability enables operators to verify whether an application has been submitted elsewhere, thereby preventing duplicate financing. Additionally, it offers a comprehensive perspective on how thoroughly political mandates are being addressed. By integrating specialized energy sector knowledge, computational linguistics, and advanced information technology, EnArgus's sophisticated ontology-driven search mechanism translates critical expert insights into formats suitable for automated computation. Ultimately, a framework built on this synthesis enables swifter, highly accurate evaluations of public funding data, thereby enhancing the clarity and accessibility of research financing for a broader demographic.

A uniquely vital component of the EnArgus database is its integrated wiki, which houses more than 2,400 specialized articles authored by energy professionals associated with the initiative [8]. Relying on Wikipedia [9] for data extraction proved inadequate for the system's requirements, primarily because the structural consistency and quality of those public entries varied significantly, and numerous essential topics were absent. Consequently, a primary objective during this developmental phase was to establish consensus on an essential corpus of articles to comprehensively map the energy sector. To accomplish this, field specialists cross-referenced their proposed topics against established literary and policy-

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based classifications, including scholarly reference materials [10, 11], official state funding sectors [12], and the inter-ministerial "Leistungsplansystematik" research framework utilized in Germany [13]. The finalized compilation of subjects underwent continuous iterative refinement through dialogues between linguistic scholars and energy specialists. Furthermore, an exhaustive drafting manual was produced to streamline the authoring process and ensure the widespread utility of the resulting wiki content.

To enable the automated computational processing of specialist expertise, such information must first be converted into structured, formal models. Drawing on the philosophical discipline concerned with the nature of existence, these structured models are referred to as "ontologies" [14]. While ontologies can map virtually any form of information, converting nuanced expert insights into systematic frameworks that machines can actively use often presents significant challenges. This challenge is twofold: first, it is imperative to explicitly identify the precise data categories the software requires to enhance its analytical output. Second, a rigorous collaborative workflow must be established to ensure continuous dialogue between data scientists and domain specialists, enabling them to reach consensus on both the information to be encoded and the model's structural format. Engaging specialists in a single initial consultation without subsequent validation risks omitting fundamental concepts. Conversely, if data scientists encode this expertise without a deep understanding of the underlying principles, the resulting models could lead to erroneous computational inferences. While ontologies are extensively utilized within the biological and medical fields [e.g., Ref. [15]]—with further applications detailed in Ref. [16]—the specific framework engineered for the EnArgus platform [17] currently, to our understanding, stands as one of the most expansive ontologies within the energy sector. Its architecture encompasses upwards of 4,000 discrete classes, exceeding 5,000 subclass associations, 27 object properties, over 200 data properties, more than 2,500 distinct entities, and in excess of 20,000 specific axioms. The comparatively smaller Open Energy Ontology (OEO4) was heavily influenced by the EnArgus framework. It endeavors to encapsulate the energy sector with equivalent breadth and employs comparably descriptive axioms to delineate elements such as the material composition of physical artifacts. OEO adheres to more rigid structural engineering standards, featuring a modular architecture that harmonizes with the Basic Formal Ontology (BFO). Assessments of the OEO have validated both its comprehensive scope and its practical utility for specialists performing document annotation [18]. Similarly, the OEMA (Ontology for Energy Management Applications) has a comparable architectural scale but focuses specifically on the operational management of smart electrical grids [19].

For us, integrating domain expertise, computational linguistic methods for text analysis, and contemporary information technology means engineering a sophisticated data processing architecture that embeds a domain ontology and leverages this ontologically structured knowledge in its operations. Furthermore, this implies that the ontological models were constructed through collaborative interactions among information scientists and subject-matter specialists.

The ensuing EnArgus platform serves as the primary information portal for the German Federal administration on energy research financing. Its open-access portal5 serves as a mechanism to establish transparency in funding and is accessible to all individuals without requiring registration. Furthermore, it permits automated indexing by web search engines and has been integrated into Google; consequently, searching for specific terminology or an appropriate grant identifier will eventually direct users to the EnArgus.public portal. The German Federal Ministry of Economics and Technology (BMWi) [20, p. 137] currently formally endorses EnArgus as an instrument for accessing data regarding financed initiatives.

The objective of this manuscript is to explore further the advantages of sophisticated, data-oriented applications within energy research. To achieve this, the centralized German energy research database 'EnArgus' [21, 22] is introduced and assessed by comparing it with the established PROFI and FÖKAT platforms. Specifically, this study seeks to identify the functional advantages and limitations of the EnArgus framework and to uncover areas for potential enhancement. To accomplish this, an assessment involving various user cohorts was conducted. Consequently, this manuscript investigates the following research questions:

1. How does the varying expertise of participants affect their utilization of the FÖKAT and EnArgus.public information systems?

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2. From the perspective of its active specialist user base, how does EnArgus.master differentiate itself from the PROFI database?

3. From the viewpoint of their intended demographic, how effectively are EnArgus.master and EnArgus.public tailored to their designated objectives?

(a) What advantages do users ascribe to the respective EnArgus interfaces?

(b) What enhancements are recommended?

In the following sections of this manuscript, an initial summary of EnArgus is provided, followed by an explanation of the methodological framework utilized for the assessment. Following this, the evaluation outcomes are detailed and analyzed before concluding.

The EnArgus Information System

EnArgus6, financed by the Federal Ministry for Economic Affairs and Energy (BMWi), functions as the primary data repository for energy scholars. It facilitates access to historical data on publicly financed energy initiatives and their associated funding records, offering a comprehensive perspective on the research ecosystem and its technological advancements **(Figure 1).**

Beyond its specialized expert portal, the EnArgus framework also acts as a medium for public communication. The information system provides a centralized entry point for data on government-backed initiatives, emerging research trajectories, and technological innovations in the energy research sector. EnArgus.public, which targets policymakers, project administrators, and the broader citizenry, was engineered and developed to enable any curious individual to conduct autonomous inquiries, with the overarching objective of fostering greater visibility and efficiency in this domain. During 2019 alone, approximately 66,000 domestic users accessed the platform to query roughly 2,800 distinct search terms (personal communication on 25 May 2020 by “Projektträger Jülich” (PTJ) to the authors).

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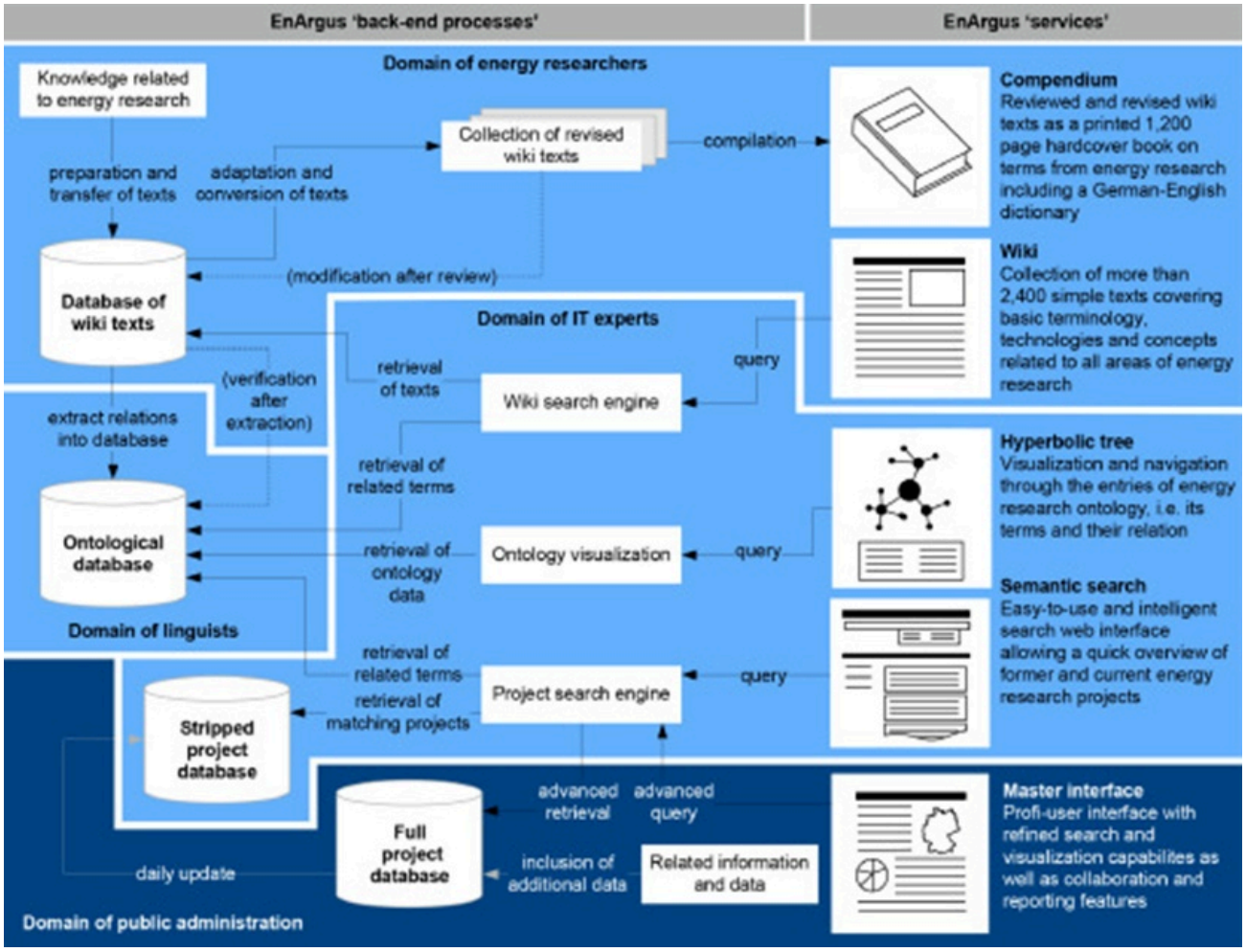


Figure 1. Overview of the EnArgus system (source: [21]).

As an augmentation, EnArgus.master provides a restricted, internal environment designed for authorized practitioners, governmental ministries, and financial sponsors. To facilitate improved cooperation, EnArgus.master uses the BSCW shared workspace architecture, a collaborative software solution that enables enrolled members to share data within virtual online environments. This architecture streamlines user and group management, access privilege delegation and the dissemination of documents and data among working teams. While both interfaces source their data from the same project registry, only a curated subset is made publicly available. Consequently, the open-access portal displays only records of sanctioned initiatives. In contrast, the specialized platform incorporates sensitive material, including proposal narratives, technical specifications for financed projects, contact information and preliminary and concluding reports.

In its entirety, the EnArgus framework relies on a funding registry that holds data on more than 28,000 state-financed energy initiatives spanning from 1968 to the contemporary era, with exhaustive documentation beginning in 1977. A fundamental component of the EnArgus architecture is its semantic search capability, which further amplifies the transparency of the energy research endeavors it supports. Utilizing an energy research ontology that leverages data semi-autonomously extracted from internal Wiki articles, the system can automatically append synonyms into search outputs; by incorporating these synonyms corresponding to the queried terms, the results for conceptually linked terminology are additionally presented within a user interface widget **(Figure 2).** This mechanism guarantees that even if a user's phrasing for a fundamental concept, principle, or technology differs from the precise search outcome, the relevant objective is ultimately retrieved.

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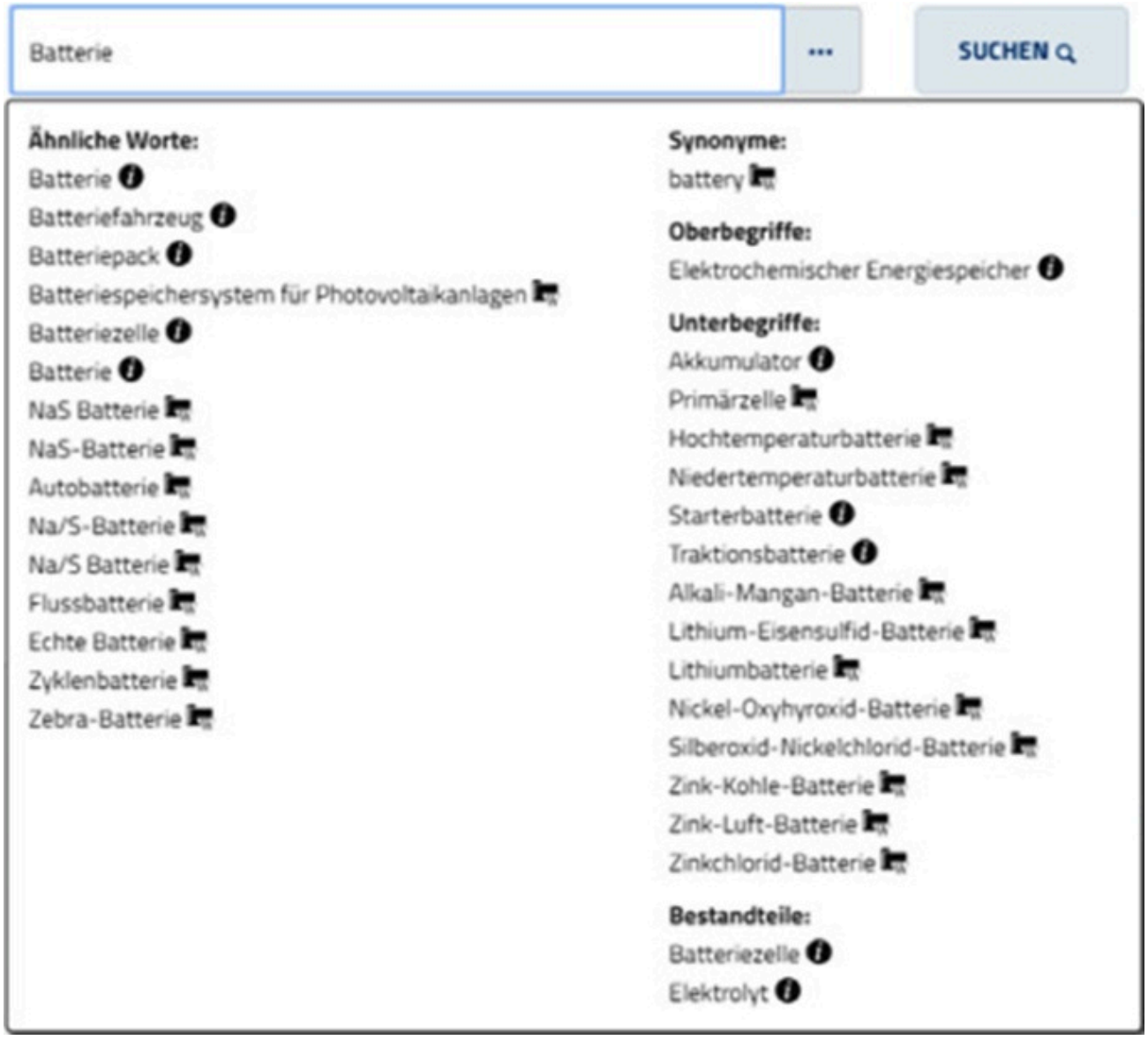


Figure 2. The semantic search supports the user with suggestions for related search terms (left) as well as synonyms, superordinate terms, subordinate terms, and components (right, from top to bottom).

To assist individual users with their inquiries, EnArgus integrates a dedicated Wiki, a hyperbolic tree structure, and an ontology-driven search mechanism to navigate or examine the energy research project repository.

Currently containing in excess of 2,400 articles, the EnArgus Wiki is designed to encompass an extensive array of energy research subjects **(Figure 3)**. In addition to providing guided navigation through the project registry and brief introductory texts that elucidate specific terminology and technologies, the Wiki serves as the foundational structure for cultivating a domain-specific ontology.

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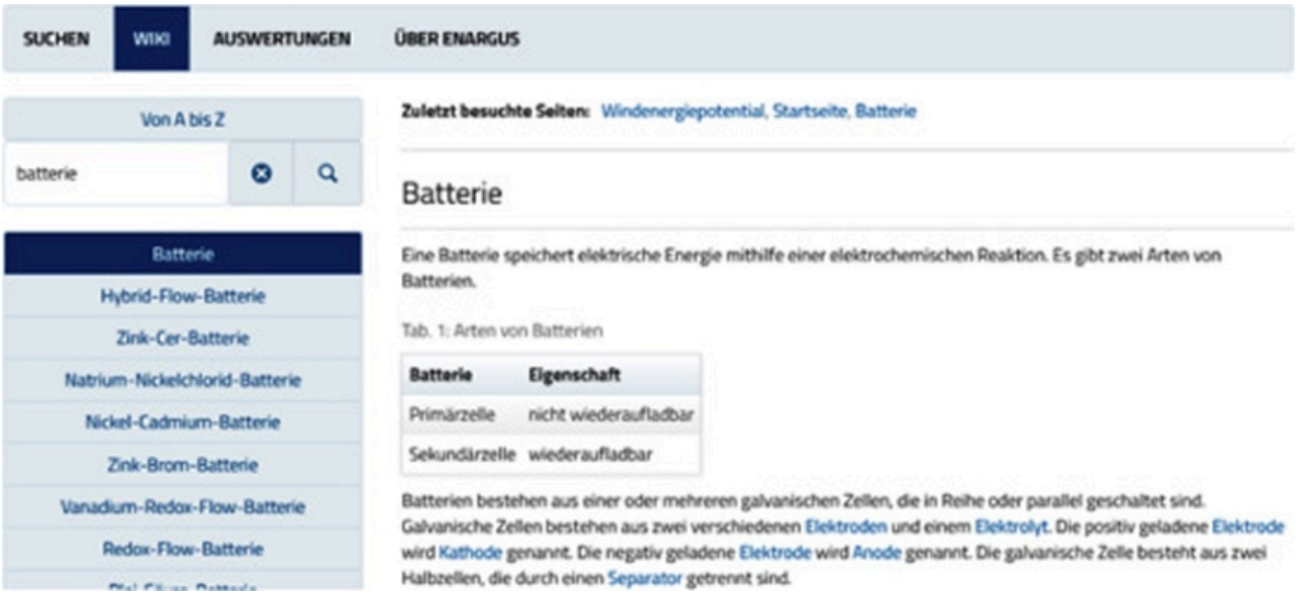


Figure 3. Wiki entry for the search term “Batterie” (battery).

This ontology is semi-autonomously compiled from Wiki entries formulated to be simultaneously a) comprehensible to laypersons and b) suitable for the automated, machine-driven extraction of core semantic attributes and relational data. Specifically, this automated generation procedure yields outputs that subsequently necessitate manual verification.

Within the ontology, specialized vocabulary extracted from the Wiki articles—encompassing broader concepts (hypernyms) and narrower classifications (hyponyms) alongside distinct instances—is mapped together with additional semantic connections (synonyms, constituent parts, etc.). An illustrative instance is shown in **Figure 4.** As a result, when querying a specific term, interconnected vocabulary (hyponyms, synonyms, and related concepts) is highlighted and can be utilized for a semantically enriched search [17]: for instance, an individual seeking a comprehensive compilation of projects concerning redox-flow batteries would ideally also retrieve initiatives classified under the alternative designation “redox-flow cell”.

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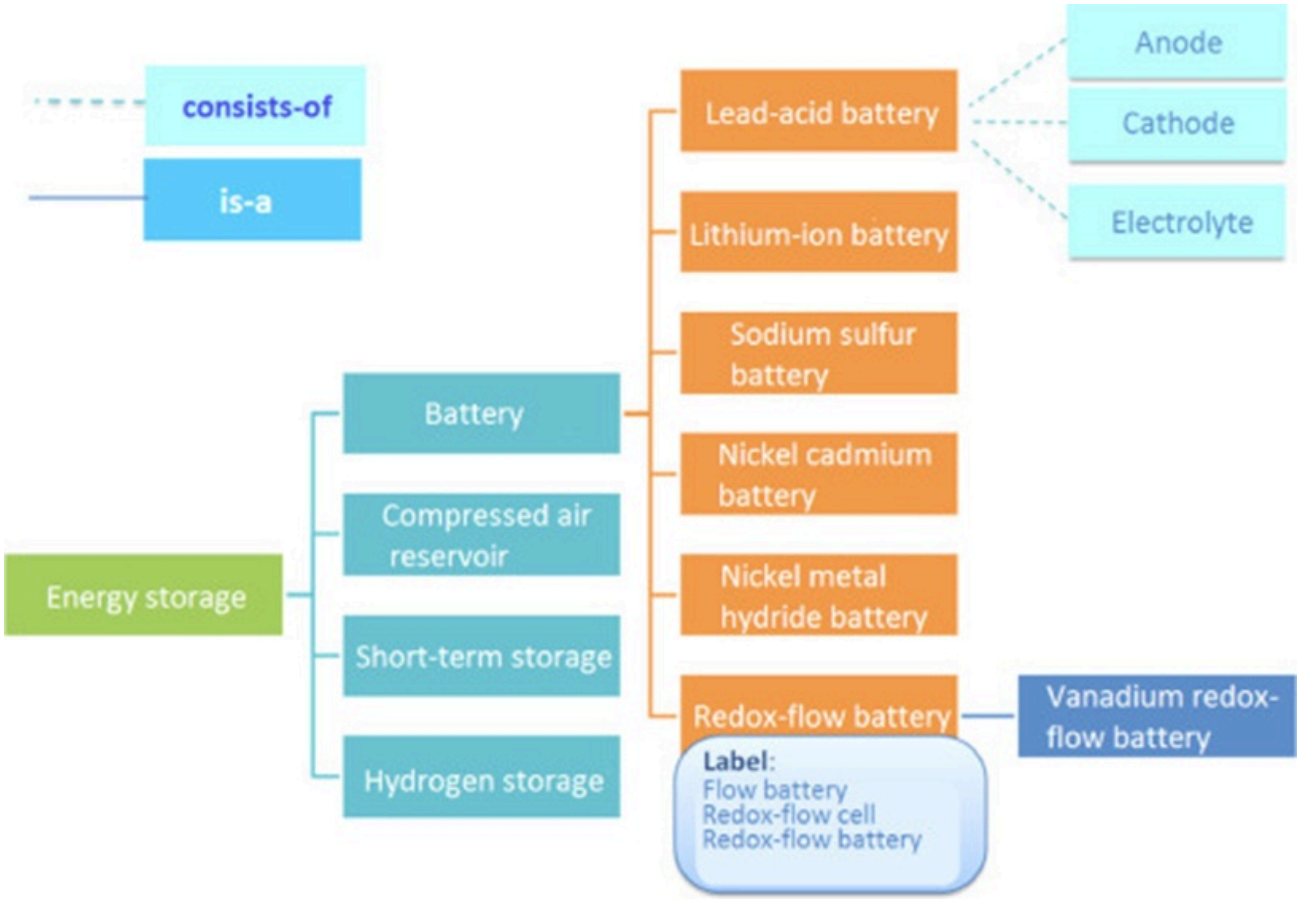


Figure 4. Excerpt from the EnArgus ontology.

Positioned beneath every Wiki entry is an interactive hyperbolic tree that conceptually relates the queried vocabulary to its broader semantic context **(Figure 5)**. It facilitates exploration across various technologies, theoretical frameworks, and thematic sectors within energy research, permitting an exhaustive investigation of conceptually affiliated terminology utilizing ontology-based keywords. Within this hierarchical framework, semantic correlations between concepts are graphically depicted, positioning the searched term at the core, concentrically framed by conceptually adjacent vocabulary and theories. With a simple button press, individuals can reveal or conceal hierarchical tiers and adjust the scope of semantic proximity. Every appended tier broadens the visual map by introducing the concentric semantic environment of the outermost terminology. Should a user select one of the adjacent terms, the visual focus transitions to it; simultaneously, the respective Wiki article is displayed.

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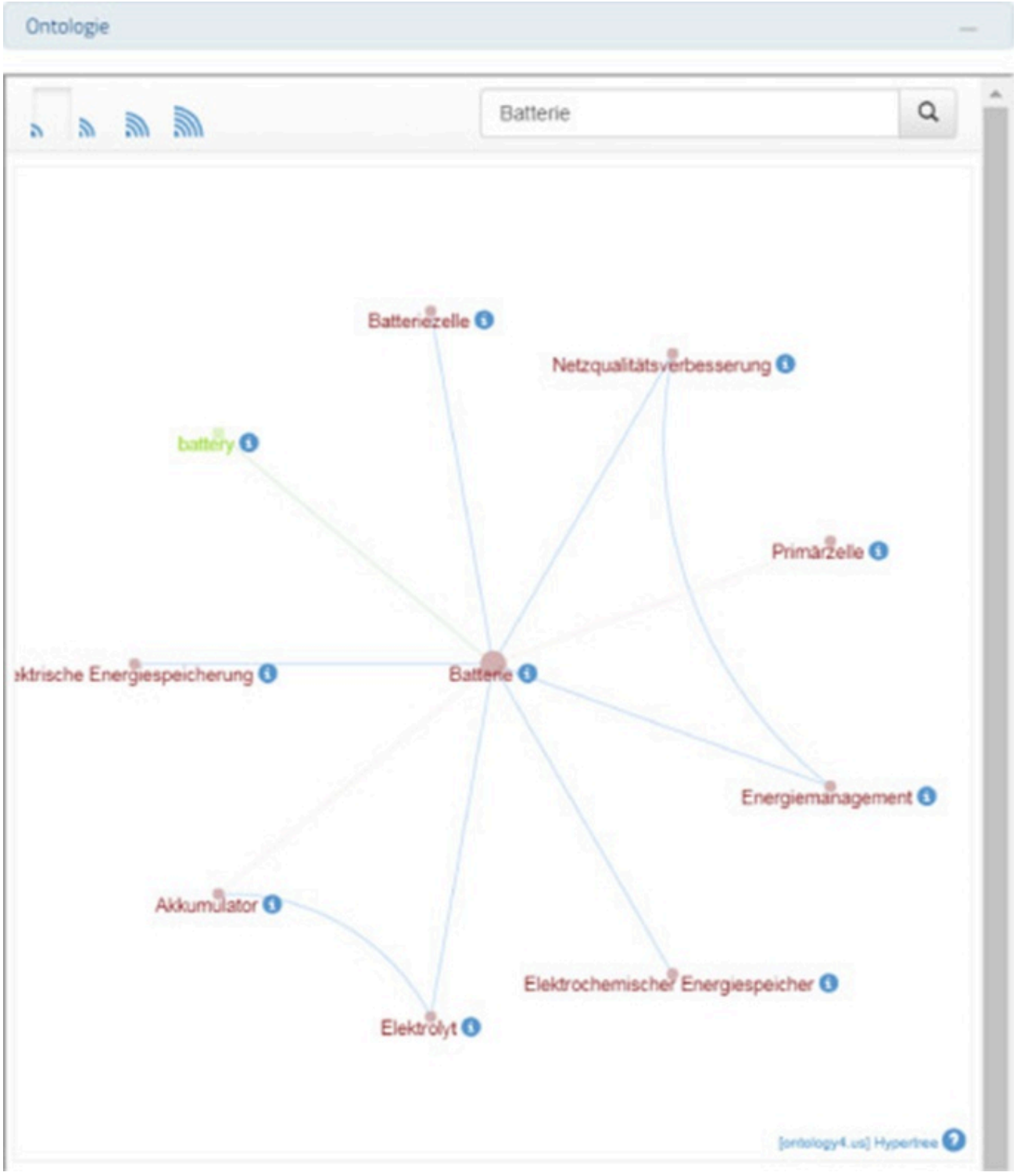


Figure 5. Under the search term “battery”, the ontology browser displays (quasi-)synonymous terms such as “accumulator” or “energy storage device” on the first level of the hyperbolic tree

On a technical level, EnArgus’ semantic search functionality integrates multiple data repositories, including the custom-built ontology. Its central element is the PROFI project administration database, managed by the German Aerospace Center DLR under the directive of the Federal Ministry of Education and Research BMBF. Securing access to this sovereign data required formal negotiations between our funding body BMWi and BMBF. Following consensus, restricted

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permissions were granted to access pertinent sections of the foundational database. Automated nightly cron jobs run queries in the Oracle database to gather information across multiple tables, generating XML output. Subsequently, these files are synthesized and processed to generate project metadata, which is archived as distinct objects per project within the object-oriented BSCW database implemented in Python. The indexing of these BSCW entities via PyLucene is automatically initiated upon their generation or modification.

PyLucene retrieves matching records whenever a user enters a query in the EnArgus portal, using a designated similarity metric. Furthermore, a fuzzy search capability is activated for specific data fields, though it is explicitly disabled for grant identification numbers. The ontology itself is housed within an independent MySQL database. When the semantic search function is active, the user-provided search vocabulary is initially processed by this ontology database to aggregate supplementary terminology (near-synonyms, hyponyms, translations). These aggregated terms are subsequently used to formulate more elaborate PyLucene queries, ultimately enabling the retrieval of projects that are conceptually linked to the initial query but would not have been classified as similar otherwise. For example, querying the German term ‘Hochofen’ yields the same list of initiatives as searching for the English term ‘blast furnace’.

The semantic search facilitates intuitive exploration of the project repository and provides access to comprehensive data on both historical and ongoing state-backed energy initiatives. Using the foundational data, the vocabulary submitted into the search interface **(Figure 2)** is interactively supplemented with contextualized details on related terminology, synonyms, superordinate concepts, subordinate concepts, and components. After a search, the results can be further filtered, refined, and arranged based on various criteria. Furthermore, users can access detailed information on individual initiatives or transform the entire dataset of search results into visual diagrams and interactive geographic maps, serving, for instance, to pinpoint trajectories within specialized energy research subjects at a supra-regional level.

The specialized expert portal also includes sophisticated filtering and search capabilities, along with supplementary administrative tools that allow users to organize their search results; furthermore, professional operators have access to more advanced data visualization tools and the ability to embed analytical findings directly on the public homepage.

Materials and Methods

Evaluation setup

Regarding the overall assessment framework, EnArgus.public and EnArgus.master are evaluated independently because they serve distinct target demographics and primary objectives. While EnArgus.public is evaluated against FÖKAT, EnArgus.master is contrasted with PROFI. The assessment comprises both qualitative and quantitative examinations, utilizing a mix of practical exercises, surveys, and dialogues with individuals representing various user groups. This was conducted across three workshops, encompassing a total of 47 participants **(Table 1).**

EnArgus.public was included in every workshop, whereas EnArgus.master was evaluated exclusively during the second and third sessions, involving a total of 25 individuals.

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

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The initial assessment workshop (WS1), conducted in October 2016, involved 22 university students enrolled in diverse academic programs at the Ruhr-University Bochum. To ensure adequate attendance, individuals received a 20 Euro compensation for their involvement. This demographic was selected to simulate the general public, possessing no specialized prior expertise regarding energy research information platforms. Consequently, they were anticipated to exhibit a predominantly impartial perspective of the interface.

The subsequent workshop (WS2) took place in December 2016 and included seven academic specialists focused on “Energy in buildings and districts,” each with both theoretical and practical expertise. Given their professional context, this cohort was designated to emulate authentic professional users who routinely execute tasks on analogous platforms.

The final workshop (WS3), organized in January 2017, involved 18 representatives from the “Projektträger Jülich” (PTJ) whose primary responsibilities involve evaluation and operational duties within the funding institution. Alongside the attendees from the second workshop, these individuals also engage with the research sector daily, though from an alternative operational standpoint. Consequently, this cohort exemplifies a typical user demographic that relies heavily on the accuracy, reliability, and clarity of funding data.

Evaluation design

The three evaluation sessions were conducted in environments resembling lecture halls or meeting rooms, where each attendee was provided with an individual computer terminal to execute the assignments. Surveys designed to contrast the distinct platforms were completed independently on paper. All instructions and survey items were administered to the attendees in German and subsequently translated for this manuscript.

Attendees received a concise overview of the EnArgus initiative, covering the organization of Wiki entries, the domain ontologies, and the associated search mechanism. Furthermore, the overarching objectives and advantages of the EnArgus platform were elucidated. It must be emphasized that, given the iterative advancement of both the software and its foundational database, the preliminary instructions and tasks were marginally modified to align with the specific version of the system being assessed. Following this orientation, attendees were assigned tasks and survey items related to EnArgus (.public and .master) and the analogous platforms PROFI and FÖKAT.

Evaluation of EnArgus.public

The primary segment investigating EnArgus comprised 24 operational tasks formulated to evaluate the platform’s efficacy, paired with 33 self-administered assessment queries. Twenty of these practical exercises had a single definitive correct response, allowing classification of outcomes as either accurate or inaccurate for this analysis.

To evaluate the platform’s efficacy relative to conventional tools, attendees in WS1 and WS3 conducted four supplementary exercises that required concurrent inquiries using both FÖKAT and EnArgus. This was followed by 8 survey items assessing the users’ impressions of FÖKAT. The second workshop (WS2) concentrated exclusively on EnArgus.public.

Upon completing the EnArgus practical exercises, attendees completed the assessment survey. Using 5-point Likert scales (ranging from 1: most negative to 5: most positive), individuals were asked to evaluate 25 closed-ended items (22 unipolar and 3 bipolar) reflecting their recent interactions with EnArgus.public. These inquiries were intended to capture user perspectives on the interfaces, specifically focusing on the advanced information retrieval capabilities enabled by the ontology browser and the EnArgus Wiki, as well as the platform’s overall usability, visual layout, and accessibility.

Attendees were given 1 hour to complete the EnArgus component and 30 minutes to conclude the FÖKAT segment.

It is important to note that the order of exercises administered during WS1 introduced an inadvertent bias, as during the comparative analysis of FÖKAT and EnArgus.public, every participant began with the FÖKAT exercises. Ideally, the

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cohort should have been divided, with half initiating the process on the alternative platform. To circumvent this methodological flaw, the procedural sequence was adjusted in subsequent workshops. Consequently, while the outcomes are analyzed objectively with an awareness of this bias, readers are advised to interpret these specific findings with discretion.

Evaluation of EnArgus.master

The assessment of EnArgus.master was conducted during the afternoon sessions of two full-day workshops (WS2 and WS3). The schedule included a brief orientation to the BSCW framework, which underlies EnArgus.master, a presentation outlining the conceptual framework for the EnArgus expansion, and a demonstration of foundational EnArgus functionalities, including data retrieval, analytical procedures, and document dissemination.

During WS2, attendees were allotted roughly one hour to independently navigate the EnArgus.master environment utilizing representative queries. These exercises involved searching via specific timeframes, keywords, or the LPS ("Leistungsplansystematik," a national R&D structural framework that categorizes federal research initiatives thematically, irrespective of the funding agency), visualizing multiple search outcomes via column charts, exporting data into Excel formats, and generating as well as publishing evaluation reports. Subsequently, participant feedback was documented during a final group dialogue. This phase did not involve any quantitative measurements.

During WS3, after the preliminary presentation, attendees executed 9 operational exercises and answered 18 assessment queries related to EnArgus.master. The survey comprised 13 items on a 5-point Likert scale, 2 dichotomous (yes/no) items, and 3 open-ended questions. Additionally, participants were instructed to conduct a comparative analysis using the PROFI platform, which involved replicating the 9 identical search tasks and responding to 15 evaluation questions. Incorporating feedback from the initial workshop, the cohort was split: half commenced with PROFI, while the other half started with EnArgus. Attendees were given 1 hour to complete the survey for each platform. Throughout this period, individuals were permitted to document their observations directly onto index cards. A concluding group discussion similarly followed this, and the details were recorded in a formal protocol. As before, the operational tasks are analyzed initially, followed by an examination of the assessment questions; subsequently, the comparative analysis between the PROFI framework and EnArgus.master is detailed.

Results and Discussion

EnArgus.public

Initially, the outcomes from the EnArgus survey are detailed, followed by the responses to the evaluation questions. Following this, the comparative analysis between FÖKAT and EnArgus is outlined. The exhaustive list of survey items is available in Ref. [23].

On average, individuals completed 79% of the assigned exercises **(Figure 6).**

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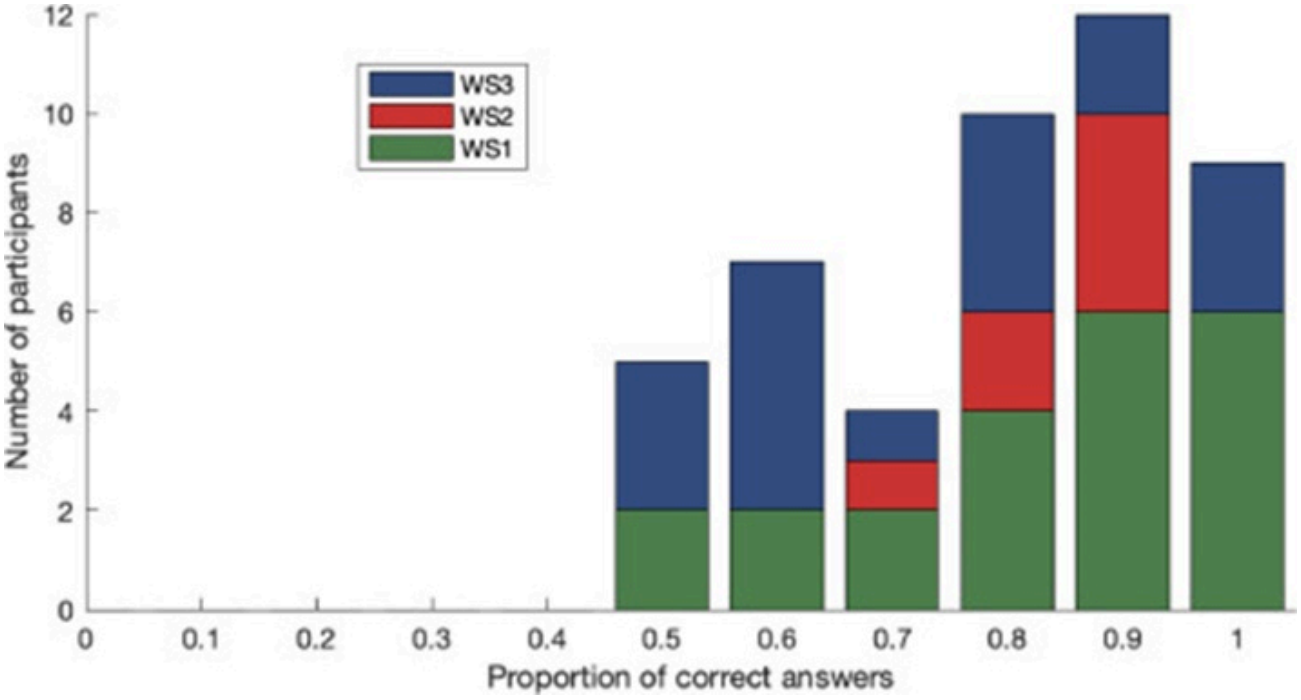


Figure 6. Distribution of the proportion of EnArgus.public tasks correctly solved by participants of the respective three EnArgus workshops WS1, WS2, and WS3.

The practical exercises required executing diverse search queries that encompassed EnArgus's extensive features.public, including inquiring about technical vocabulary, extracting project details, organizing and filtering records, and generating graphical representations and maps. Across the workshops, the primary source of failure was individuals' inability to locate the necessary tools. This difficulty was similarly reflected in the feedback from WS1 attendees. During WS2 and WS3, a practical exhibition of these features during the preliminary orientation proved critical in resolving the confusion observed among WS1 attendees. Furthermore, individuals cited inadequate time allocation for the EnArgus tasks as a contributing factor in some attendees' failure to complete all exercises.

Evaluation

Regarding unipolar rating mechanisms, responses are scaled ordinally, meaning that selections can be assigned numerical values and ordered hierarchically. Nevertheless, the scale descriptors across all surveys were meticulously phrased to permit the assumption of equidistant scale intervals. Consequently, the median and range of responses are documented, along with the standard deviation and the arithmetic mean, which serve as complementary data.

The survey items were categorized into "EnArgus in general" (E1–E5 and E20–E28), Wiki-specific elements (E7–E9), and components concerning the ontology browser (E13–E17).

Evaluating the median feedback from attendees across the three sessions, it is evident that EnArgus received a generally favorable appraisal. The complete collection of unipolar assessment items administered across all sessions yielded an average score of 4.09 (SD = 1); specifically, attendees in WS1 reported an average of 4.31 (SD = 0.88), WS2 attendees documented an average of 4.13 (SD = 0.87), and WS3 attendees provided an average of 3.8 (SD = 1.13). Although the aggregate evaluation of the specific items was perceived as favorable, acknowledging the slight downward trend in scores across the three sessions, one prominent observation was the broadly unfavorable evaluation of the items related to the ontology browser.

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Consequently, to more rigorously analyze the various dimensions of EnArgus and its user reception, the complete question set was systematically reviewed utilizing the subsequent classifications **(Figure 7)**: general EnArgus features (E1–E5 and E20–E28), the platform's Wiki (E7–E9), and the ontology browser (E13–E17).

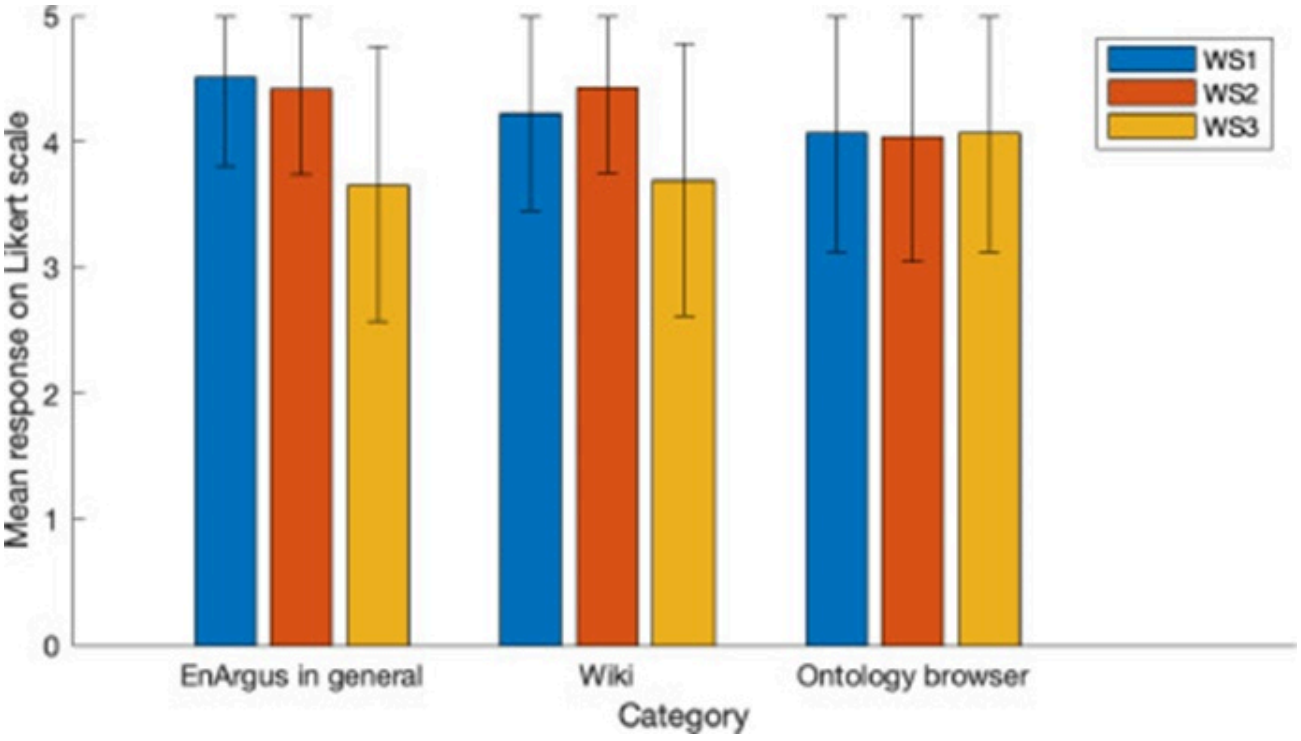


Figure 7. Mean response on Likert scale sorted by question categories: ontology browser, Wiki, and EnArgus in general; the error bar indicates the standard deviation.

The favorable reception of the EnArgus Wiki, predominantly captured in the unipolar Likert items, appears similarly reflected in the bipolar questions included in the EnArgus assessment document.

Recognizing that the midpoint of the Likert scale (in this case, three) signifies the optimal value for this type of question, whereas values shifting toward the extremes of one and five indicate unfavorable outcomes, every participant across the three analyzed workshop groups reported a median score of three.

The majority of attendees found the length of the Wiki articles suitable (M = 3.20; SD = 0.73); a similar consensus was reached regarding the depth and detail of these texts (M = 3.09; SD = 0.8).

Regarding the display of informational depth and detail within the ontology browser, both WS1 and WS3 documented a median of three (WS1: M = 3.23; SD = 0.61; WS2: M = 3.31; SD = 0.7979), whereas WS2 registered a median of four (M = 3.6767; SD = 0.8282). Notably, the ratings indicate that all three cohorts—particularly WS3—generally perceived the level of detail in the Wiki texts as beneficial.

Based on the yes/no items from the EnArgus assessment, the following frequencies emerged: In the second workshop cohort, 57.14% of the 7 individuals had prior experience with EnArgus. Similarly, 10 of the 18 individuals in WS3 had previously used the system, representing 55.56%. This specific query was excluded from the assessment administered to the WS1 students.

For the second yes/no question, 40% of participants reported lacking a specific feature while using the EnArgus system. This encompasses nearly one-third of the WS1 students (29.42%), over two-fifths of the observing researchers in WS2

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(42.68%), and 61.11% of the WS3 cohort, representing over double the proportion observed in the initial workshop.

Beyond the aforementioned assessment items, the survey included three open-ended questions for written feedback. Although feedback from WS1 attendees was more favorable toward the EnArgus system than toward FÖKAT, the remarks from the more seasoned users in WS2 and WS3 frequently focused on specific system features. Nearly everyone in WS3 expressed a desire for supplementary filtering and search capabilities. Although with markedly fewer remarks, attendees from WS1 and WS2 similarly advocated for additional filters and display settings; the latter group specifically requested features to compare, sort, and connect the presented projects. Regarding the ontology browser, users from both WS1 and WS3 requested enhanced support (e.g., a user manual) due to operational challenges. Whereas WS1 primarily struggled with navigating the map and diagram interfaces, WS3 attendees expressed that an extended orientation phase would have been beneficial.

Furthermore, WS1 found the wiki articles functional but recommended improved formatting for longer texts and additional visual aids. Conversely, WS3 users maintained that while the Wiki offers substantial value to novices, its utility for specialists is relatively limited. Overall, drawing from a smaller pool of remarks, WS1 perceived EnArgus as highly responsive, rapid, and effective, whereas WS3 characterized it as sluggish and perplexing.

EnArgus.public / FÖKAT comparison

Attendees of WS1 and WS3 executed four assignments (a to d) from the EnArgus task sheet concurrently with FÖKAT.

Within the student cohort assessed in WS1, identical search inquiries yielded more consistent correct responses when using EnArgus **(Table 2)**. Across the 22 students, the average was 92.05% of the four inquiries resolved accurately using EnArgus. Conversely, using FÖKAT, these students accurately resolved nearly two of the four queries, yielding a 48.86% success rate. On average, this represents a deficit of 1.75 correct responses compared to utilizing the EnArgus framework.

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

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c	14	8	0.636
d	7	15	0.318
Mean	**10.75**	**11.25**	**0.489**

Nevertheless, it must be stressed that these findings may be subject to bias, as the order in which tasks were assigned to students could have introduced positional effects. This methodological shortcoming stems from the fact that all WS1 students were instructed to tackle the inquiries using FÖKAT first, followed by EnArgus, which, in turn, allegedly skewed outcomes in favor of EnArgus. Consequently, while the comparative findings of FÖKAT and EnArgus from the initial workshop must be interpreted cautiously, the subsequent comparative analysis mitigated this issue by counterbalancing the assignments; the groups were split into two halves, with each segment initiating the process on an alternate system.

To ascertain the statistical significance of these variations, the Wilcoxon signed-rank test was employed, as it is independent of underlying distributional assumptions and suitable for small sample sizes [24]; the computational analysis was executed via IBM SPSS Statistics. A fundamental requirement is the exact pairing of one value from each sample to a corresponding value in the other. To generate a dependent sample, each individual's count of accurate responses in FÖKAT and EnArgus was mapped to them. Accordingly, a user earned 1 point per question, resulting in a prospective total of 0-4 for either system. Using FÖKAT, the WS1 students averaged 1.95 out of 4 potential points (SD = 1.68); conversely, an average of 3.68 points (SD = 0.72) was attained using EnArgus. Statistically, these outcomes demonstrate high significance (w_s = 0; z = -3.550; P < 0.001).

As illustrated in **Table 3**, individuals from Project Management Jülich (WS3) achieved an 86% success rate with the EnArgus interface, compared to 79% with FÖKAT.

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

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Although attendees secured stable outcomes across the majority of inquiries in both platforms, performance on question b dropped noticeably when operating EnArgus, yielding only 56% accurate responses. It is hypothesized that the participants were misled by the navigational structure of the EnArgus interface. Rather than investigating the precise timeframe, they relied on broad categorizations provided by the system's facets, leading to incorrect evaluations. Such complications were absent during the execution of the same assignment within FÖKAT.

Similar to the findings from WS1, the outcomes from the third workshop were logged and compiled into tables to facilitate a Wilcoxon signed-rank test. Using EnArgus, the WS3 cohort achieved a mean score of 3.44 precise answers (SD = 0.70); using FÖKAT, they achieved an average of 3 accurate responses out of 4 queries (SD = 1.19).

Regarding WS3, the recorded variations lack statistical significance (w = 3; z = -1.710; P = 0.087). Therefore, based on these four search tasks, it is not possible to deduce that individuals in this specific user cohort perform markedly better with either EnArgus or FÖKAT than with the alternative platform.

Contrasting the concurrent assessment questions administered across both platforms distinctly reveals that the EnArgus.public framework garnered substantially higher acceptance among the attendees of WS1 and WS2 than its rival, FÖKAT.

In general, EnArgus elicited highly favorable appraisals; across all participants in both cohorts, the EnArgus platform secured a minimum median score of 4 on the Likert-scale items. Conversely, FÖKAT was evaluated considerably poorer, showing slightly lower ratings in WS1 than in WS3.

Although a substantial disparity was immediately apparent, the juxtaposition was subjected to statistical scrutiny using the Wilcoxon signed-rank test. This assessment conclusively demonstrates that EnArgus received significantly superior ratings than the comparative FÖKAT platform across the comprehensive suite of evaluation queries.

Beyond the formal evaluation queries, individuals were allowed to provide remarks on the funding directory. The submitted feedback is detailed below, categorized by thematic focus and frequency of occurrence:

Analyzing the observations from the WS1 cohort, it is evident that FÖKAT is perceived largely unfavorably. Ten individuals reported being unable to locate actionable results using FÖKAT, nine described the platform as overly perplexing, and an additional seven deemed it excessively slow. Furthermore, five attendees reported a lack of functional tools, e.g., filters.

Attendees from Project Management Jülich (WS3), for whom FÖKAT is a staple of their daily professional routines, similarly assessed both data systems. Given their professional background, they inherently carry a slight bias and may therefore not serve as an ideal, impartial target demographic for the EnArgus public portal.

Within the WS3 demographic, the FÖKAT interface was largely reviewed positively. Five individuals compared its search capabilities with those of EnArgus, finding EnArgus to be either equivalent or marginally inferior. Three additional participants highlighted the superior abundance of search and filtering tools available in FÖKAT; moreover, three others expressed appreciation for FÖKAT's inclusion of project summaries via abstracts. The final ten remarks, which resisted direct comparison due to their focus on FÖKAT's distinct technicalities, reflect not merely a profound proficiency with the platform, but also a favorable reception of the framework by the specialized users in WS3.

EnArgus.master

This segment details the outcomes of the EnArgus.master assessment gathered during WS2 and WS3. Initially, the findings from the practical exercises and survey questionnaires concerning the EnArgus.master portal, compiled from WS3, are outlined. Subsequently, the comparative analysis against the PROFI infrastructure is detailed. The contributions and conclusions generated from the collaborative dialogues in WS2 and WS3 will be integrated into the overarching discussion found in chapter 5.

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Questionnaire

Examining the task outcomes concerning the EnArgus.master and PROFI frameworks among the third workshop's attendees, an actionable quantitative analysis proved unattainable. Regardless of the accuracy of their search results, the cohort completed only 42% of the overall assignments. Additionally, the submitted responses lacked consistency with both EnArgus.master and PROFI. The items featured in the EnArgus.master surveys were intentionally designed to be high in difficulty, having been pre-approved and deemed viable by a specialist. The comprehensive EnArgus.master survey document is appended to this manuscript.

The integration of highly intricate queries alongside the proportionately significant volume of unaddressed or inaccurately resolved items aligns with subsequent participant feedback, in which many reported that the tasks felt exceptionally challenging and that the allocated completion time was inadequate. Furthermore, users reported frequent connectivity issues with the PROFI network.

Evaluation

While quantifying the responses was impossible due to the lack of a viable dataset, every individual engaged with the platforms, allowing the extant evaluations to be still analyzed. Nonetheless, it must be acknowledged that the limited timeframes resulted in numerous omissions across the assessment sheets. Specifically, within the EnArgus.In the master survey, 30 items were left blank; similarly, in the PROFI evaluation, 9 questions were ignored.

Consistent with the EnArgus.In public appraisal, the Likert-scale intervals are treated as equidistant, with medians and ranges used to define the dataset, while the standard deviation is used as a supplementary metric.

The assessments across all Likert items yielded a median of 3. The specific inquiry about whether users enjoyed navigating EnArgus received the lowest score, with a median of 2. Among the other items, one-third attained a median of three, while the remaining two-thirds achieved even higher scores. Given the context of these questions, the findings imply that users view EnArgus.master as a promising future asset and an effective tool for illuminating energy research data, albeit one that requires a learning curve.

The dichotomous yes/no queries from the assessment survey yield the following insight: No attendee from Project Management Jülich (WS3) had prior experience with the EnArgus.master interface. Within this cohort, one-third indicated an absence of certain system functionalities, another third denied any missing features, and the final third abstained from answering the prompt.

The concluding inquiries solicited feedback regarding omitted capabilities, operational issues, and additional observations. All feedback compiled from the assessment forms, index cards, and the ensuing dialogues was aggregated: Noted in 15 of 18 instances—nearly double the frequency of any alternative comment—was the participants' strong preference for an instructional manual to resolve uncertainties right from the start. Eight individuals noted the restrictive time limit for task execution. An identical count of users articulated a need for enhanced sorting and filtering mechanics for their search yields, specifically mentioning parameters such as active projects, financial allocation, LPS, PTJ unit, ZE, and operating unit. Finally, five attendees encountered difficulties interpreting the acronym "ZE" (grant recipient; German: "Zuwendungsempfänger" instead of "Zahlungsempfänger"), a term they had previously understood in a different context.

EnArgus.master / PROFI comparison

As previously noted, the high volume of unanswered task queries renders a statistical comparison of performance between EnArgus and PROFI largely uninformative. Nevertheless, the self-reported system evaluations remain comparable: To facilitate this, 15 identical evaluation questions were administered to both EnArgus.master and PROFI, with 10 using a scaled format.

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Examining the mean scores for the assessment queries across both systems, as depicted in **Table 4**, it is evident that EnArgus.master received a more favorable reception among WS3 attendees.

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**

Overall, while EnArgus achieved a median score of 3 across the Likert items, the PROFI framework achieved a median of 2. Furthermore, PROFI recorded a median of 1 for both its search engine velocity and its contribution to fostering transparency in energy research funding. The perceived personal utility of the system for users' daily professional tasks received the highest rating, with a median of 3. The inquiry into interest in the system's prospective use yielded a median of 3.

The Wilcoxon signed-rank test was employed to assess statistical significance. The analytical findings revealed that five of the ten pairings demonstrated significance (E10 and E12) or high significance (E4, E13, and E16). Consequently, EnArgus.master received markedly superior ratings than PROFI on these five specific items. For the remaining five questions, EnArgus.master performed marginally better, yet the variance lacked statistical meaningfulness. Thus, compared to the PROFI infrastructure, EnArgus is perceived as a substantially more effective mechanism for enhancing the transparency of energy research funding. However, the fundamental differences in the systems' core purposes must be acknowledged. Notably, a direct comparison is technically flawed, given that PROFI was never designed to promote transparency in this field. Even if the direct comparison and its statistical validity are set aside, the strong ratings provided by the WS3 expert cohort indicate a positive trajectory for the EnArgus system's transparency capabilities. Additionally, EnArgus.master significantly outperformed the baseline system across user objectives, the informational value of its search displays, its evaluation features, and search engine promptness.

The primary objective of this evaluation was to assess the EnArgus information system's overall quality, practical utility, and functional applicability. Drawing on outcomes across various assessment categories, the following section details the strengths and vulnerabilities of the EnArgus platform compared with the FÖKAT and PROFI systems. Subsequently, the conceptual origins of EnArgus and the deployment of ontology-driven information networks are contextualized within the broader sphere of contemporary AI research.

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A synoptic view of the systems

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

Reviewing the outcomes of the exercises executed within the EnArgus.public environment, it is apparent that all three workshop cohorts secured comparably positive results, irrespective of their varying degrees of prior expertise. Similarly, the assessment feedback for EnArgus.public demonstrated that the platform was predominantly well-regarded across all three sessions. Notably, the student cohort—acting as a proxy for the general public in this analysis—rated the system exceptionally high overall. While the accompanying researchers and the Project Management Jülich attendees (who naturally set higher standards) provided slightly lower ratings than the students, they still rated the system favorably.

Conversely, WS1 attendees successfully resolved considerably fewer queries utilizing the FÖKAT platform. This underperformance aligns with their self-reported evaluations of FÖKAT, which were markedly inferior to those of EnArgus. Given the methodological bias—whereby all WS1 individuals evaluated FÖKAT before EnArgus—it is plausible that EnArgus benefited from a favorable contrast effect. Nonetheless, the extreme disparity in the evaluations leaves little ambiguity regarding the participants' preferred platform. Corroborating this, WS1 members expressed a distinct preference for EnArgus in their open-ended commentary, while delivering overwhelmingly critical remarks about FÖKAT.

Within WS3, EnArgus consistently outperformed FÖKAT in user evaluations; however, due to their routine professional engagement with FÖKAT, these users accurately answered an equivalent number of search queries on both platforms **(Table 3)**. This cohort's feedback regarding FÖKAT also reflected a more nuanced, critical perspective. Even though they achieved marginally higher task-completion rates on EnArgus—a fact reflected in their largely favorable ratings—numerous comments underscored a strong, ingrained acceptance among the Project Management Jülich staff of operating within the FÖKAT environment. While a minority of WS3 members judged the systems as equivalent (or nearly so), many highlighted distinct advantages of FÖKAT alongside specific drawbacks of the EnArgus.public interface. A detailed analysis of the feedback, however, indicates that much of the praise for FÖKAT centered on its unique, highly specific functionalities. Conversely, critiques of EnArgus frequently called for clearer explanations of certain system features, with approximately half of the WS3 group requesting extended training periods. All users were intimately familiar with FÖKAT, but roughly half had been introduced to EnArgus only recently. Publicly, it is reasonable to deduce that some critiques stemmed from their entrenched comfort with the legacy system. This is particularly evident when the critiques focus on the lack of familiar, specialized processes. Such resistance suggests that rapid transitions to novel platforms pose inherent challenges, a notion bolstered by the frequent requests for comprehensive manuals and longer familiarization phases. During the EnArgus.public trials, the allocated time and the available system documentation emerged as primary constraints. Even though the comparative data from the third workshop lacked statistical significance, it is anticipated that EnArgus.public offers a more user-friendly experience overall.

Synthesizing the positive performance metrics and assessment feedback paints a highly encouraging picture for EnArgus.public. Unlike the WS3 group, the student attendees possessed no prior experience with either platform. In this context, EnArgus achieved an exceptionally positive reception, particularly among absolute novices. This suggests that the system facilitates a straightforward onboarding process, making it significantly more appropriate for a general audience than FÖKAT.

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

During the assessment of EnArgus.master, a substantial proportion of attendees left numerous task and evaluation questions blank. This widespread omission rendered a quantitative tally of accurate task responses statistically meaningless; consequently, the analysis shifted strictly to the evaluation queries. The WS3 assessment of

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EnArgus.master generally left users with a favorable impression of the expert platform. However, individual opinions varied widely. In particular, the visual mapping and diagrammatic representations of search results received high praise. In contrast, certain operational constraints were identified in the ontology browser.

Across all 10 comparative criteria, the EnArgus.master portal achieved superior scores relative to PROFI, with 5 of these 10 metrics proving statistically significant **(Table 4)**. From a qualitative standpoint, it is evident that legacy systems like FÖKAT and PROFI offer minimal capability to foster transparency in energy research—or, by virtue of their foundational design, lack this capacity entirely. This underscores a primary strategic advantage of EnArgus.

In the second workshop, no statistically significant evaluations were conducted for the EnArgus.master platform. Rather, following a system orientation and a 60-minute practical session utilizing sample queries (during which participants were encouraged to record observations on index cards), a collaborative discussion was held to explore the following themes and issues:

· Attendees of WS2 indicated a preference for the search filters to automatically refresh following each adjustment. This, however, was deemed unfeasible, as applying multiple filter criteria would trigger a disruptive page reload with every single input.

Beyond the inquiries derived from user notes during their interaction with EnArgus.master, the dialogue expanded to encompass several other critical topics:

· For the observing researchers, the interplay among various technologies is of significant interest (for instance, tracking which concepts or technologies routinely intersect with the keyword “heat”). Currently, EnArgus relies on pre-established technological relationships that merely highlight similarities with alternative projects. Consequently, users proposed integrating features that generate word clusters and map conceptual correlations.

· Furthermore, users identified a usability conflict within the semantic search function. Typically, when entering topics, the system provides dynamic, keystroke-by-keystroke suggestions to guide the user to the correct terminology via alternate spellings or semantically related concepts. However, if the ontology yields no matches, the interface explicitly displays “no suggestions.” Users found this phrasing deceptive, as relevant topics might still be discoverable through the actual search execution. To circumvent this misinterpretation, it was recommended that the system leave the suggestion field empty in such instances.

What advantages do users associate with the respective EnArgus platforms? What recommendations for enhancement are proposed?

The assignments presented during the EnArgus.master assessment were described as highly challenging; notably, there was a consensus among participants that the inquiries did not represent standard PROFI queries or that the assignments would be unsolvable within PROFI (although this assumption was incorrect). In general, EnArgus was deemed to possess superior functionality compared to the PROFI framework, albeit with certain constraints. Participants emphasized that the utility of EnArgus depends on its having identical data to PROFI (requiring access to the complete dataset). This dependency is further illustrated by the fluctuating result volumes between EnArgus.public and EnArgus.master, which depend on their respective underlying databases. Additionally, EnArgus identified vulnerabilities in the foundational PTJ data; for instance, Bosch’s fuel cell initiatives were omitted by LPS due to their classification under electromobility.

Because EnArgus.public operates on a reduced iteration of the project database, specific information might be hidden. For instance, although the comprehensive project database includes records of private photovoltaic installations, privacy regulations prevent their display in EnArgus.

Concerning the user interfaces, numerous attendees contrasted EnArgus.master with EnArgus.public, occasionally critiquing their disparities. While the standard search capability within EnArgus.master was deemed beneficial, the search

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mechanism in EnArgus.public was characterized as marginally more intuitive. It was broadly agreed that the EnArgus.public search delivers a rapid and accessible overview, whereas the EnArgus.master search is viewed as somewhat intricate. Consequently, it was suggested that the expert interface could benefit from a unified input field similar to that of EnArgus.public. Furthermore, the evaluation feature was widely regarded as excellent; although it operated more swiftly than the comparative system, it was still considered somewhat sluggish.

Attendees expressed minor dissatisfaction with the day's schedule, noting a desire for more time to become familiar with the EnArgus platform. Even though EnArgus.master represented unfamiliar ground for the users, and they realized it demanded greater training investments (relative to the public version), their interest in the ongoing development of the EnArgus system persisted.

The feedback provided during the assessment helped evaluate the system from a user-centric perspective, detailing individual workflows and highlighting areas for potential improvement. These recommendations encompassed straightforward methods for navigating the ontology browser, as well as proposals for prospective filtering capabilities, graphical displays, and operational procedures to improve the user experience through more intuitive, streamlined navigation. Moreover, there was strong demand for a user guide. In response, two informational leaflets were generated: one detailing the project broadly and another serving as a concise instruction manual [23].

Based on the open-ended feedback, PROFI faced substantially more frequent criticism for being sluggish and unwieldy. Certain individuals expressed outright frustration with PROFI, attributing numerous daily complications and inaccuracies to the software. Conversely, others maintained that despite its lack of user-friendliness, the application remains adequately functional for daily tasks. PROFI lacks graphical assessments and constituent search capabilities. It is similarly devoid of ontological search mechanisms and professionally pertinent sorting tools. Because EnArgus.master resolves all these deficiencies, the engagement level among test participants was noticeably elevated.

When evaluating the platform's usability, a clear differentiation is required between EnArgus.public and EnArgus.master. Given its considerably broader feature set and its alignment with a "more professional" demographic, EnArgus.master is appraised as a valuable instrument and viewed more favorably than the PROFI infrastructure. Nonetheless, during the assessment period, it garnered a less favorable reception than EnArgus.public, prompting the articulation of several additional user requirements.

Interpreting these results, it is reasonable to conclude that the EnArgus.master expert interface harbors significant implementation potential within specialized domains. Particularly, given that every WS3 attendee had prior experience with PROFI yet none with EnArgus.master, it can be inferred that the comprehensive capabilities of the EnArgus expert platform proved compelling, even amidst the challenges encountered during initial use.

Approaches to AI research

This manuscript demonstrated that semantic, ontology-driven information platforms such as EnArgus already exhibit substantial utility in their current state. They disseminate previously restricted database information to the general public. Consequently, we perceive a distinct advantage in enhancing funding transparency by broadening the adoption of such frameworks across additional governmental ministries and departments in Europe and internationally. These platforms structure and enrich administrative data, rendering it discoverable and actionable. Liberating this information to align with FAIR principles (Findable, Accessible, Interoperable, Re-useable) [25] is critical for facilitating its distributed application within AI contexts. EnArgus accomplishes this specifically for energy research data and associated initiatives. Architecturally, EnArgus distributes its comprehensive collection of over 2400 wiki articles on the energy sector under a permissive Creative Commons license (CC BY-SA 3.0 DE), mirroring the licensing of the ministry's online portal.

The foundational headless EnArgus architecture features a REST API that supplies data to the frontend interfaces, a component currently being leveraged for a substantial "mobile-first" overhaul of the public-facing platform. In conjunction

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with this update, the initially monolingual German EnArgus framework and its corresponding wiki articles have been expanded into five languages by integrating the DeepL neural machine translation API.

Unsurprisingly, numerous supplementary concepts emerged throughout the project's development and from its inception. The potential to publish the ontology as open data was deliberated. However, this initiative received a subordinate priority to ensure resources were focused on finalizing the core application. Releasing the EnArgus ontology remains a prospective endeavor, likely coinciding with the website's eventual relaunch. For pragmatic reasons, other foundational concepts were developed into prototypes. The EnArgus initiative engineered a capability that identifies the N most comparable projects within the database relative to a provided project narrative. This feature enables users to verify whether a similar proposal has been previously lodged, thereby preventing duplicate funding for initiatives.

Nevertheless, operationalizing this feature necessitates overcoming specific legal hurdles related to data privacy and security credentialing (e.g., ISO 15408) in subsequent developmental phases. An additional prevalent challenge involves sustaining developmental momentum to prevent "bit-rot" across both the software and the (ontology) datasets. Several insights emerge from this context. Frequently, project portals are taken offline shortly after the initiative concludes. EnArgus circumvented this fate by migrating operational responsibilities to an alternative legal organization (PTJ), representing a commendable strategy. However, this transition introduces minor supplementary challenges, such as complexities in procuring necessary licenses and service contracts, or simply maintaining the domain URL. The more substantial challenge lies in the labor required to continuously modernize the software and the underlying ontology. The previously referenced European platform, CORDIS, exemplifies best practices in this area, having undergone continuous advancement since 1994.

During a 2019 public session of the German Federal Parliament's AI committee of inquiry, Auer emphasized that breakthroughs in artificial intelligence have consistently relied on the availability of expansive, readily accessible datasets [9, 26]. There is a fundamental necessity for explainable AI and principled data science. Consequently, AI systems must avoid functioning as opaque black boxes, remaining instead reliable, traceable, unbiased, and fair. Such AI frameworks require that data be linked with provenance metadata and contextual information—essentially, knowledge graphs [27] constructed from linked open data [28] that have been liberated from information silos. Specifically, enhancing the interoperability and reusability of the EnArgus ontology could be achieved through modular design and alignment with established standards, as with the Open Energy Ontology. Given that the primary use case involves information retrieval, aligning the EnArgus ontology with the W3C Simple Knowledge Organization System (SKOS) appears particularly advantageous. SKOS provides a standardized vocabulary for hierarchical classification of concepts, offering multilingual labels that support both search functionality and human communication. This system is supported by collaborative curatorial tools such as VocBench [29], which is officially endorsed by the European Union for centralized management of metadata and controlled vocabularies in public administration to foster interoperability, and the commercial platform PoolParty8 [30]. Beyond SKOS, the application of linguistic ontologies—such as the Lemon Lexicon Model for Ontologies9—and language-specific resources, such as WordNet10 and GermaNet11 for German, offers a promising path toward addressing the challenges of word clustering and topic correlation identified during the evaluation [31]. The advantages of adopting such standards include the ability to leverage tools built on related datasets and ontologies, such as the SKOS-based AIDA (Academia/Industry DynAmics) Knowledge Graph, which is designed to analyze the evolution of emerging R&D topics and collaboration between industrial and academic sectors [32].

Data exchange protocols should be simplified, perhaps even mandated, to minimize redundancy and institutionalize privacy by design. Nevertheless, it is equally vital to respect data sovereignty, for instance, by empowering data owners to specify who may access their information and under what constraints. For the semantic web to thrive, the implementation of persistent identifiers is essential—a requirement that funded projects and the academic community in general, including EnArgus specifically, do not always adequately prioritize. Significant effort is still required to establish the foundation for a symbiosis between energy research and artificial intelligence.

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These represent multifaceted challenges. A component of the European strategic response is the Federated Data Infrastructure GAIA-X12, whose “Energy” domain group has established seven publicly documented use cases, including leveraging municipal grid or critical infrastructure data for innovative business models and preventing grid failure via AI-optimized redispatching [33]. Achieving a unified understanding of data is essential; it requires formal representations for machine processing alongside meaningful dialogue between human stakeholders. McCarthy introduced the term Artificial Intelligence (AI) in 1955, and the discipline has since expanded into a prominent field within computer science and beyond [34]. Although sometimes overlooked in AI discourse, Engelbart famously championed the application of technology to enhance human cognition, a concept known as intelligence augmentation (IA) [35]. We believe there is a substantial opportunity in bridging artificial and human intelligence to harmonize technology and humanity, fostering a human-centric vision of both AI and IA [36].

Conclusion

The evaluation detailed in this study, comprising three EnArgus workshops conducted in 2016 and 2017, yielded significant insights into both the current state of EnArgus interfaces and their intended future state. Utilizing both qualitative and quantitative research methodologies where appropriate proved beneficial, as did the careful consideration of feedback from both laypeople and experts concerning the functional and usability requirements of these systems.

In summary, the evaluation of the EnArgus interfaces—EnArgus.public and EnArgus.master—yields a positive assessment. This is particularly true for the public-facing interface, which was evaluated favorably by all three workshop cohorts. The explicit acceptance and positive reception of this system across all groups demonstrate a clear benefit for the general public and support the ongoing effort to enhance transparency regarding energy sector research requirements and funding documentation.

Regarding the expert-oriented platform EnArgus.master, the specialist workshop groups displayed positive resonance and increased engagement, as reflected in both their formal evaluations and workshop discussions. Furthermore, the constructive input from these experts yielded numerous actionable suggestions to optimize the EnArgus system.

Although opportunities for refinement remain, this study demonstrates that the EnArgus.master system, when paired with a contemporary database, is fully competitive with comparable systems and is, in many respects, the preferred option.

Additionally, the positive response across varying levels of expertise confirms that EnArgus fulfills the requirements for an intelligent information system. By incorporating an ontology-based search that improves retrieval accuracy via semantically related terms, the statistical likelihood of obtaining relevant results is enhanced, thereby facilitating a more precise search for funded research initiatives. Furthermore, the internal wiki and, following a brief orientation period, the hyperbolic tree emerged as critical components for making complex subject matter accessible to a broader audience.

In conclusion, we maintain that the integrated EnArgus solution provides a valuable contribution to comprehensive information retrieval, encouraging the reuse of existing project data while identifying gaps for future research. Upon completion of the development phase, the EnArgus system was transferred to the PTJ for continuous operation. Subsequent efforts have primarily focused on maintenance and operational stability. However, recent enhancements—including automated translations and a redesigned, more responsive mobile interface—have expanded its accessibility to an international user base.

Our strategy of leveraging domain knowledge through custom Wiki-articles and a tailored domain ontology is extensible to other fields. Similar to open-source software initiatives, it would be advantageous to open the EnArgus data and ontology for further development and application. Although these steps would have been straightforward to implement, they were deferred during the project to maintain focus on system completion and to mitigate the risk of “hi-jacking,” or the semantically inconsistent redefinition of ontology terms by third parties [37]. Nevertheless, these remain desirable next steps. Extending the EnArgus system architecture to other research domains is also a plausible future application. Once

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real-world legal and data-access complexities are resolved by emerging sovereign data-exchange infrastructures like GAIA-X, we expect a new wave of applications to emerge from these datasets, driving the next breakthrough in reliable, traceable, fair, and non-discriminating artificial intelligence.

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Conflict of interest

None

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Ethics statement

None

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