Enhancing Software Sustainability: Transferring Open-Science Solutions from ZLE to NFDI4Energy

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1 Introduction

The transition to a sustainable energy system relies on digitalization to navigate the energy sector's increasing complexity. Digital platforms play a key role in integrating renewable energy sources, decentralizing energy supply, and sector coupling by enabling data management, transparency, collaboration, and standardization, driving innovation and achieving climate goals [1], [2].

The research project "Zukunftslabor Energie" (ZLE), funded by the Federal State of Lower Saxony, addresses critical energy sector challenges by advancing digitalization on energy research and fostering the exchange of sustainable solutions. It connects researchers, structures cooperative research, manages energy digital objects, integrates models in simulations, and disseminates research results to the community [3].

NFDI4Energy, a consortium of Germany's National Research Data Infrastructure (Nationale Forschungsdateninfrastruktur, NFDI e.V), is focused on research data management (RDM) for energy system research. It standardizes data management and sharing according to the FAIR principles (Findable, Accessible, Interoperable, Reusable) [4]. The German consortium promotes best practices, data registries, and collaboration to foster innovation. NFDI4Energy has been developed with experiences and background from the first years of ZLE, thus driving new ideas while building on experiences in the field of RDM in energy system research.

ZLE and NFDI4Energy [5]–[8] aim to collaborate in the advancement of energy research, leveraging their shared principles of openness, transparency, structured connectivity, best practices, energy data, knowledge management, and exchange. Launched in 2019, ZLE has established processes and frameworks to enhance energy research, while NFDI4Energy, launched in 2023, addresses emerging needs in FAIR digital objects. By combining their efforts, the two initiatives work towards their mission to advance the energy sector through digitalization and standardized practices.

2 Foundations of ZLE and NFDI4Energy Collaboration

ZLE aimed to create a collaborative energy research community focusing on making research results reusable and accessible. To support this, its members developed and published an Open Science Declaration emphasizing Open Access, Open Source, Open Data, and Open Methods [1]. They documented and shared research outcomes transparently, laying a foundation for future initiatives to build on ZLE insights.

The objective of NFDI4Energy is to digitize energy research and enhance accessibility to digital resources. As a result, communication between the two projects was facilitated, resulting in a workshop where both projects examined their respective work, leading to further collaboration at the initial NFDI4Energy conference [3].

As part of the workshop, responsible persons from each element of the ZLE met with their counterparts from NFDI4Energy to establish a mutual understanding of the areas of collaboration. Table 1 outlines the one-to-one pairings established during the workshop.

Table 1. Pairing of the elements of both projects.

ZLE		NFDI4Energy
Competence	$\longleftrightarrow$	Competence
Methods	$\longleftrightarrow$	Best Practices
Repository	$\longleftrightarrow$	Registry
Simulation	$\longleftrightarrow$	Simulation
Transparency	$\longleftrightarrow$	Transparency

Subsequent meetings focused on individual elements, with particular attention given to the *Competence* element. Discussions included how NFDI4Energy could adopt and integrate the work done by ZLE. Beyond the publicly accessible resources, such as the documentation in the GitLab repository [9], additional materials, including documentation on a collaboration platform, were shared to improve transparency around workflows and task structures. The team members have accompanied these efforts with continuous communication to support adoption and adaptation.

3 Collaborative Outcomes

For this abstract, the text focuses on the element *Competence*. The objective of the ZLE *Competence* element is to provide researchers and developers with a platform to showcase their qualifications and to connect with potential project partners [3].

Competence itself has multiple functions available: Profiles, a Research Network, a Research Cluster, and a Research Map, which are further explained in the following:

- *Profiles* are detailed descriptions that provide information about research group's main competences and interests, and potential affiliations with academic institutions.
- *Research Networks* showcases the collaborative associations between institutions/profiles. They can be projects with multiple institutes collaborating.
- *Research Cluster* categorizes profiles according to their interest areas, e.g., co-simulation or grid integration of electric vehicles.
- *Research Map* works as a way to connect (local) institutes with similar research goals for possible future collaboration by displaying the profiles on a map.

Through the close cooperation of the representatives and the feedback, the developers of the *Competence* element in ZLE added institutes to the profiles of each potential group. Furthermore, they created a dedicated webpage for documentation, which includes comprehensive API documentation.

To transfer the element *Competence* to NFDI4Energy, the prototype developed during the runtime of ZLE must be adapted so that it can be run as an online service in NFDI4Energy. To this end, the following changes have been implemented:

- The UI has been adapted to fit in with the other NFDI4Energy services, illustrated in Figure 1a and 1b.
- The software used has been updated to its latest stable release (e.g., Angular).
- Creation of profiles, etc., have been locked behind a login, illustrated in Figure 1b and 1c.
- A login and user management have been added to the backend.
- The backend and documentation have been adapted to better fit the purposes of NFDI4Energy.

## 4 Outlook and Conclusion of the Cooperation

The cooperation between ZLE and NFDI4Energy has shown how existing open source solutions [2] can be further developed and adapted to new requirements to promote sustainable energy research approaches. The successful transfer of the *Competence* element demonstrates the potential to implement interoperability and FAIR principles [4] through collaboration effectively.

A key aspect of the collaboration is that personal exchange plays a central role in addition to detailed documentation of code and results. This exchange not only improves processes but also promotes the broader use and further development of research results.

Looking ahead, the cooperation opens up opportunities for integrating further elements and scaling the approaches to other projects. Therefore, the progress made can help strengthen the digitalization and sustainability of the energy sector in the long term.
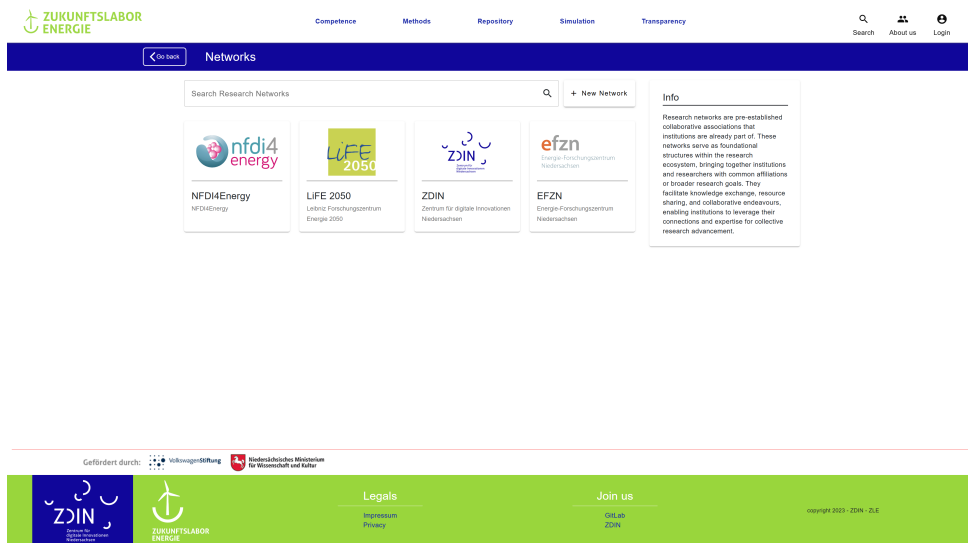
(a) ZLE *Competence* with no user management.
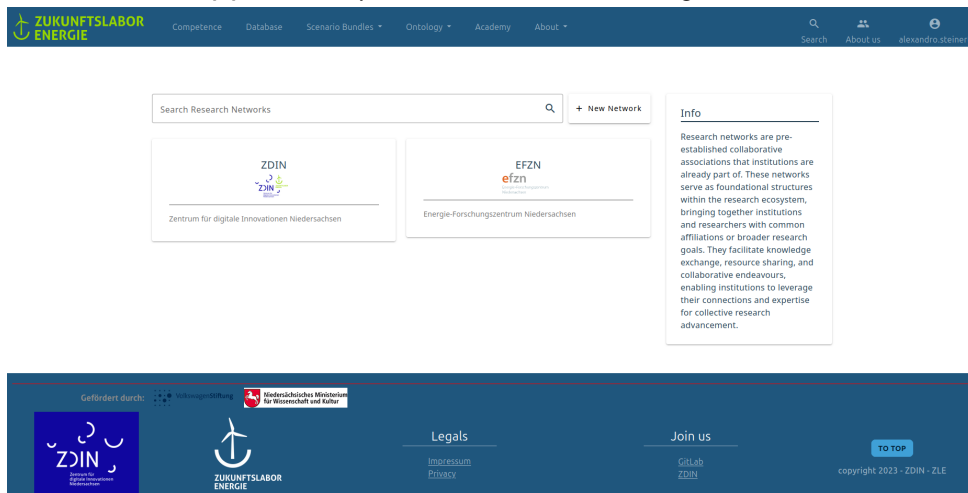
(b) Adapted *Competence* in NFDI4Energy with the addition of user management.
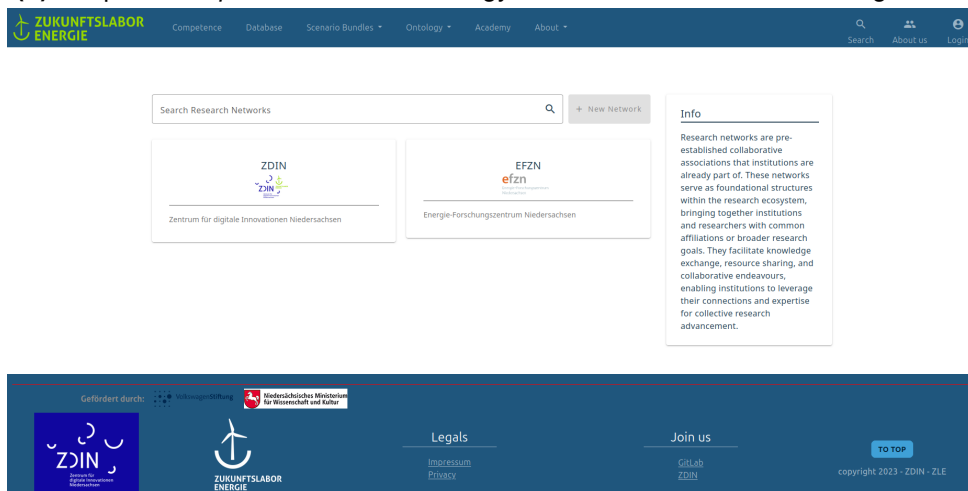
(c) Picture of the adapted *Competence* in NFDI4Energy with the addition of user management showing disabled network creation.

Figure 1. The *Competence* element with some adaptations for NFDI4Energy.

Data availability statement

The source code and documentation are openly available at GitLab (ZLE) [9]. Basis of this abstract are the versions with tag "Deliverable_D2.3_Zukunftslabor_Energie_ ZN3488" and "Deliverable_D2.4_Zukunftslabor_Energie_ ZN3488".

Author contributions

Luca Manzek: Writing - Original Draft, Software. **Laura Niemann**: Writing - Original Draft. **Alexandro Steinert**: Writing - Original Draft, Software. **Henrik Wagner**: Writing - Review & Editing, Software. **Oliver Werth**: Writing - Review & Editing. **Fernando Penaherrera Vaca**: Writing - Review & Editing, Software. **Sarah K. Lier**: Writing - Review & Editing, Software. **Michael H. Breitner**: Supervision. **Bernd Engel**: Supervision. **Sebastian Lehnhoff**: Supervision. **Astrid Nieße**: Writing – Review & Editing, Supervision.

Competing interests

The authors declare that they have no competing interests.

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