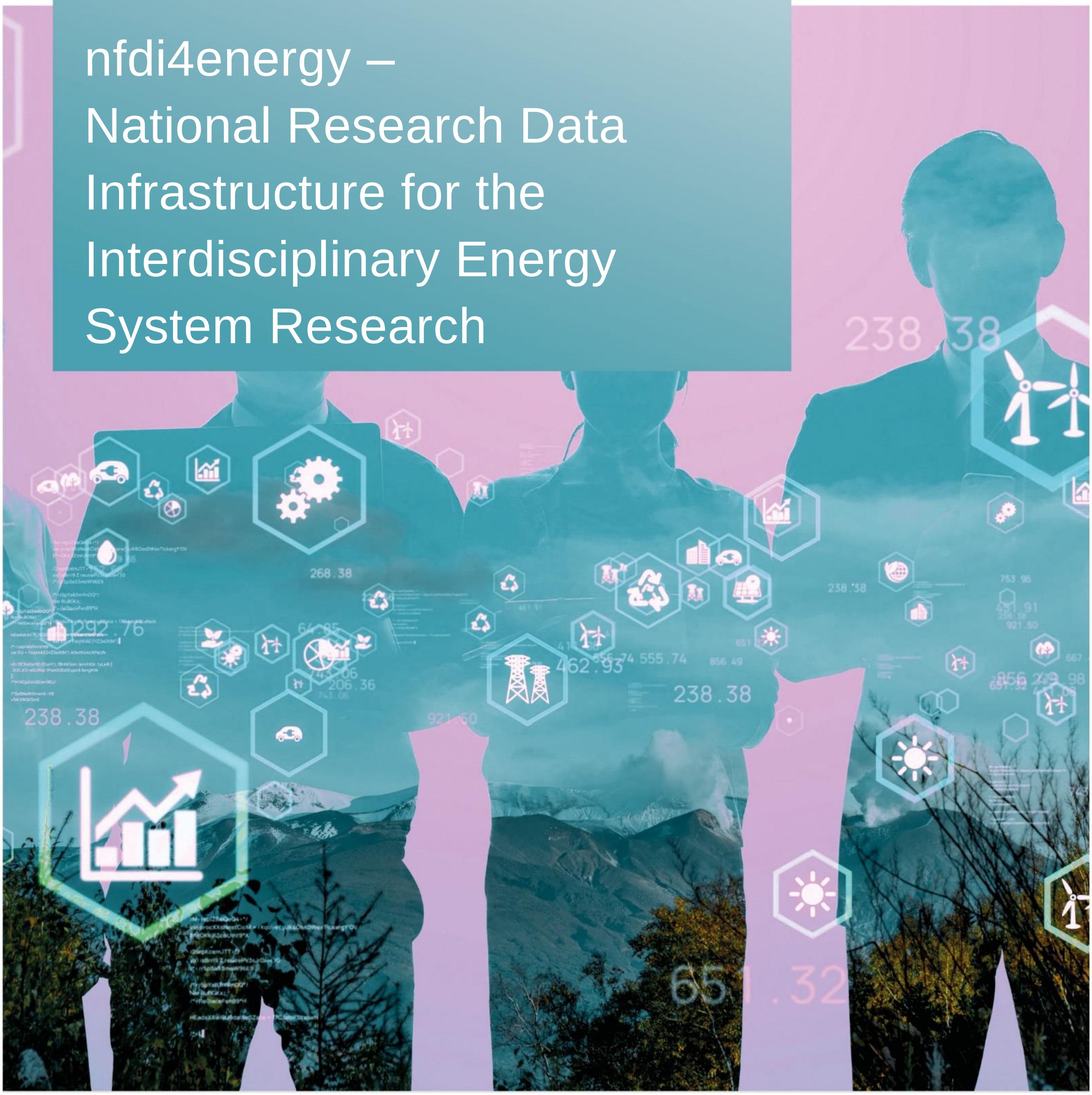
Consortium Proposal

nfdi4energy – National Research Data Infrastructure for the Interdisciplinary Energy System Research



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1 General Information

- Name of the consortium in English and German

National Research Data Infrastructure for Interdisciplinary Energy System Research
Nationale Forschungsdateninfrastruktur für die interdisziplinäre Energiesystemforschung (nfdi4energy)

- Summary of the proposal in English

The necessary transformation of energy systems towards net zero greenhouse gas emissions provides a plethora of new research challenges. New interconnections between different energy sectors, such as power, heat and mobility, increase the system's complexity. In this context, the digitalisation towards **cyber-physical energy systems** (CPES) alleviates change, and equally affects technical, social, and societal topics, as well as the mode of research in the CPES research community.

Research efforts towards CPES heavily rely on **modelling** and (co-)**simulation-based approaches**. Tracking of models together with all data creates a complex software and data management challenge, which needs to be addressed in each research project.

To this end, **nfdi4energy** covers the whole **research and transfer cycle** of projects in energy system research ranging from (1) identifying relevant competences for a project; (2) defining relevant scenarios and experimental setup; (3) integrating models and data; coupling tools and laboratories; (4) extracting results, facilitating public consultation; to (5) identifying research challenges for follow-up activities.

We define the following **key objectives**: (1) Establish common research community services for FAIR data, models, and processes in energy system research and motivate its use in the community. (2) Allow traceability, reproducibility, and transparency of results for the scientific community as well as for the society, improving the overall FAIRness. (3) Enable and motivate the involvement of society for the identification and solution of relevant research questions. (4) Promote better collaboration and knowledge transfer between scientific research institutes and business partners via FAIR research data management. (5) Simplify identification, integration, and coordination of simulation-based models. (6) Integrate the provided services for energy system research within the wider NFDI ecosystem to improve cross-domain collaboration.

To fulfil these objectives, nfdi4energy concentrates on five **key services** to provide a non-discriminatory access to digital research objects: (1) *Competence* to help to navigate the interdisciplinary research field, (2) *Best Practices* to get information about successful

conduct of research including research data management, (3) *Registry* to find suitable data and software, (4) *Simulation* to couple existing simulations and, therefore, reuse software artefacts, and (5) *Transparency* to involve more stakeholders in all research stages.

With these services, nfdi4energy aims to develop and provide an **open and FAIR research ecosystem** in the energy system domain containing a large share of common workflows from data gathering to the inclusion into research software, together with data publications for researchers spanning from single component development (like battery storage systems or other new smart grid equipment) up to system-of-systems research (based on mathematical or analytical models).

- Summary of the proposal in German

Die Energiewende und die zunehmende Sektorkopplung stellen die **Energiesystemforschung** vor große Herausforderungen. In diesem Zusammenhang erleichtern Digitalisierungsprozesse hin zu **cyber-physischen Energiesystemen** (CPES) den Wandel in vielerlei Hinsicht und wirken sich gleichermaßen auf technische, soziale und gesellschaftliche Themen, aber auch auf den Forschungsprozess selbst aus.

Die Forschungsbemühungen zu CPES stützen sich in hohem Maße auf modell- und (co-) **simulationsbasierte Ansätze**. Hierbei stellt die Nachverfolgung von Daten und Modellen eine **komplexe Herausforderung dar,** die in jedem Forschungsprojekt neu bearbeitet werden muss.

Diesen Herausforderungen begegnet **nfdi4energy** über den gesamten **Forschungs- und Transferzyklus** von Projekten in der Energiesystemforschung: Von (1) der Identifizierung von Partnern mit relevanten Kompetenzen und Wissen für ein Projekt, über (2) die Formulierung von Forschungsvorhaben und Experimenten, (3) der Identifizierung und Kopplung von Methoden, Modellen und Daten, (4) der Vorbereitung von Ergebnissen zur Veröffentlichung bis hin zur (5) Identifizierung von Folgeaktivitäten.

Unter dieser Maßgabe definiert nfdi4energy die folgenden **Hauptziele**: (1) Aufbau einer gemeinsamen Forschungsinfrastruktur für FAIRe Daten, Modelle und Prozesse und Motivation zu ihrer Nutzung. (2) Reproduzierbarkeit und Transparenz der Ergebnisse sowohl für die wissenschaftliche Community als auch für die Gesellschaft, um die FAIRness insgesamt zu verbessern. (3) Einbeziehen der Gesellschaft bei der Identifizierung und Lösung relevanter Forschungsfragen. (4) Förderung der besseren Zusammenarbeit und des besseren Wissenstransfers zwischen Forschungseinrichtungen und Wirtschaftsunternehmen durch ein FAIRes Forschungsdatenmanagement. (5)

Vereinfachung der Integration und Koordination von simulationsbasierten Modellen. (6) Integration der bereitgestellten Infrastruktur für die Energiesystemforschung in die breitere nfdi-Infrastruktur zur Verbesserung der disziplinübergreifenden Zusammenarbeit.

Um diese Ziele zu erreichen, konzentriert sich nfdi4energy auf fünf **Hauptdienste (key services)**, um einen diskriminierungsfreien Zugang zu Forschungsartefakten zu ermöglichen: (1) *Kompetenz*, um sich im interdisziplinären Forschungsfeld zurechtzufinden, (2) *Best Practices*, um Informationen über die erfolgreiche Durchführung von Forschungsarbeiten, einschließlich des Forschungsdatenmanagements, zu erhalten, (3) *Registry*, um geeignete Daten und Software zu finden, (4) *Simulation*, um bestehende Simulationen zu koppeln und somit Software-Artefakte wiederzuverwenden, und (5) *Transparenz*, um mehr Interessengruppen in alle Forschungsphasen einzubeziehen.

Mit diesen Diensten möchte nfdi4energy eine **offene und FAIRe Forschungsinfrastruktur** im Bereich der Energiesystemforschung entwickeln und betreiben, und so einen großen Teil relevanter Arbeitsabläufe unterstützen - von der Datenerfassung bis zur Einbindung in Forschungssoftware sowie Datenveröffentlichungen.

- Applicant institution

Applicant institution	Abbreviation	Location
Carl von Ossietzky Universität Oldenburg Ammerländer Heerstr. 114-118 26129 Oldenburg Head: Prof. Dr. Ralph Bruder	UOL	Oldenburg

- Spokesperson

Spokesperson	Institution	Location
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Co-applicant institutions

Co-applicant institutions	Abbreviation	Location
Albert-Ludwigs-Universität Freiburg Friedrichstraße 39 79110 Freiburg Head: Prof. Dr. Kerstin Krieglstein	ALU	Freiburg
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- Co-spokespersons

Co-spokespersons	Institution, Location	Task Areas[1]
Prof. Dr. Anke Weidlich anke.weidlich@inatech.uni-freiburg.de	ALU, Freiburg	TA2, TA4, TA5, **TA6**, TA7
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Prof. Dr. Sören Auer auer@tib.eu	TIB, Hannover	TA4, TA7

- Participants

Participating institutions	Abbreviation	Location
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Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. Prof. Dr.-Ing. Reimund Neugebauer Hansastraße 27c, 80686 München Here: Fraunhofer Institut für angewandte Informationstechnik (FIT) Prof. Dr. Stefan Decker stefan.decker@fit.fraunhofer.de	FhFIT	Sankt Augustin

[1] Bold font: Task Area lead

Contribution of RLI:

The RLI contributes with its rich experience in developing open tools, IT infrastructures, and its application for digitised energy system research. Its experience spans from developing energy domain-specific databases to scenario comparisons, appropriate licensing of software and data, ontology development, and implementation. Through its work, it is able to contribute with many best practices in digital energy research and significantly contribute to effective platform development. By participating in the project at the intersection of ontology development, digitised scenario comparison in practice and leading the provision of best practices for the platform, the RLI can leverage its strength for the project's successful outcome.

Contribution of FhFIT:

The Fraunhofer FIT (FhFIT) supports RWTH in Task Area 3 with establishing a link to relevant industry partners. While RWTH is leading this Task Area, FhFIT contributes to Measure 3.1 and Measure 3.2. FhFIT will use its network of industry partners to help identifying industry requirements for platform adoption and data sharing in Measure 3.1. Within Measure 3.2 RWTH defines a process for industry partners to contribute to and use the data and services developed in Task Area 4 and Task Area 5. FhFIT contributes by being the main contact point to the industry partners identified before and guiding their contribution process as well as gathering feedback from industry partners.

- Names and numbers of the DFG review boards (DFG-Fachkollegien) that reflect the subject orientation of the proposed consortium

  111 Social Sciences

  112 Economics

  407 Systems Engineering

  408 Electrical Engineering and Information Technology

  409 Computer Science

2 Scope and Objectives

2.1 Research domains or research methods addressed by the consortium, specific aim(s)

The necessary transformation of energy systems towards net zero greenhouse gas emissions provides a plethora of new research challenges. New interconnections between different energy sectors, such as power, heat and mobility increase the system's complexity, thus requiring stronger interconnections and data exchange between different research communities. In this context, the **digitalisation towards cyber-physical energy systems (CPES)** alleviates change in many respects: First, it drives and enables new levels of automation and sector-coupling and thus allows to address new optimisation potentials towards energy efficiency. Second, the long-envisioned idea of a direct integration of new stakeholders, right down to private households, becomes feasible based on a broad range of new participation opportunities. Third, digitalisation creates the conditions for improving energy research itself and for fostering a change towards transdisciplinary energy system development and research. Thus, digitalisation in energy systems equally affects technical, social, and societal topics, as well as the mode of research of the energy system research community.

A cyber-physical system is a composite of electro-mechanical components with IT interfaces and functionalities that are connected via a communication system. It is characterised by its high degree of complexity. The formation of cyber-physical systems arises from the interconnection of embedded systems through communication networks. The concept formation follows the need for a new theoretical basis for the study and development of large, distributed, complex systems [1]. Energy informatics specialises this need for a theoretical foundation for the research and development of energy systems that are CPS but with very special properties and unique characteristics. It is counted among society's critical infrastructures, as such it is an indispensable lifeline of modern societies, it is of cross-continental size (in case of the European synchronous system from North Africa to Scandinavia, from Ireland to Asia), energy systems exhibit almost instantaneous propagation speed of phenomena and instabilities as well as ubiquitous conflicting goals by its interconnected actors (e.g. monetary, technical, national/international political interests). Research on CPES requires the integration of relevant subdomains/-disciplines that are now the focus of the international energy informatics community.

Individual research efforts towards CPES heavily rely on modelling or (co-)simulation-based approaches: Either system components spanning different sectors must be improved and combined, or interactions between a large number of actors, possibly with differing modelling approaches, need to be integrated. Either way, tracking of models, their respective versions and states, together with the input data creates a complex software and data management challenge, which needs to be addressed and solved in each research project.

Thus, nfdi4energy focuses on supporting activities surrounding reproducible research and best practices in the domain of energy system modelling and simulation. This includes models, workflows, (standardised) datasets, benchmark or reference scenarios, in short: various digital objects (DO) needed to conduct repeatable experiments across scales, domains, and modelling approaches within the energy sector. These range from detailed component simulations of energy equipment up to analytical socio-economic models of whole continents.

To support this wide range of approaches, nfdi4energy develops and bundles a suite of community services through a common platform for the research community. These services support the different phases of the typical research and transfer cycle of projects in energy system research.

Research and Transfer Cycle in Energy System Research

Today's interdisciplinary energy system research is mostly project-oriented. This gives rise to a cyclical time-frame for most research endeavours, which are aligned with the time frames of typical research and development projects (2-5 years). We conceptualise this process as an idealised research and transfer cycle as composed of 5 phases, as shown in Figure 1. nfdi4energy aims at supporting this cycle based on community services.

While this Section outlines the research activities and common challenges per phase, Section 4.4 describes key services aimed to address these challenges.

During phase I, a research group identifies its core competencies and expertise, e.g. modelling methods, simulation techniques, or particular knowledge with respect to technological, engineering, economic or societal aspects. The aim is a complementary match in relation to its immediate partners, while searching for suitable industry partners with matching research and business goals to form consortia. Typical challenges involve finding and establishing contacts with potential research partners. This is particularly true for newly formed groups and young researchers, and especially challenging in fast-moving fields, like energy system research, which has gained traction, size, and speed during the last two decades, making it hard to follow the pace of new developments. Additionally, the interdisciplinarity of this field has increased dramatically, making it more difficult to find and connect with new relevant partners.

Figure 1 CPES research and transfer cycle; 5 phases with indicative activities

Phase II, occurring during proposal development and during the first project stage, includes defining relevant scenarios and experimental setup, which should be reviewed by the relevant research community through conference participation or white paper publication. This phase can benefit from findable curated, opinionated best-practice guidelines and demonstrations of existing best practices for experimental setups, research data management as well as privacy concerns. These concerns are more common knowledge in the social sciences, but not yet established practice in the more engineering and modelling oriented parts of energy system research, which on the other hand relies on community-driven processes and established practices, e.g. in electrical engineering.

During phase III, partner collaboration takes the centre stage as individual models and data are integrated, interfaces are configured, and tools and laboratories are coupled. CEPS research is often based on simulating behaviour and, therefore, it requires multiple different data and models as input. Finding suitable upstream models, data sources or a clear lack thereof is still a major challenge and has not yet benefited from standardisation. Furthermore, there are a multitude of segmented community-curated repositories and libraries for energy system research but no documented standard to follow for data providers of energy system model data and metadata models for simulation authors, so that plug & play interoperability could be accomplished for downstream users. This leads to friction and inhibits the reuse of DO in research. Therefore, a lot of effort is needed by each individual research group for strikingly similar tasks, e.g. repetitive time series preparation for demand curves or meteorological capacity factors for fluctuating renewable sources.

In phase IV, results are extracted and their persistence is ensured. Also, the results are part of public consultation and discourse. A prominent challenge lies in the large inferential distance between the complex inner workings of a (distributed) simulation model in energy system research and its outputs, which often require specialised knowledge to be interpreted. Also, it is almost never possible for laypersons to interact with those research methods directly to gain an intuitive understanding of their mode of operation. This understanding is crucial to build trust for energy system research in the public and society in general. Providing easy-to-interpret model results with process guidelines for public discussion and validation on top of a complex simulation model is a hard problem, on which even modest progress will be valuable.

Phase V, identification of research gaps and challenges for follow-up activities, closes the loop of the whole research and transfer cycle and is the precursor step to phase I. In this phase, the direction and next steps for future research are identified. Challenges here lie in selecting which of the many follow-up questions to pursue, which method and approach to tackle next, and which past paths to abandon. By including politics and society, the amount of possible follow-up questions can be reduced in a meaningful way, since energy system research claims to be useful for the energy transition. Also, this phase could profit from a more structured overview about other current projects, project ideas, and both technical and methodical suggestions.

2.2 Objectives and measuring success

The mission of nfdi4energy can be summarised by some major objectives that will be outlined including the measures for success in the following.

Objective 1: Establish a common research platform for FAIR data, models, and processes in energy system research and motivate its use in the energy system research community.

This objective has been successfully addressed when a set of services exist that have been recognised as valuable and validated through wider uptake within the energy research community. The services support the sharing of FAIR data, models, and processes for both data users and providers. Usage metrics and user feedback from key actors have been collected to fine-tune features, content, and presentation of the various facets of the overall data services. Consortium members participate actively on community events for low-friction interaction with junior researchers up to senior group leaders.

Objective 2: Allow traceability, reproducibility, and transparency of results for the scientific community as well as for the society, improving the overall FAIRness within energy system research.

This objective has been successfully addressed when there is a small number of agreed upon guidelines in place, aligned with the FAIR principles, that can be followed to identify and reference key input datasets, thus make data usage in individual experiments citable, as well as to archive model results for independent validation.

Objective 3: Enable and motivate the involvement of society for the identification and solution of relevant research questions including a social and societal perspective.

This objective has been successfully addressed when participation and involvement of public and policy within energy system research becomes common practice and is widely accepted by the scientists and the society. In this way, meaningful results can be achieved suitable for policy recommendations, with positive expectations regarding societal acceptance. Additionally, new sources for public participation are directly connected to suitable policy-driven energy system models.

Objective 4: Promote better collaboration and knowledge transfer between scientific research institutes and business partners via FAIR research data management, respecting conflicting interests and options regarding openness of data and software.

This objective has been successfully addressed when industry and business partners within the energy domain participate actively in data sharing, supported by the FAIR criteria, access services provided by nfdi4energy, or transfer scientific results into practice using nfdi4energy community services, as verified by usage statistics and validated by stakeholder feedback.

Objective 5: Significantly simplify finding, identification, integration, and coordination of simulation-based models to allow multi-disciplinary research questions to be addressed with less effort.

This objective has been successfully addressed when there is a domain-wide registry with significant coverage of existing, actively-maintained simulation models. For these models, the registry should include a rich ontology-based description of machine-readable metadata. In this way the FAIRness of the provided models can be improved. Additionally, the set-up and usage of distributed simulation models shall be approachable by a significantly larger share of the research community, thus supporting a non-discriminatory access.

Objective 6: Integrate the provided services for energy system research within the wider NFDI ecosystem to improve cross-domain collaboration, e.g. by the common use of domain-independent upper ontologies and unified metadata schema.

This objective has been successfully addressed when processes and guidelines developed within nfdi4energy are transparently compatible with best practices established by neighbouring and base service consortia within nfdi. Validation happens through expert review with members from other NFDI consortia.

3 Consortium

Some of the co-spokespersons of nfdi4energy are already involved in other existing NFDI consortia, thus strengthening the coupling to infrastructure providers. Prof. Dr. Sören Auer is co-applicant in NFDI4Ing, where he contributes to the semantic mapping of methodological knowledge and the development of metadata and terminology services. Additionally, Prof. Dr. Sören Auer is co-applicant in NFDI4DataScience, where he contributes to the extraction, linking, and integration of research metadata; creation, annotation, and curation of data; and to the high-performance computing and infrastructure. Also, Prof. Dr. Sören Auer is participant in NFDI4Microbiota and FAIRmat.

On the institutional level additional consortia can be listed. Without direct integration and without participation of our co-spokespersons of nfdi4energy, the institutes / universities of our members are also participating in:

- **ALU**: Co-applicant: DataPLANT, MatWerk; Participant: DAPHNE4NFDI**,** PUNCH4NFDI**,** Text+
- **FAU**: Co-applicant: DAPHNE4NFDI, NFDI4Cat, NFDI-Matwerk; Participant: FAIRmat, MaRDI, NFDI4Culture
- **KIT**: Co-applicant: DAPHNE4NFDI, FAIRmat, NFDI4Cat, NFDI4Chem, NFDI4Earth, NFDI4Ing, NFDI-Matwerk, PUNCH4NFDI; Participant: NFDI4Microbiota
- **OFFIS**: Participant: NFDI4Health
- **RWTH**: Co-applicant: DAPHNE4NFDI, NFDI4Cat, NFDI4Chem, NFDI4Ing, NFDIMicrobiota, NFDI-Matwerk, PUNCH4NFDI; Participant: FAIRmat, NFDI4Earth
- **TIB**: Co-applicant: NFDI4Chem, NFDI4Culture, NFDI4DataScience, NFDI4Ing; Participant: FAIRmat, NFDI4Earth, NFDI4Microbiota, PUNCH4NFDI
- **UOL**: Participant: DAPHNE4NFDI, NFDI4Biodiversity, NFDI4Earth

Thus, a multitude of connections exist to other consortia that will be strengthened to setup functional and interoperable interfaces between the developed services and the relevant infrastructure.

3.1 Composition of the consortium and its embedding in the community of interest

The term Energy Informatics was first coined in Germany 12 years ago in 2009 with the establishment of an Interest Group (EIG) "Energy Informatics" within the **Gesellschaft für Informatik (GI)** and with the first **dedicated professorship** "Energy Informatics" at the University of Oldenburg. In 2015, the EIG became a **GI Special Interest Group (SIG) "Energy Informatics"**[2], which is a discipline now established at several universities and research institutions and annually meets at the European **flagship conference "DACH+ Energy Informatics"**[3]. At the international level, these activities continue within the Association of Computing Machinery (ACM) and its **ACM SIGEnergy**[4], newly founded in 2019. Its flagship conference "E-Energy"[5], initiated in Germany in 2010, continues to network this core community worldwide to this day. Oldenburg continues to operate the world's largest research group for energy informatics focusing on digitalised energy systems. Beside the committees mentioned above, the energy system research community is represented in many additional national and international working groups and committees, like **VDE** working groups (e.g. VDE AG Planung dezentraler Energiesysteme), **BDI**, **Leibniz Research Alliance** on Energy Transitions, the national "Energy Systems of the Future" project (ESYS), coordinated by **acatech**, The National Academy of Sciences, **Leopoldina,** and the Union of the German Academies of Sciences and Humanities, and so forth. These activities are combined with further engagement on state level, like Smart Grids Plattform Baden-Würtemberg, or Energieforschungszentrum Niedersachsen (Energy Research Centre of the federal state of Lower Saxony, EFZN).

The consortium as a whole is composed of **active members and speakers** in these working groups and committees. They are key individuals from the above communities (e.g., speakers of SIG Energy Informatics, Steering Committee Chairs of both DACH+ Energy Informatics and ACM E-Energy, and very active community members), and the driving forces behind these developments as well as multipliers and responsible for key initiatives necessary for this community (e.g. curating specialised and widely used repositories as well as standard tools and methodologies in the target community). With energy system research being a large and established research area, most of the partners represent a relevant energy system research facet. The first phase described in this proposal focuses on representative use cases identified within the core community. Clearly, not all partners from this community can be included and funded in this initiative. The consortium is composed of experts who are competent in the sub-

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[2] https://fg-wi-eins.gi.de
[3] https://energy-informatics2021.org
[4] https://energy.acm.org
[5] https://energy.acm.org/eenergy-conference/

areas and elements necessary for these use cases, in addition to being responsible leaders of the international community activities, thus serving as multipliers for nfdi4energy's services and solutions. nfdi4energy has emerged from community activities and discussions, and thus has a mandate to drive this initiative forward with a promising perspective of adoption and multiplication. The Scientific Advisory Board (SAB) will be used to include additional representatives from the community both during setup and provision of the key services.

In the following, each member of the consortium is described in detail in relation to the respective community. In this context, interdisciplinarity is of utmost importance. We will highlight each nfdi4energy member's role within the consortium reflecting their role in the community of energy system research. Additionally, for each member, we will hint to relevant expertise in the field of research data and research software management. Last, we will reflect who is not involved and why.

The consortium as a whole is set up from three relevant groups:

a) **energy research expertise**:
   representation of the relevant energy system research facets
   - Power grids and automation systems: FAU, FhFIT, KIT-IAI, OFFIS, RWTH, UOL
   - Long-term energy scenarios: ALU, IASS, RLI
   - Energy policy and societal aspects: IASS, KIT-IISM

b) **methodological foundations and their application in the field of research data and software**:
   - Infrastructure and domain-invariant service providers: TIB
   - Simulation techniques incl. labs: FAU, KIT-IAI, OFFIS
   - Domain-specific ontologies: KIT-IAI, RWTH, OFFIS, RLI

a) **community and public involvement expertise** (IASS, KIT-IISM, SOFI):
   - Acceptance studies and modelling of acceptance: IASS, SOFI
   - Citizen science and involvement strategies: KIT-IISM, SOFI

As can be seen from this list, some of our partners belong to more than one expertise group, thus strengthening the grounding in both the community and methodological context.

The University of Oldenburg (UOL), with **Prof. Dr.-Ing. Astrid Nieße** as spokesperson and coordinator of the consortium, is speaker of the Special Interest Group "Energy Information Systems" (EI/WI-EINS) within the German Informatics Society (GI - Gesellschaft für Informatik). She is an active member of ACM SIG Energy and actively promoting the conferences in this field as a (steering / organisation / programme) committee member (ACM e-Energy, DACH+ Energy Informatics). She is editor of SpringerOpen Energy Informatics and ACM Energy Informatics

Review. She is active in the DFG Priority Programme SPP 1984 "Hybrid and multimodal energy systems" with current research activities and supervision of doctoral projects. Astrid Nieße is organiser of several community-driven workshops with a focus on digitalised energy system research. The energy informatics group in Oldenburg – led by Astrid Nieße, Sebastian Lehnhoff and other colleagues – with about 100 researchers is one of the largest working groups in this field internationally.

Prof. Dr. Anke Weidlich from Albert-Ludwigs-Universität Freiburg (ALU) is member of the board of directors of Smart Grids-Plattform Baden-Württemberg e.V. Additionally, she is member of the board of the Special Interest Group „Energy Information Systems" (EI/WI-EINS) within the German Informatics Society (GI). She is co-lead of one working group at the project "Energiesysteme der Zukunft" of the National Academy of Science and Engineering, Leopoldina – German National Academy of Sciences and the Union of the German Academies of Science and Humanities. At University of Cologne, she is member of the Scientific Advisory Board of Energiewirtschaftliches Institut an der Universität zu Köln (EWI). She is active in the in DFG Priority Programme 1984 with current research activities and supervision of doctoral projects.

Prof. Dr. Reinhard German from Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU) has contributed to the DACH+ Energy Informatics conference series as an author and TPC member, also as a TPC member of the associated PhD workshop. He is scientific representative for Connected Mobility in the Center Digitalization of Bavaria (ZD.B), coordinator of ESM-Regio (multi-sector coupled energy system modelling at regional level), a joint project with FAU, Hochschule Coburg, Stadtwerke Bayreuth, Energieagentur Nordbayern, Bayern Innovativ, funding by Federal Ministry of Economic Affairs (BMWi) and has also coordinated KOSiNeK (BMWI). He is active in the GI/ITG working group on Measurement, Modelling, and Evaluation of Computing Systems and is an adjunct professor at Monash University, Melbourne, Faculty for Information Technology, Sustainable Energy Group.

The IASS, headed by **Prof. Dr. Dr. Ortwin Renn**, is represented by **Prof. Dr. Johan Lilliestam**. Prof. Renn is member of the board of acatech - Deutsche Akademie der Technikwissenschaften, member of Leopoldina (Nationale Akademie der Wissenschaften), as well as Berlin-Brandenburger Akademie der Wissenschaften, ensuring a close link between IASS and these high-level advisory bodies. Prof. Lilliestam leads the Energy Transition Dynamics group at IASS, involved in this consortium, and focuses on policies and strategies for a transition to a fully renewable energy future, mainly in Europe. He holds a grant from the European Research Council. The IASS develops and applies methods for transdisciplinary research and stakeholder engagement for different sustainability fields, including landscape protection, climate change mitigation, and energy transition policy. The IASS is involved in the open energy modelling initiative (openmod) community and works closely with other energy system research/modelling groups, mainly through collaborations with energy system modellers and through the SENTINEL project (Horizon 2020). IASS researchers published extensively in the field of linking energy models to the needs of model users in policy and society, and on how to integrate social and political factors into energy models (most of this work in SENTINEL/Horizon2020 and TRIPOD/European Research Council).

The group KIT IAI, represented by **Prof. Dr.-Ing. Veit Hagenmeyer**, is part of the respective communities via participation at conferences like Energy Informatics, ACM e-Energy, IEEE Power Tech, and via participation at national projects as Kopernikus ENSURE, SINTEG c/cells, and the Helmholtz Metadata Collaboration (HMC), including active participation in the BMBF Kopernikus-ENSURE board of directors. Prof. Hagenmeyer is spokesperson and member of the Board of Helmholtz POF IV programme Energy System Design, and additionally member of the personal think tank of the president of the Helmholtz Association.

Prof. Dr. Christof Weinhardt from KIT group IISM has been part of the BDI working group “Internet der Energie” (internet of energy) for many years. As a member of the GI special interest group on energy informatics, he and members of his group are actively participating in the organisation of DACH+ Energy Informatics and the ACM eEnergy conference. Additionally, he has been workshop organiser at ACM eEnergy on the topic of Energy Market Engineering, and co-organiser of energy informatics tracks at the German Wirtschaftsinformatik Tagung. He heads a transdisciplinary research project on Digital Citizen Science of the KIT funded through the excellence initiative funds.

Prof. Dr. Sebastian Lehnhoff is chairman of the board of the OFFIS - Institute for Information Technology - and speaker of its research division Energy. Since 2019, he is Management Board member of the Special Interest Group „Energy Information Systems“ (EI/WI-EINS) within the German Informatics Society (GI). Since 2019, he is Executive Board Member of the EFZN. Since 2018, he serves as CTO of openKONSEQUENZ e.G. – a registered Industry Cooperative for Engineering of modular and open SCADA (Supervisory Control and Data Acquisition) and EMS (Energy Management Systems). Since beginning of the conference, Sebastian Lehnhoff has been Steering Committee member of the European conference DACH+ Energy Informatics. He is Executive Committee Member of the ACM Special Interest Group Energy (SIGEnergy) and steering committee chair of its e-Energy flagship conference. He is programme committee member of the DFG Priority Programme 1984 Hybrid and multimodal energy systems with current research activities and supervision of doctoral projects. He is Member of the national “Energy

Systems of the Future” project, coordinated by acatech, The National Academy of Sciences, Leopoldina, and the Union of the German Academies of Sciences and Humanities.

The RWTH and FhFIT is represented by **Prof. Dr. Antonello Monti**. He is leading several projects at European level in the field of Smart Energy. In particular, the projects OneNet and Platone, both developing key contributions towards the definition of European level platforms for data management in the Energy Sector. During 2020, Prof. Monti led the Task Force of the European Commission for the definition of the Research and Innovation Strategy in the Energy Sector. Currently, he is also serving as Chair of Technical Activity Council of the Linux Foundation Energy, where he manages the open source development of several software projects at global level. He is also part of the Scientific Advisory Board and leader of the Energy vertical within the FIWARE foundation. He is also supporting the International Energy Agency (IEA) within the project 3DEN aimed at determining the needs for a progressive digitalisation of the energy networks with particular focus for countries under development. Prof. Monti is also active within IEEE where he is leader of the Task Force on Modelling and Simulation of large power networks with high penetration of Converter Interfaced Generators.

Prof. Dr. Berthold Vogel from SOFI is member of the Board of Directors of the EFZN. Moreover, Prof. Dr. Berthold Vogel is spokesperson of the Research Institute Social Cohesion (FGZ), Section Göttingen, where the issue of energy as a common good is discussed in the research area “institutional structures and common goods”.

The TIB - Technische Informationsbibliothek - is represented by **Prof. Dr. Sören Auer**. As a member of the Leibniz Association, TIB is involved in various research alliances and working groups. TIB is a founding member of Leibniz Research Alliance Open Science. Key activities in research include the new working habits of researchers, user behaviour research, and technological development. Prof. Auer is active in many interdisciplinary activities within this field, e.g. the Arbeitsgemeinschaft Deutscher Patentinformationszentren e. V. (PIZnet), Coalition for Action Copyright for Education and Research, German Initiative for Networked Information (DINI e. V.), German Library Association (dbv), German Patent and Trade Mark Office (DPMA), Patent Information Centre, L3S research centre, Hannover, FIZ Karlsruhe – Leibniz Institute for Information Infrastructure, and nestor – the German competence network for digital preservation. In a cooperation with the FZ Jüllich within the Task Area ELLEN in NFDI4Ing, the TIB already has experience with integrating the field of energy system research into general research data infrastructure.

The Reiner Lemoine Institute, represented by Dipl.-Ing. **Mascha Richter**, is an active member within the Open Energy Modelling Initiative (openmod) community. RLI and its research groups are active in several national boards, e.g. the project advisory board of the Leibniz Research Alliance on Energy Transitions and the scientific board of the conference "Powertrains and Energy Systems of Tomorrow" hosted by Automobiltechnische Zeitschrift (ATZ). RLI is a member of the BEST (Blockchain for a smart energy market) advisory board. RLI is a partner in in several national funded research projects in the field of energy system research, data, and modelling within consortia that are part of the community, e.g.: LOD-GEOSS: Linked Open Data and Use of the Global Earth Observation System, GEOSS in Energy System Analyses, SIROP-Automated comparison of energy scenarios and SzenarienDB. Additionally, RLI is the leading development partner of the Open Energy Platform (OEP)[6]. In cooperation with FZ Jülich, part of this work is already included in services from TIB within NFDI4Ing.

3.2 The consortium within the NFDI

The general idea of nfdi4energy is to develop application-specific community services and infrastructures addressing the CPES research challenges building on results and current work from existing and new NFDI consortia, thus including domain-invariant services for research data and software repositories from existing infrastructure providers. Thus, while the services have to be provided by nfdi4energy, the underlying methods and concepts will build upon cooperation with the following consortia, as briefly summarised in Figure 2:

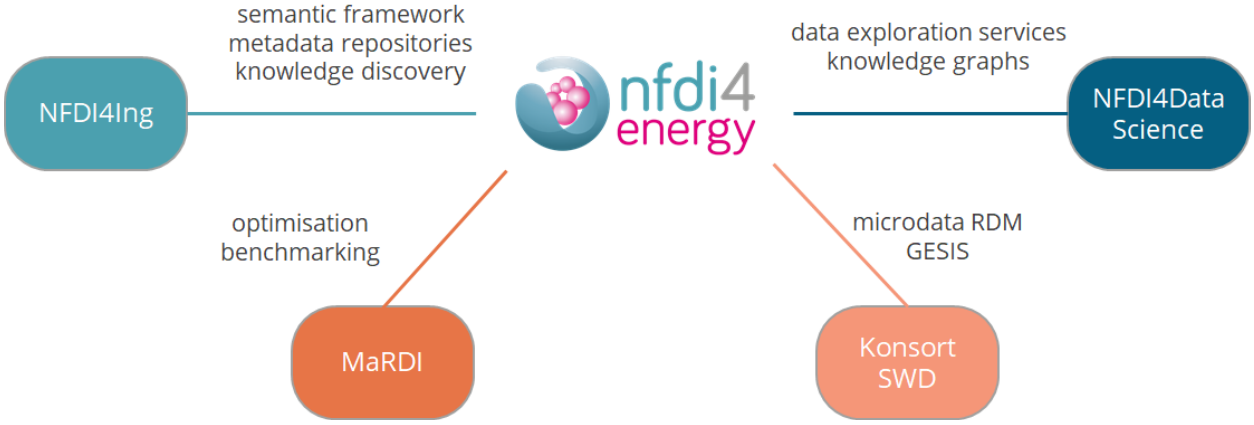

Figure 2 The nfdi4energy consortium in relation to its immediate cooperation partner consortia

[6] https://openenergy-platform.org/

NFDI4Ing works on FAIR data and open science principles with a special focus on the engineering sciences. With this focus, NFDI4Ing addresses interdisciplinary research as well. The cooperation with this consortium will focus on metadata and terminology services, repositories, and storage, as well as automated data and knowledge discovery. With TIB, already cooperating with FZ Jülich on energy data in NFDI4Ing‘s Task Area ELLEN on integrating energy ontologies, a relevant partner builds the bridge between the consortia.

NFDI4DataScience is a consortium with a special focus on data science in academia. Initially, data intense application areas are the core area, like biomedical and social sciences. With the services developed from this consortium though, additional application areas like CPES research are both straightforward and intended. The development and use of knowledge graphs is a key method within this consortium. An intense cooperation in this regard is planned.

The NFDI consortium **MaRDI** focuses on the task of applying the FAIR principles to mathematical research software, models, and data. Within CPES research, many approaches apply methods from applied mathematics, especially in the field of multi-criteria optimisation. For this, working with well-known benchmark functions is a crucial step in early iterations of the research and transfer cycle, thus paving the ground for larger system evaluations in later iterations. The MaRDI consortium has shown interest in cooperation.

As nfdi4energy addresses socio-technical aspects in CPES research, a cooperation with **KonsortSWD** is planned as well. Among other initiatives, with RatSWD, this consortium already has a long-term expertise in addressing research data aspects in social, economic, and behavioural sciences. It is planned to cooperate with this consortium regarding the social, societal, and socio-technical aspects in nfdi4energy. To be more specific, it will be discussed which data and research software could be integrated into GESIS as a relevant research data centre. Up to now, no energy system research data centre has been set up by KonsortSWD. A discussion on this with the KonsortSWD coordinator B. Miller has already been started and concerned e.g. the quality assurance process within KonsortSWD.

With the third funding round in nfdi, **base consortia** will be funded as well. nfdi4energy explicitly expresses the motivation to cooperate with and reuse results from these consortia as well as serve within the requirement analysis process of these consortia.

3.3 International networking

To yield a lasting effect on the energy system research with respect to research data and software management, the international networking of the consortium as a whole is of utmost importance. The members of the consortium are active in all fields of both domain-specific, i.e. energy system research activities, as well as methodological communities in the field of research data, research data infrastructures, and simulation techniques. We will highlight the most important aspects of international network in this Section.

Association of Computing Machinery (ACM): Many of our members are part of the relevant special interest groups of the ACM, namely ACM SIGCOM and ACM SIGEnergy, and e.g. members of the flagship conferences‘ steering committees. They will use this network to actively present, promote, and discuss the results of nfdi4energy within the international community, and take a leading role in promoting FAIR research data and software - a topic already discussed intensively in the international community.

Institute of Electrical and Electronics Engineers (IEEE): Most of our members are IEEE members, with some of them in prominent positions in key conferences and dedicated relevant working groups, e.g. IEEE CA4EPI Working Group P2030.4™ (Guide for Control and Automation Installations Applied to the Electric Power Infrastructure).

European Energy Research Alliance (eera): Our members have been active for years in eera, and participated e.g. in the ELECTRA IRP funded within this context. The community is highly relevant on a domain-specific level and was and will be used to further enhance the European cooperation in the field of research data infrastructure.

International Energy Agency (IEA): Our members actively promote the International Smart Grids Action Network (ISGAN) Annex 6 – appointed by the Federal Ministry for Economic Affairs and Energy (BMWi).

European Institute for Energy Research (EIFER): Members of our consortium are active within EIFER, including prominent positions (e.g. Prof. Hagenmeyer as president of the board of directors of EIFER.)

HORIZON2020 projects: Members of our consortium successfully conducted projects within HORIZON2020, e.g. ERIGRID[7] (smart grid research infrastructure), SENTINEL[8](energy system

[7] https://erigrid2.eu/
[8] https://www.iass-potsdam.de/en/research/sentinel

modelling), TIPPING+[9] (societal transition dynamics), MUSTEC[10] (concentrating solar power, policy analysis + system modelling).

International journals and conferences: All of our members are active in leading positions in international journals (editors: Springer, SpringerOpen, Elsevier) and relevant conferences. For reasons of brevity, we omit the details with regard to this.

Open Source activities: FAIRification of data is often correlated with activities in the open source software community. On an international level, member from our consortium are active e.g. in the Linux Foundation Energy (as Chair of the Technical Activity Council) and at FIWARE foundation, both general and in the Smart Energy Domain section of FIWARE.

Scientific networking as visiting / hosting scientist: Many of our members show strong activities in international networking in this category. Many of the members are either hosting or visiting scientists within this context, e.g. at / from ETH Zurich and Universität St. Gallen. Additionally, members have been visiting / hosting scientist at / from Monash University, Melbourne, the Birzeit University, Palestine, and University of Florence, Italia. Additional close scientific cooperation can be mentioned to MIT (Anuradha Annaswamy), University of Cagliari (Prof. Carlo Muscas), Politecnico di Torino (Prof. Ettore Bompard), Politehnica University of Bucharest (Prof. Mihaela Albu), University of Melbourse (Prof. Pierluigi Mancarella, University of South Carolina (Prof. Andrea Benigni), and Arizona State University (Prof. Anna Scaglione).

International activities with respect to technical libraries and open research: Members of our consortium are active in DataCite e. V.[11] (an international consortium on research data management, founded in 2009 by TIB and various partners), the Chinese Academy of Sciences (CAS), Beijing, TechLib[12] (a network of leading technology libraries in Europe, including TIB, TU Delft Library, Technical Information Center of Denmark), Facilitating Open Science Training for European Research (FOSTER[13]): promotion of the series of online seminars "CoScience – Collaborative research and publishing via the web" (2014 and 2015), International Federation of Library Associations and Institutions (IFLA[14]), International Association of University Libraries (IATUL), Library for Natural Sciences of Russian Academy of Sciences, Association of European Research Libraries (LIBER[15]), National Institute of Informatics (NII) (Tokyo), Open Preservation

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[9] https://www.iass-potsdam.de/en/research/tipping
[10] https://www.iass-potsdam.de/en/research/mustec
[11] https://datacite.org/
[12] https://www.tib.eu/en/tib/profile/cooperation/techlib
[13] https://www.fosteropenscience.eu/
[14] https://www.ifla.org/
[15] https://libereurope.eu/

Foundation (OPF[16]), Open Researcher and Contributor ID (ORCID17), Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP[3]), The International Council for Scientific and Technical Information (ICSTI) and the WorldWideScience Alliance. Prof. Auer, Director of TIB, was founding director of the Big Data Value Association, led the semantic data representation in the International Data Space, is an expert for industry, European Commission, and **W3C[18]**. Also, TIB is a founding member of the EOSC (European Open Science Cloud) Association representing the EOSC community. As a co-applicant in the NFDI4Chem project, TIB already coordinates cooperation with international bodies such as the Research Data Alliance (RDA[19]) and the International Union of Pure and Applied Chemistry (IUPAC). The good networking and cooperation with the RDA could be further broadened and intensified in nfdi4ernergy.

GAIA-X: From the nfdi4energy consortium, several partners are involved in GAIA-X activities. The Fraunhofer Gesellschaft is among the founders of the GAIA-X initiative and involved in the development of all the use cases for every sector and in particular for the energy part (energy data-X: Energy data space for data exchange in GAIA-X, funding as of 2022). RWTH also recently applied to be part of the working group in Energy and should become active before the end of the year 2021.

3.4 Organisational structure and viability

The organisational structure of nfdi4energy is based on five requirements:

I. Set up an efficient **internal communication and decision structure** supporting cooperative work within the consortium
II. Realise **scientific sounding** by external expertise
III. Involve the **scientific community** as key stakeholders and future users for the nfdi4energy services
IV. Involve the energy companies as **key partners within the application domain** of nfdi4energy
V. Realise a sustainable operation of the developed community services

To fulfil these requirements, the structure given in Figure 3 is defined. As internal structures within nfdi4energy, the structures of General Assembly, Steering Committee and Project Office are chosen:

[16] https://openpreservation.org/
[17] https://orcid.org/
[18] https://www.w3.org/
[19] https://rd-alliance.org/

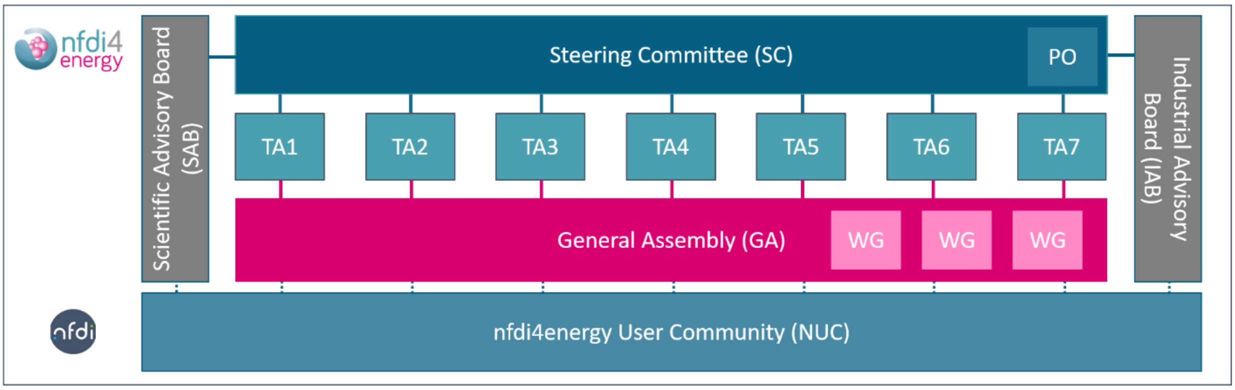

Figure 3 Organisational structure of nfdi4energy

The **General Assembly (GA)** meets once a year with all members and all involved persons funded within nfdi4energy. The GA (1) is an annual meeting to communicate progress, (2) discuss current and upcoming issues in the realisation of nfdi4energy and (3) prepare decisions for the Steering Committee. Ad-hoc Working Groups (WG) will be formed for cross-cutting topics, e.g. WG Metadata & Ontologies and WG Scenario Description Standardisation.

The **Steering Committee (SC)** is closely related to the organisation using Task Areas (TA) and Measures (M). TAs comprise tasks that are content wise aggregated within Measures. TAs have a Task Area lead, as indicated in the working programme. TA leads are responsible for all work done within TAs and members of the SC. Additionally, in each TA a Measure lead is chosen as a TA-deputy for the SC. For TA7, the spokesperson and the project coordinator (see Project Office) are part of the SC.

The **Project Office (PO)** supports the consortium within all administrative aspects with respect to the transfer of funds, realisation of consortium agreement and so on. It is represented by the project coordinator, supervised by the spokesperson at UOL. The PO reports to the SC on a quarterly base to identify issues fast and define countermeasures, if needed.

The **nfdi4energy User Community (NUC)** comprises the community in energy research and transfer that nfdi4energy is obliged to support with its services. The community is invited to the annual meeting of the consortia to get involved. From this community, additional partners can be identified for the consortium that might be included using variable funds. With the duration of the project, some partners might become relevant, e.g. young scientists that should be involved for both content-wise participation and promotion of young talents.

Additional boards will support nfdi4energy to setup the services for the community: First of all, the **Scientific Advisory Board (SAB)** will comprise additional experts in the field of both FAIR research data and software and energy system research, to reflect major decisions from the SC.

Thus, the work from the consortium representing relevant groups in CPES research will be sounded within the broader community. As research and transfer work in the field of energy systems is closely related to both requirements and limiting factors from the energy-technical and -economical practice, the **Industrial Advisory Board (IAB)** will support to include this view into the nfdi4energy service development.

3.5 Operating model

We distinguish the aspects of the operating model between project phase and the long-term perspective:

Project phase: The consortium nfdi4energy will be operated under an academic consortium model. To realise this, a consortium agreement (CA) will be set up to clarify the operational dependencies between all members. This model is well-known to all partners and an established operating model to realise the transfer of funds from the applicant institution to the other members. NFDI e.V. already supports this model and offers exemplary CAs. Possible new participants of the consortium will be included based on mechanisms already developed within NFDI e.V., taking care of the funding transfer process.

Long-term perspective: The long-term operation of the developed community service is a major goal of nfdi4energy. To this end, FAIR data management is essential to the power systems research community. NFDI4Ing as a consortium taking into account the needs of different engineering disciplines, therefore provides important services to this community as well. Furthermore, in recent years, the energy informatics community has recognised the need to systematically support continuous processes that follow the standard lifecycles of energy system research projects and link different knowledge, data, and tool repositories during its annual workshop on tools and methods[20]. The goal of nfdi4energy is to enable these process services on top of sophisticated FAIR data management. As such, it is independent of the provision and operation of the data infrastructure and services at the base layers, which are adopted and imported by NFDI4Ing. TIB as representative infrastructure provider and important player in NFDI4Ing in included in the consortium. Additional infrastructure providers are needed in the field of e.g. simulation services. To realise this, nfdi4energy will (1) actively promote interoperability of the developed services with research data research and software infrastructures from the wider NFDI ecosystem, e.g. from the base consortia, and (2) actively support the discussion process that is relevant for all NFDI consortia on the NFDI e.V. level.

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[20] https://energy-informatics2021.org/tools-methods-workshop/

4 Research Data Management Strategy

4.1 State of the art and needs analysis

Current research on energy systems is mainly based on models and simulations, as already discussed in Section 2.1. These simulations need a lot of different input data and also produce data. Their scope ranges from small software components like simulation models of energy storage systems up to simulation frameworks for the analysis of transition pathways [2]. The digitalisation of energy systems towards cyber-physical energy systems (CPES) increases the complexity of these simulations and, therefore, the need for research data and research data management as well.

Research data needed in energy system research is diverse: There is real-world data from research projects, like demand and generation data; data from official statistics, like energy consumption of countries; socio-economic data, like economic growth or technology acceptance rates; industrial data, like energy consumption of companies; market data; and data concerning critical infrastructure, like grid topologies, data on grid assets, or equipment specifications.

While, in the past, research data was mainly kept restricted at different institutions, the share of open data and open source software is nowadays constantly increasing specifically in the energy domain. Open data and open source software are often published on websites of different institutes (e.g. the open data portal of the FfE[21]). To this end, the overall situation of research data has improved enormously in the field of energy system research. While this is an important step, typically descriptions and documentations are still diverse, and come without machine-readable metadata. Therefore, the FAIRness of research data and software needs additionally be increased like its openness is already doing.

A few platforms already address this issue, where Table 4.1 lists some of them. One example is the OEP, which was partly developed by the RLI. The platform includes a database on different frameworks, scenario descriptions, and data. All information is searchable and filters can be applied [3]. Data can also be accessed by using an API. An ontology to better describe the energy data is provided but not yet included in the metadata of data and frameworks [4]. Still, these approaches are far from being used by the whole community and only present particular island solutions for specific applications in energy system research. To this end, there is a need to bring the different approaches together and to train and support researchers across the energy domain accordingly - despite their diverse disciplinary background.

[21] http://opendata.ffe.de/

Table 4.1 Examples of data platform for energy system research

Database	Host	Access	Scope
Open Energy Platform (OEP)	Otto von Guericke University Magdeburg; Flensburg University of Applied Sciences; University of Flensburg; Reiner Lemoine Institut	website, API	model-oriented
Open Data Energy Networks	French RTE and partners	website, API	French Energy System
Open Power System Data	University of Flensburg; DIW Berlin; Technical University of Berlin; Neon Neue Energieökonomik	website, API	Western Europe power system
OpenEI	US Department of Energy	semantic web	US Focus
Renewables.ninja	ETH Zurich; Imperial College London	website, API	worldwide hourly Photovoltaic and wind
SMARD	German BNetzA	website	DE electricity systems
Openmod Wiki	openmod	website	List of models and data
FfE Open Data Portal	FfE	website	Data from FfE projects

An open and FAIR research ecosystem in the energy domain should support the CPES research and transfer cycle (see Figure 1) and thus contain a large share of common workflows from data gathering to the inclusion into research software, together with result data publication for researchers spanning from single component development (like battery storage systems, transformers, or other new smart grid equipment) up to system-of-systems research (based on mathematical or analytical models). The development of this ecosystem is only possible by combining methods from general research data management with the requirements and the knowledge from the energy research domain [5]. While the first can be set up based on infrastructure services from the overall nfdi ecosystem, a research community specific approach is added in nfdi4energy, thus leveraging the full potential of FAIR data and software in the energy system research community.

4.2 Metadata standards

Metadata is indispensable to meet the requirements of the FAIR principles for research data and other research DOs. Metadata can include information such as author, provenance, quality, access rights, version information or metadata about metadata. The description with metadata creates a context that allows the unlocking of DOs in research and its reuse by humans and machines. In the context of energy system research, scientific results are generated in the form of data, simulation software or co-simulation, and scenario descriptions in addition to publications. Depending on the nature of the artefact, different metadata attributes are relevant to support the FAIRness of the DOs in research by using metadata.

Energy system research has become highly interdisciplinary, if not multidisciplinary in character. Responsible for this is the further development of simulations for the analysis of current or future energy systems, which combine models from various disciplines such as engineering, social sciences, physics, economics, meteorology, and geography. The dichotomy here resides in the challenge of identifying domain-specific relevant metadata and establishing a common metadata standard. Metadata standards establish a common understanding of which metadata elements are required to describe which DO. This improves the level of FAIRness and machine readability at the same time. Instead of defining a completely new metadata schema, in order to accommodate domain-specific elements and requirements, it is possible to combine modules or elements from existing schemas to an application profile. Using application profiles, domain-specific and domain-independent metadata elements can be combined into a single schema. The generic, domain-independent elements require interoperability with common standards such as DataCite[22], schema.org[23], CodeMeta[24], DCAT-AP[25], and Dublin Core[26] to be highly machine-readable; therefore, their elements must be derived into domain-specific metadata standards. To improve interoperability between different metadata schemas further, crosswalks can be used. A crosswalk defines a mapping of elements of one metadata schema to another. Although there are some domain-specific approaches to metadata schemas in energy system research, no common standard has yet emerged.

With the Open Energy Metadata (OEM[27]), the OEP provides a standardised human- and machine-readable metadata schema, developed specifically for energy research modelling, which can be used for publishing open data on the OEP. The OEM supports the detailed documentation

[22] https://datacite.org
[23] https://schema.org
[24] https://codemeta.github.io
[25] https://www.dcat-ap.de
[26] https://dublincore.org
[27] https://github.com/OpenEnergyPlatform/oemetadata

of data sources, data origin, data models, but also information on the quality level of the data. Furthermore, the OEM enables the description of assumptions on scenarios and the specification of multiple resources for the parametrisation of input parameters. The OEM derives in parts from the metadata specification of frictionless data[28], but is otherwise not based on any generic standards. The use of controlled vocabularies is limited to a few generic elements e.g. language (IETF BCP47[29]), dates and time (ISO 8601[30]) and licence (SPDX[31]) while the use of an energy ontology is not required. The OEM is complemented by the Open Energy Datamodel[32] (OED), which is a template data model data as Entity–relationship model ERM format to store energy and scenario data efficiently. The OED is available in two forms – the OED-concrete for user-friendly data input and the OED-normalised for efficient data storage in databases. Both metadata schemas suffer from a lack of interoperability due to the absence of links to more general metadata schemas. However, this is the prerequisite for a metadata schema to become a standard that is generally applied in energy system research and beyond. One goal is therefore to extend and modify these schemas.

nfdi4energy pursues the metadata strategy of reusing existing metadata standards and applying them to establish localised application profiles that are optimised for domain-specific elements. A further goal of the nfdi4energy is the application of the W3C[33] standards for semantic metadata where possible. Metadata becomes semantic metadata by linking metadata entities to the formal description of the corresponding concepts in an ontology. In addition, the nfdi4energy will interact with the hierarchical approach of NFDI4Ing - as already pointed out in Section 3.2. Besides, nfdi4energy acknowledges the importance of standardisation of common metadata elements and will support the corresponding work within the NFDI Section.

Ontologies in energy research

The Open Energy Ontology (OEO)[34] is a domain ontology tailored to energy system modelling and analysis [4]. The OEO aims not only to create a common vocabulary of the domain with a broad coverage, but also to integrate and link relevant terminologies from other domains such as geography, meteorology, economics, engineering or mathematics. Therefore, the OEO includes

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28 https://frictionlessdata.io
29 https://tools.ietf.org/rfc/bcp/bcp47.txt
30 https://www.iso.org/iso-8601-date-and-time-format.html
31 https://spdx.org/licenses
32 https://github.com/OpenEnergyPlatform/oedatamodel
33 https://www.w3.org
34 https://openenergy-platform.org/ontology/

concepts from other ontologies such as the Financial Industry Business Ontology (FIBO)[35], the Unit Ontology, the Relations Ontology, and the Information Artefact Ontology (IAO)[36]. Besides, the structuring of knowledge through the OEO is intended to improve the navigation in the domain. The OEO based on the „upper level" basic formal ontology (BFO) is developed in OWL2 and follows a modular approach [6]. The domain-specific modules of the OEO cover entities of models and data (oeo-model), social, economic and political entities (oeo-social) and entities characterising the physical part of energy systems (oeo-physical).

While the OEO focusses on energy models and scenarios, the Common Information Model (CIM) defines a domain ontology and a common vocabulary for aspects of the electric power system [7]. Developed by the electric power industry and adopted by the International Electrotechnical Commission (IEC), CIM today represents a series of standards (IEC 61968, IEC 61970, and IEC 62325) for data models in electrical networks. Thereby, CIM enables interoperability in the exchange of data between different systems of energy supply companies. However, CIM does not cover the entire energy system and lacks the definition of district heating or natural gas networks, which is necessary for example to describe sector coupling semantically. CIM is complemented by the Substation Configuration Language (SCL, IEC 61850), which is developed in parallel.

The EnArgus[37] ontology is used for the funding information system for energy research in Germany [8]. EnArgus is the only generally known terminological resource in this field and covers a large part of energy research with its semi-automatically derived terms. The ontology is yet not publicly available, and thus reuse of EnArgus is currently not possible. Also, the authors admitted that they followed less strict ontology engineering rules than the developers of the OEO.

The partners of nfdi4energy are involved in the development and implementation of several ontologies in the domain of energy system research. RLI is a developer and maintainer of the OEO and the metadata standards OEM and OED. KIT-IAI, FhFIT, and OFFIS have extensive experience in implementing solutions based on CIM and SCL, the LF Energy SOGNO project[38] is one example. RWTH developed SARGON[39] [9], the smart energy domain ontology, which extends the smart appliance reference ontology (SAREF [10]) to cover formalised knowledge of the building and electrical grid automation domains. The nfdi4energy partners will integrate their

[35] https://spec.edmcouncil.org/fibo/
[36] https://github.com/information- artifact- ontology/IAO/
[37] https://www.enargus.de/
[38] https://www.lfenergy.org/projects/sogno/
[39] https://git.rwth-aachen.de/acs/public/ontology/sargon

existing collaboration with the communities of the mentioned ontologies into the development of the nfdi4energy ontologies in order to develop relevant practical ontologies based on their needs.

Access to terminologies and ontologies is a prerequisite for the semantic integration of the nfdi4energy services (TA4). In addition, a powerful service for the collaborative development of the ontologies (M4.1, M4.2, M5.2) in nfdi4energy is needed, which also enables larger groups, such as the energy system research community, to participate in the development. With the terminology service (TS)[40], the TIB provides a repository for terminological resources that can be accessed via a unified API. The TS will be the central access point to terminologies for all services of nfdi4energy. To this end, the TS will be expanded and a community-specific service will be developed within nfdi4energy (Task 4.1.4). In addition, the TS provides a sophisticated platform with governance and versioning capabilities to manage the collaborative development and curation of ontologies. The nfdi4energy will also leverage the TS capabilities to make nfdi4energy metadata standards and ontologies freely available and thereby reusable.

4.3 Implementation of the FAIR principles and data quality assurance

In the context of research data, the FAIR principles, introduced in 2016, provide a guideline on how to make data more findable, accessible, interoperable, and reusable (FAIR) [11]. These principles can support best scientific practice. Since research software can partly be seen as research data, it is currently under scientific discussion how the FAIR principles can be mapped to research software [12]–[14]. Due to the importance of simulation in energy system research, as identified in Section 4.1, the scope of nfdi4energy is not limited to FAIR research data, but also includes applying the FAIR principles to research software with a special focus on simulation software artefacts.

While the FAIR principles are rather high-level concepts, nfdi4energy will provide hands-on examples how to provide different DO in research, like research data and software, aligned with these principles (TA1) based on additional services provided by nfdi4energy. The examples will include information on licensing and how to develop research data management plans in energy system research projects. By making this information and services available for the energy research community, it becomes easier for researcher to provide FAIR research data and software. To this end, nfdi4energy paves the way to a standardised best practices approach for FAIR research data and software in energy system research.

[40] https://service.tib.eu/ts4tib/index

The issue of **findability** is especially relevant for energy system research due to its interdisciplinary nature, which needs data and software from different domain and providers. To improve findability, nfdi4energy will provide a Persistent Identifier (PID)-service for FAIR Digital Objects (FDO) [15] including research data and research software. The metadata of the FDO will be registered within the registries of nfdi4energy, which are open and easy searchable. nfdi4energy focusses on only referencing research data and software, acknowledging the fact that research data and software are often already publicly provided in existing repositories. If publication is still needed, nfdi4energy will recommend certain services.

To improve **accessibility and interoperability**, nfdi4energy will further develop and standardise ontologies and terminologies for energy system research. These could be used to improve the quality of research data and software description, e.g. in their metadata. In this way, these metadata become readable for machines as well as for researcher from other domains, highly important in the interdisciplinary setting in energy system research. Therefore, research using this data and software becomes understandable and more transparent for a broader audience. Additionally, the search functionality of the registries will be improved by using semantic web technologies. In this way, the whole knowledge included in metadata of research data and software can be explored and used for searching and further tasks like comparing the different DO, recommending compatible software and data up to semi-automatic simulation creation (TA4, TA5).

nfdi4energy will also focus on **reusability**. Especially for simulation in energy system research, the reuse of research data and software is often necessary to allow reproducibility and to decrease development costs. Also, reusing existing research software and data reduces entrance barriers for young researchers. By standardised interfaces based on the defined terminologies, the reusability of software and data can be increased. Additionally, nfdi4energy will offer improved tools for coupling of simulations which support the reuse of research software as well (TA5).

Besides improving the FAIRness of data and software from researchers, nfdi4energy also concentrates on developing methods to improve the FAIRness of data from the industry and applied research. This data is often applied as input data for energy system research, but - as it is often partly confidential - new approaches for FAIRification supporting the needs of industrial partners are required (TA3).

In addition to researchers in science and industry, other citizens have to be informed and can also contribute data for research (e.g. within the field of citizen science). The motivation for this is twofold: On the one hand, data can be generated and delivered by this group, on the other hand, relevant research fields and specific acceptance questions can thus be supported in early phases of the research and transfer cycle. nfdi4energy wants to include and sensitise this user group for the FAIR criteria, as well.

With regards to data quality standards, no standards have evolved so far in energy system research. The quality of research data and software is highly complex, due to the variety of data used in energy system research like shown in Section 4.1. nfdi4energy aims to develop standards and guidelines to improve data quality. The consortium implements measures to include the whole research community in the process to integrate different perspectives and to achieve acceptance for the new data quality standards (TA1).

Overall, nfdi4energy will support the energy system research community to make research data and software FAIR and, therefore, easier to find, access, interoperate, and reuse.

4.4 Services provided by the consortium

Based on the research and transfer cycle, presented in Section 2.1, we identified five key services, which must be addressed to support researchers in energy system research and provide a non-discriminatory access to research data, software, best practices as well as other relevant information within the research and transfer process: (1) *Competence* to help to navigate the interdisciplinary research field, (2) *Best Practices* to get information on successful conduct of research in the field of energy systems and their research data management, (3) *Registry* to find suitable data sets and software modules, (4) *Simulation* to couple existing simulations and, therefore, increase the reuse of software artefacts, and (5) *Transparency* to involve more stakeholders in all research stages, especially integrating their data, and to convey the appropriate key research results to all relevant stakeholders. In Figure 4, we show how these five key services can be aligned with the research and transfer cycle. In the following, we give a more detailed overview of these services, which will be the focus of nfdi4energy:

- ***Competence*:** Building on the platform EnArgus[41], which gives an extensive overview on over 30,000 energy research projects, a database of scientific institutes, scientists, and relevant industrial partners will be created as part of TA1. It will be used as a foundation and reference point for metadata of the different DOs in the other services. The database will be searchable and can also help to identify the right research and transfer partners like scientists and companies for upcoming research projects.

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

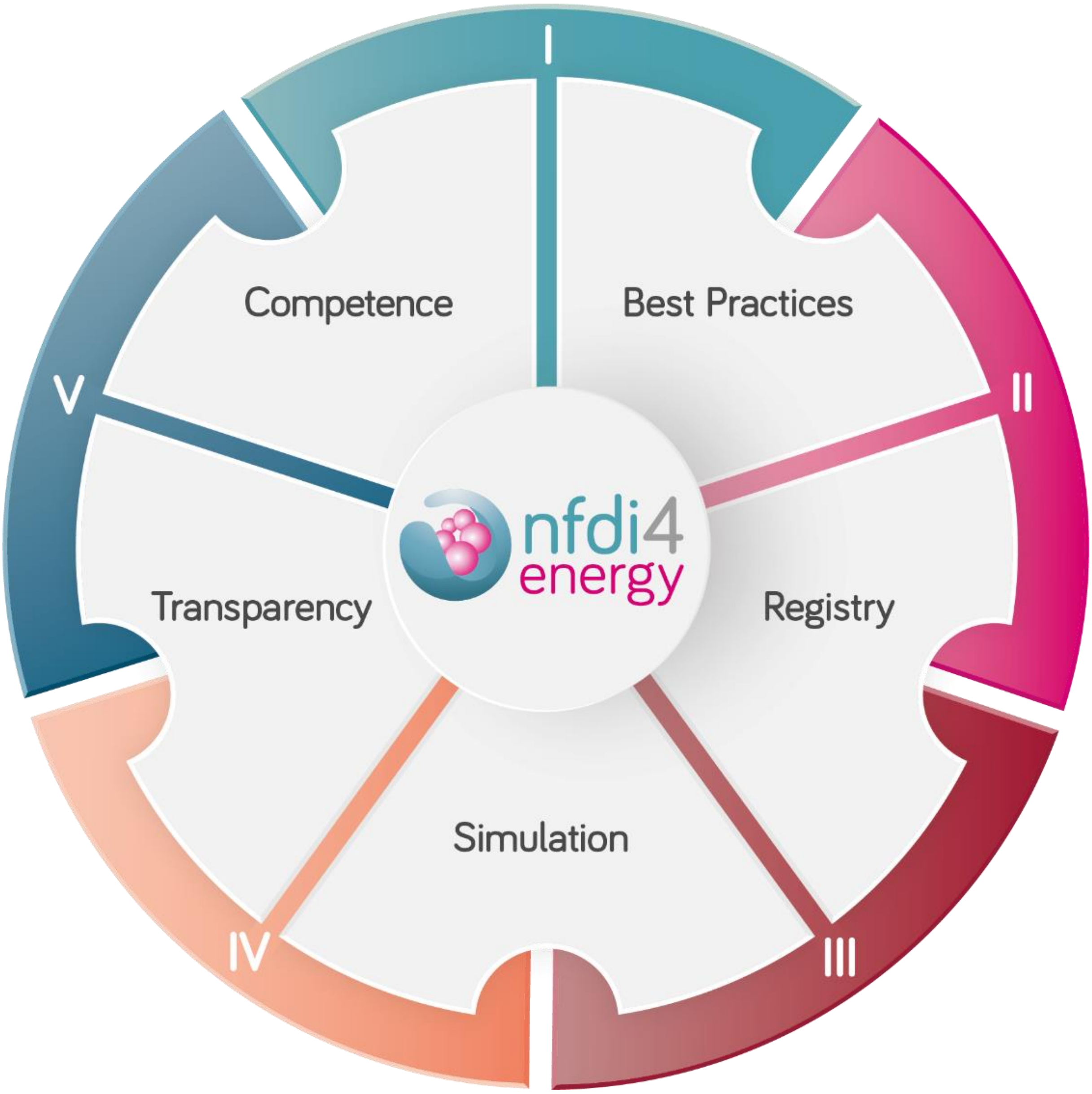

Figure 4 CPES research and transfer cycle supported by the nfdi4energy key services

- ***Best Practices*****:** This key service will provide an overview of good practices of research data management and usage in research projects, list training courses, e.g. on software engineering for non-computer scientists, and give guidelines for using the other services of nfdi4energy. Successful examples of cross-institutional research data management provide a low-threshold offer, which is complemented by mapping community standards collected through surveys and information to support the establishment of the FAIR standards through domain-specific guidelines and recommendations, e.g. on licensing. The development of the material will be part of TA1 and will be supported by the use cases in TA6. Besides textual description, the Best Practices Service is enriched with audio-visual material, hosted by the TIB AV-Portal[42], which offers a whole range of services including automatic video analysis, Digital Object Identifier[43] (DOI) allocation, video recording, and long-term archiving. We will also include and extend existing tutorials of the OEP[44], and provide an integrated access for the research community based on the developed nfdi4energy platform.

- ***Registry*****:** A registry for metadata for DOs like research data and software, based on existing approaches like the OEP, is developed based on an intense requirement engineering and involvement process for the community (TA4, TA5, requirements: TA1). *Registry* supports the creation and continuous integration of appropriate metadata based on standards and controlled vocabularies like the OEO (partly developed by the RLI), SARGON, and other relevant standards, as introduced in Section 4.2. The *Registry* service will be based on existing general services like the **PID-Services** of the TIB[45], DataCite, DOI, ORCID, and the TS of TIB. Access restrictions for data and software will be considered. The *Registry* service supports researchers in finding the right input data, existing models, and scenarios. We will include existing datasets from all co-applicants into our registry and integrate the whole community. For storing data, the *Registry* service will recommend existing repositories like the OED, which is a community developed and hosted PostgreSQL database for open energy system research with a RESTful API specifically designed for storing high temporal resolution data.

- ***Simulation*****:** The *Simulation* service provides Simulation-as-a-Service (SaaS) capabilities on the platform as well as support for "on premise" distributed (co)-simulation and hardware-in-the-loop simulation facilitated by community-driven harmonisation of simulation interface standards (TA5). The creation and use of simulations by non-computer scientists are key goals, e.g. for the Citizen Science aspects of the nfdi4energy project but also for supporting multi domain models for experts from various energy domains. Distributed simulations, enabling the combination of different domains, abstraction layers, and increased performance, have to be supported by an improved simulation middleware [16]. We build on existing co-simulation tools for close or tight simulation coupling like mosaik[46] [17] and interface exchange standards like the functional mockup interface (FMI)[47]. In order to achieve loose coupling and facilitating

[42] https://av.tib.eu/
[43] https://projects.tib.eu/pid-service/persistent-identifiers/digital-object-identifiers-dois/
[44] https://openenergy-platform.org/tutorials/
[45] https://projects.tib.eu/pid-service/
[46] https://mosaik.offis.de
[47] https://github.com/modelica/fmi-standard/releases/tag/v2.0.2

even larger scenarios, we will adapt existing approaches from the mobility domain [18]. For hardware-in-the-loop simulation, we will incorporate the VILLAS framework[48], which enables the coupling of different laboratories for hardware-in-the-loop simulation. Furthermore, we will follow an ontology-based approach for including necessary semantic knowledge from the *Registry* service to assist in simulation creation and validation, heavily relying on our own related work from Schwarz and Lehnhoff [19]. While favouring an open source ecosystem, the *Simulation* service also supports the integration of non-open datasets and non-open source software to support intellectual property (IP) exploitation.

- ***Transparency*:** The *Transparency* service supports the comparability of scenarios, reflects social and societal aspects and needs and integrates components from Citizen Science. Thus, this service plays an important role for the identification of new research questions and societal challenges occurring in energy system research and transformation. In science, results are regularly published in scientific journals as well as on academic conferences. While these options mainly reach other scientists, in the context of the energy systems' transition, it is important to convey new information to the general public (TA2) as well as into businesses (TA3), from both ongoing and finished research projects. Therefore, the *Transparency* service will be used within the whole research and transfer cycle and is the place to present simulation plans and discuss them with the society, industry, and scientific community.

All five key services will include persistent identification, licensing, and provenance and will enable semantic integration to fulfil the FAIR criteria. Within nfdi4energy, we combine these five key services into one platform, which enables linking the services and simplifies their use for the energy system research community. We build on existing infrastructure and include and combine knowledge from the research domain of energy systems and knowledge on basic research infrastructure (TIB).

[48] https://www.fein-aachen.org/projects/villas-framework/

5 Work Programme

The work programme of nfdi4energy includes seven Task Areas (TAs) as displayed in Figure 5 and listed in Table 5.0. The first three TAs address different stakeholders in energy system research: The research community (TA1), public & society (TA2), and the industry (TA3). Especially, including the society into energy research data remains an open methodological question and is therefore especially addressed in TA2. TA4 focuses on FAIR research data, needed e.g. within simulations, which are in the centre of TA5. To determine more requirements and to evaluate the community services in TAs 1 to 5, we define three standard use cases of energy system research. These use cases are examples of three general types of energy system research projects, which should be supported by the developed community services in TAs 1 to 5. Finally, TA7 covers the overall organisation, realising the operation as defined in Section 3.4, as well as the engagement with the NFDI community.

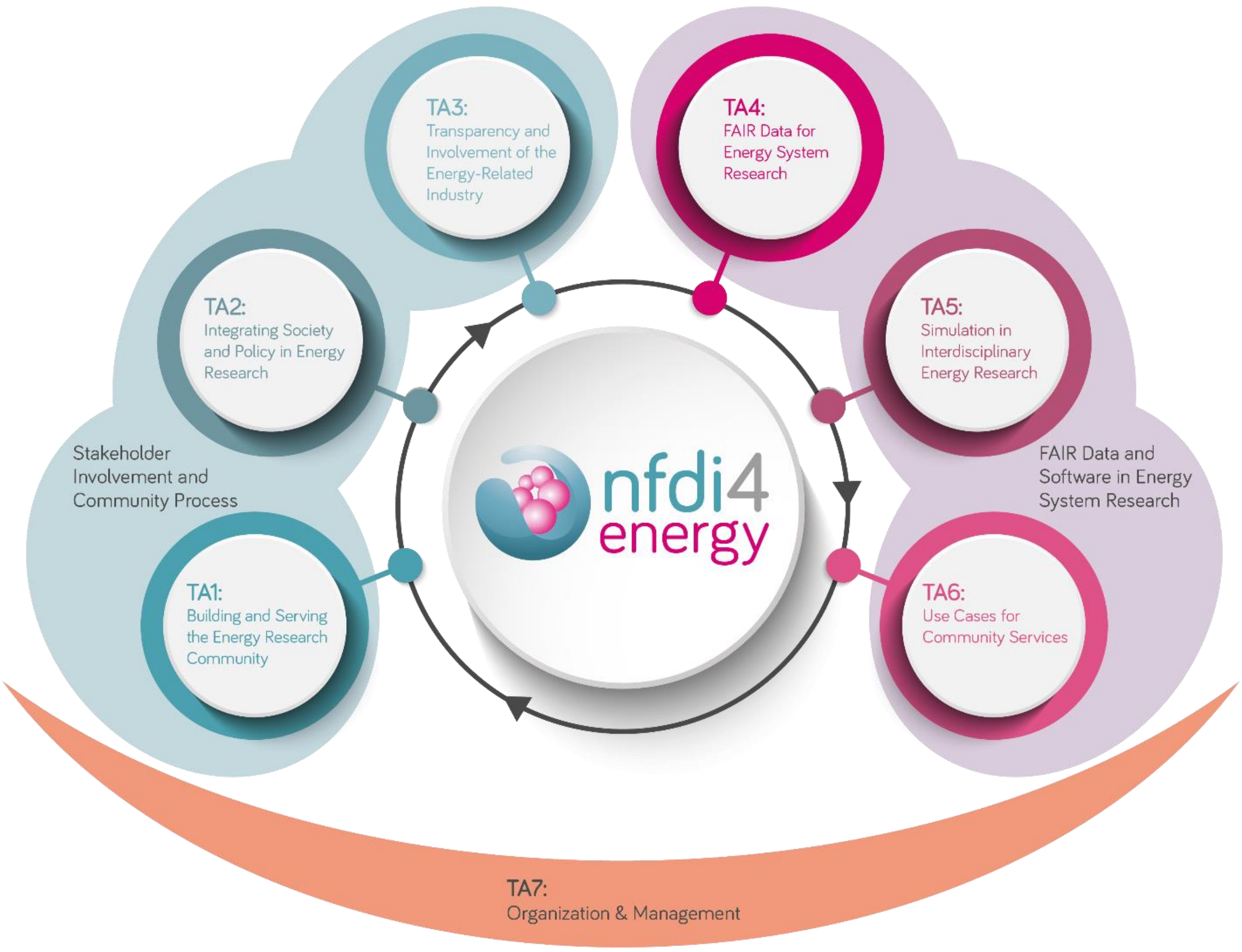

Figure 5 Overview of Task Areas

Table 5.0: Overview of Task Areas

Task Area	Measures	Responsible Co-spokesperson(s)
TA1: Building and Serving the Energy Research Community	M1.1 - M1.4	Prof. Nieße
TA2: Integrating Society and Policy in Energy Research	M2.1 - M2.6	Prof. Weinhardt
TA3: Transparency and Involvement of the Energy-Related Industry	M3.1 - M3.3	Prof. Monti
TA4: FAIR Data for Energy System Research	M4.1 - M4.5	Prof. Lehnhoff
TA5: Simulation in Interdisciplinary Energy Research	M5.1 - M5.4	Prof. German
TA6: Use Cases for Community Services	M6.1 - M6.3	Prof. Weidlich
TA7: Organisation & Management	M7.1 - M7.5	Prof. Nieße

As a large-scale project within an open research community, nfdi4energy bears some risks, some of them specific for the addressed research community domain, others general within large consortia with a long project duration. As a special risk, nfdi4energy aims at realising community services that endure the project funding phase. In Table 5.1, we will pinpoint these risks and discuss mitigation strategies. It will be within the duties of the Project Office (PO) to assess the probability of entry for these risks and to inform the Steering Committee (SC), if additional mitigation measures have to be taken.

Table 5.1: Overview of risks

TA	Risk	Effect	Mitigation Strategy
TA1	Benefits of developed services are not seen or understood.	No involvement of research community in the usage of the developed services.	To avoid a lacking support and interest of the energy system research community, a detailed requirements analysis will be performed. Community workshops will support the promotion of the provided services.
TA2	No incentive for citizens to participate in the development of	Involvement of citizens in the development of the community	In social science, two approaches are state of the art to mitigate this risk: First, gamification is an established means to establish involvement with citizens. Second, active participation, e.g.

	the community services.	services does not work.	in surveys, can be incentivised. We follow both approaches to minimise this risk from the beginning.
TA3	No acceptance of FAIRification principles within the energy-related industry.	FAIRification process would not be tailored to the specific needs of the industrial partners relevant in the addressed research context.	An Industrial Advisory Board (IAB) is set up to address the relevant needs of industry partners within the addressed research & transfer context. Landmark decisions are discussed with the IAB before realisation. Regular meetings with the IAB reflecting and discussing the current work progress will be set up.
TA1, TA2, TA3	Community and public requirements are not reflected.	Community services do not fulfil the stakeholders' needs.	We follow an intense requirement-driven process in the first phase of the project to identify the most relevant needs. In the course of the project, the Scientific Advisory Board (SAB) will be asked to discuss and reflect the findings from the requirements analysis and the fundamental decisions derived from this.
TA4	Ontology integration of open and restricted access ontologies does not work.	No integrated ontology addresses all relevant use cases including industry applications.	The main risk with regard to this aspect is that industry partners (have to) rely on standards typically grounded in International or at least European standardisation committees (e.g. based on IEEE standards). Some of these are already based on ontologies or realised ontologies, thus simplifying the integration. nfdi4energy will focus on those standards in the first place that already support this concept.
TA5	Parallelisation effort in simulation using publish-subscribe patterns is not	The *Simulation* services are not accepted and used by the energy system research community.	To alleviate the understanding of the chosen parallel simulation concept, tutorials are developed and published within the service of *Best Practices*. Reference scenarios will be published that allow an easy adaptation of ready-to-run simulations, thus reducing the effort of understanding the methodological

	understood by the community.		background of the simulation technology in detail.
TA6	Exemplary research questions require more effort.	Requirements for the community services cannot be derived as intended.	The use cases are setup with minimal funding based on background and side ground from the involved partners (see Section 6). Therefore, the risk can be reduced by supporting the general idea of methodology-pushing tasks with other research projects. The SC will discuss this aspect on a regular base to reduce this risk by adapting the use cases on time, if needed.
TA7	Missing interaction with other nfdi-activities, especially base consortia	No synergetic effects can be seen, realisation of domain-independent methods as services has to be realised within nfdi4energy as well.	The NFDI association play an important role in the mitigation of this risk, as the association should ensure synergetic effects, harmonise activities and support consortia to develop community services that can be adopted for long term community service. As a consortium, nfdi4energy will actively promote and look for synergetic potential within the context of domain-independent services. Infrastructure provision is a domain-independent task, thus we are fully aware of the importance of interacting with other consortia - additionally to TIB - to realise the long-term provision of our services.

5.1 TA1: Building and Serving the Energy Research Community

Lead: UOL

Measure Leads: KIT-IISM, SOFI, UOL

Description and Objectives

Energy system research has become more and more reliant on modelling and simulation approaches. These endeavours are enabled by continuously improving tools and methods for developing, maintaining and sharing of DO in research, namely models and data. Knowledge on how to better conduct, share and archive one's research has become increasingly complex and hard to manage for individual researchers or single research groups. However, there exists a plethora of best practices, guidelines on how to prepare data, models and results in ways that make them easier to discover, verify and build upon. Within this TA, the nfdi4energy platform is set up, which will include all key services as introduced in Section 4.4. As a first service, *Best Practices* should curate and present the current best practices from the energy system research community. As a second service, *Competence* will guide young researchers within the research community. For this TA, we follow a requirements-driven process that takes the envisioned users - scientist, industry and society - into focus in the design process of the platform [5].

Task Area 1 targets the following objectives:

- [O1.1] Collect and update platform requirements by the energy modelling and simulation communities
- [O1.2] Create a platform for sharing best practices, community guidelines and access points to the community services
- [O1.3] Continuously monitor, adapt and improve offerings according to community feedback
- [O1.4] Develop guidelines, materials and tutorials for best practice in energy system research

Measure 1.1 Community requirements and needs

Lead: SOFI

Contributions: FAU, KIT-IISM, RLI, UOL

Goals: Identify needs of the energy system research community

Description: To develop a platform which is going to be used frequently and beneficially, it is crucial to asses profoundly what the specific needs of the research community are [5]. Every profession in the field of energy system research requires data, but which data exactly is useful and needed? Since energy system research itself is an interdisciplinary community, it is even more necessary not to set fixed assumptions in the beginning about the requirements and needs of the community. Instead, our aim is to identify requirements that would facilitate the work of all researchers depending on their expertise, i.e. simulator development experts, scenario experts, data analytics experts and so on. The contact to the community is ensured via the consortiums profound integration into the national and international energy system research community (see Section 3.1 and Section 3.3) as well as via SOFI's integration into the EFZN as well as close cooperation with the contributors of this measure.

Year	Milestone
1	[MS1.1.1] Single and group interviews with at least 20 energy system researchers completed
2	[MS1.1.2] Qualitative empirical analysis of community requirements and needs performed
	[MS1.1.3] Platform requirements analysis report circulated with consortium

Task 1.1.1 Develop an interview guide

Description: Development of an interview guideline in close consultation with experts of the consortium.

Deliverable: [D1.1.1.1] Interview guideline (document)

Task 1.1.2 Distribute a call for participation

Description: All partners are asked to share a call for participation in their disciplinary networks. Moreover, we are going to use the EFZN network to address different disciplinary groups within the community.

Deliverable: [D1.1.2.1] Anonymised interview participation schedules

Task 1.1.3 Conduct single and group interviews with energy system researchers

Description: In this task, we organise and conduct (group)interviews with at least 20 energy system researches, covering a vast disciplinary diversity. We plan and calculate 3 group interviews and 5 single interviews.

Deliverable: [D1.1.3.1] Interview protocols (for internal use)

Task 1.1.4 Analyse expectations, requirements and needs

Description: Based on the transcribed and anonymised interview protocols we analyse the community's expectations, requirements and needs. We will present our results in an analysis

report which is going to be circulated in the whole consortium and will be discussed especially in TA1.
Deliverable: [D1.1.4.1] Platform requirements analysis report

Measure 1.2 Synergies and incentives
Lead: KIT-IISM
Contributions: RLI, SOFI, UOL
Goals: Monitor usage and assure organic growth of the developed platform and its services
Description: In order to guarantee organic growth of the platform beyond the project duration, it is essential to design the platform along the needs of the community as well as to establish feedback and quality assurance measures during the project duration. Once the platform is online, it is important to grow it to a critical mass of users to ensure its long-term usefulness to the energy community. To reach this critical mass, feedback of the (first) users will be necessary to analyse what the needs of the community are, regarding platform usage and guidelines for data and model sharing on the platform. During the project lifetime, various feedback and quality assurance mechanisms will be tested in this TA. Based on the feedback, the platform will be improved continuously according to the needs of the community.

Year	Milestone
2	[MS1.2.1] Monitoring of platforms' usage is active
3	[MS1.2.2] A set of feedback mechanisms is identified and implemented
4	[MS1.2.3] Evaluation of the implemented feedback mechanisms is finished
5	[MS1.2.4] Long-term feedback and incentive mechanisms are established

Task 1.2.1 Identify best practices from existing platforms
Description: In the area of e-participation and citizen science, there are various (research) platforms[49] that have successfully grown and enabled a meaningful interaction amongst their users. With a structured review of their strengths and weaknesses, best practices for user incentivisation and user feedback will be identified. In this task, the KIT-IISM can also draw from their expertise on platform requirements and research on user behaviour on platforms.
Deliverables:
[D1.2.1.1] List of incentive and feedback mechanisms (document)
[D1.2.1.2] Rating of mechanisms for application to platform (table)

[49] https://www.adhocracy.plus, https://www.buergerschaffenwissen.de

Task 1.2.2 Monitor the platform's usage

Description: To understand how users interact with the platform, the platform's usage first needs to be monitored and analysed. To this end, usage statistics will be tracked and evaluated throughout the project lifetime.

Deliverables:

[D1.2.2.1] Implemented monitoring of the platform's usage, including quantitative and qualitative criteria

[D1.2.2.2] Written and visual evaluation of collected data

Task 1.2.3 Develop feedback and incentive mechanisms during platform usage

Description: To ensure that the platform meets the needs of the community in the long term, feedback mechanisms will be developed based on the quantitative and qualitative surveys in Tasks 1.2.1 and Task 1.2.2. Mechanisms to obtain active feedback from the community will be implemented to enable a continuous improvement and development of the platform mechanisms along the needs of the community. Feedback mechanisms on shared datasets and energy system models will ensure that new content on the platform meets the quality requirements of the community. In addition, gamified elements, such as reward badges for uploading data will be implemented to incentivise contributions to the platform's growth.

Deliverable: [D1.2.3.1] Mockups and prototypes for identified incentivisation mechanisms

Task 1.2.4 Evaluate mechanisms and improve long-term usability

Description: The implemented mechanisms for feedback and incentivisation will be continuously evaluated during the project lifetime. Based on the quantitative surveys from Task 1.2.2 as well as qualitative data from surveys and expert interviews with platform users from the community we will compare the mechanisms developed in Task 1.2.3. An important criterion for the evaluation of feedback and incentive mechanisms is that they enable a sustainable growth and usage of the platform beyond the project lifetime.

Deliverables:

[D1.2.4.1] Survey and expert interviews (documentation)

[D1.2.4.2] Finalised rating of mechanisms for long-term suitability

Measure 1.3 Platform development

Lead: UOL

Contributions: KIT-IISM, RLI, SOFI

Goals: Develop an energy system research platform that integrates *Competence* and *Best Practices* and serves as an access point for all offered community services of nfdi4energy

Description: To enable a swift launch of a first version of the envisioned platform, a minimal version is prioritised to be developed during the first project year. It enables tighter collaboration with the other TAs by providing a common visible artefact on which newly developed results can be published to the community. On that basis, ongoing feature development begins, based on the finer requirements and community needs provided by the accompanying measures. Besides providing the general infrastructure for the platform, this measure includes the development of the key service *Competence*, based on enArgus[50], and the base for the key service *Best Practices*. The development of the platform is closely interlinked with the work of M1.2 to ensure the long-term success of the platform. Additionally, a quality process is developed to ensure high quality of the DOs presented on the platform.

Year	Milestone
1	[MS1.3.1] Initial version of platform launched
2-5	[MS1.3.2-5] Incremental upgraded platform versions deployed
3	[MS1.3.6] Evaluation workshop conducted

Task 1.3.1 Develop initial platform

Description: Develop a minimum-viable version of the core features to enable a timely launch of the platform. This includes design and usability mockups developed for fast feedback from key stakeholders identified within Task 1.1.3.

Deliverables:

[D1.3.1.1] Minimum-viable feature set (design document)

[D1.3.1.2] First draft of system architecture (software documentation)

Task 1.3.2 Iteratively develop additional features

Description: Incrementally add different features to the platform, prioritised by community feedback that was gathered in Task 1.1.3 and Task 1.1.4. These features could include centralised and programmatic access to services provided by TA4 and TA5; streamlined guidelines for common research workflows and customised portals to guide users to them. Also,

50 https://www.enargus.de/

the key services *Competence* and *Best Practices* as introduced in Section 4.4 will be developed and integrated in the platform.

Deliverables:

[D1.3.2.1] Change log of released platform changes (software documentation)

[D1.3.2.2] List of curated community content (changelog)

Task 1.3.3 Conduct platform evaluation workshop

Description: To gauge acceptance and usage in addition to the continuous feedback from Task 1.2.2, a concerted evaluation workshop is to be conducted mid-project to steer the development for the second project half. The workshop builds upon the community requirements gathered by M1.1, but includes the information direct evaluation and feedback loop in M1.2.

Deliverables:

[D1.3.3.1] Evaluation report (report)

[D1.3.3.2] Follow-up documentation (planning)

Task 1.3.4 Develop a quality assurance process

Description: To ensure the long-term success of the platform, content submissions from the community must be reviewed and cleared for publication on the platform. While there exist proven moderation and peer review processes in both the scientific and open source communities, a suitable realisation must be selected and implemented for this platform within the energy system research community.

Deliverables:

[D1.3.4.1] Quality assurance process description (documentation)

[D1.3.4.2] Implemented process in platform (software)

Measure 1.4 Energy system research best practices

Lead: UOL

Contributions: RLI

Goals: Curate and contribute tutorials and best practices for energy system research

Description: Shared energy models and data ought to fulfil multiple prerequisites to ensure their usefulness and subsequent use; mostly legal and content-related nature. Open science principles in research as well as the FAIR principles advocate for transparency and accessibility of methods, data and results but lack clear definition and proceedings. In recent years, best practices and effective means of open research publishing developed, covering legal aspects and techniques of information exchange. The FAIRification process especially has emerged as the common path to increase the accessibility of data and metadata within a given research community. The goal of M1.4 is to serve the needs of the energy system research community for established and well-working methods of open science and FAIRness in energy research. Based on the general recommendations for Open Science and FAIRness, nfdi4energy will provide hands-on examples how to provide DOs, like research data and software, aligned with these principles. Tutorial material and best practices reports will be developed to achieve this. Both should be conceived as a mix of descriptive and instructional content and presented in interactive formats if applicable. FAIRification of energy system research data, both from science and industry, will be reflected in TA4 and integrated in this measure as well.

Year	Milestone
1	[MS1.4.1] Tutorial topics identified
3-5	[MS1.4.2-4] Tutorials and best practices reports produced
	[MS1.4.5-7] Tutorials and best practices deployed within the *Best Practices* service

Task 1.4.1 Identify tutorial topics

Description: After surveying the energy community, tutorial topics are identified, clustered and prioritised. A collection of tutorial topics is made and already existing teaching material of the consortium identified. A list of tutorial topics that one would like to have in a complete collection and already existing tutorial topics is made. Within this area, the defined use case in TA6 help in identifying the most pressing needs, thus supporting the results from the requirements analysis (M1.1).

Deliverable: [D1.4.1.1] Prioritised tutorial topics including responsibilities and timeline (document)

Task 1.4.2 Produce tutorials and best practices

Description: An appropriate format per tutorial topic has been chosen and highest prioritised tutorials are produced. A balance should be sought between "instructional" and "teaching" content to ensure sufficient knowledge transfer. Tutorials and best practices could be descriptive text, Jupyter notebooks, videos or workshops.

Deliverable: [D1.4.2.1] Tutorials/best practices reports

Task 1.4.3 Deploy tutorials for the *Best Practices* service

Description: The tutorials are deployed within the *Best Practices* service. This includes coordination processes within the project to gather feedback, provide incentives and monitor usage by the community.

Deliverable: [D1.4.3.1] Published tutorial contents within the *Best Practices* service

5.2 TA2: Integrating Society and Policy in Energy Research

Lead: KIT-IISM

Measure Leads: ALU, IASS, KIT-IISM, SOFI

Description and Objectives

Energy has become one of the major social challenges and causes for societal conflict in the last five years [20]–[22]. The energy transition requires a huge transformation of society and the accustomed way of life. Therefore, research projects addressing this process need to incorporate strategies to engage and communicate with the public. As a consequence, the same holds true for a scientific research data service that - among other goals - is intended to provide guidelines on good research practices for academics in the energy domain. Therefore, an energy system research data service should provide the possibility for non-professionals to become informed and it should communicate scientific results in a way that allows for a universal understanding. Furthermore, citizens' preferences should also be considered as part of this data. In this regard, it is of the essence to ensure that the target group is as broad as possible so that information on the energy transition is not reserved to an engaged minority or small elite, which might either support or oppose the energy transition. This requires research projects to develop a strategy for the corresponding communication for which guidelines are currently not available. Additionally, no infrastructure is given that would allow researchers to publish and discuss appropriate guidelines with this regard.

Today, energy system models are becoming increasingly powerful and detailed regarding techno-economic parameters, but they rarely include social and political factors, even though we know that these factors are strong determinants for the optimal design of energy systems. For example, the most detailed power system modelling is irrelevant if public opposition makes it impossible to construct wind farms or power lines. Availability and accessibility of robust data on social and political factors are essential elements for policy-relevant energy modelling, but presently such data is scarce. In addition, the decentralised character of the energy transformation makes the local level and its specifics an important factor. Hence integrating qualitative and quantitative data of the decentralised energy transformation (including aspects of acceptance) constitutes an imperative for effective system modelling. We will draw on the findings of the project Sustainable Energy Transition Laboratory (SENTINEL) (EU Horizon 2020 project co-led by IASS) which established a great knowledge base for better understanding the needs and expectations in energy modelling.

In this TA, we explore best practices for incorporating social and political drivers and constraints of the energy transition in the research and transfer cycle of energy system research. Therefore, we generate and link relevant data, and prepare it for incorporation into the developed community services and data infrastructure. The aim of this TA is further to co-design the nfdi4energy platform and key services, which will feed into new or existing energy models to help inform the public and political decision makers to determine socially acceptable energy pathways of the future. In addition, we will involve citizens during the project lifetime in the development of the platform that enables and incentivises the active participation of public stakeholders in energy system research.

Task Area 2 targets the following objectives:

- [O2.1] Identify public stakeholders, learn from local conditions and involve citizens in the service development process
- [O2.2] Collect regulatory data and identify political preferences and logics to feed into the service development
- [O2.3] Explore public acceptance as well as social trends and link them to political preferences and regulatory frameworks
- [O2.4] Examine the status quo of incorporating societal and political factors into energy system models and develop guidelines and data sources for future energy research
- [O2.5] Enable active participation of citizens in energy system research based on the developed services
- [O2.6] Communicate data and model results to different audiences from society and policy using developed best practices

Measure 2.1 Learning from local conditions: conflicts, citizens preferences and implementation projects

Lead: SOFI

Contributions: ALU, IASS, KIT-IISM

Goals: Identify local social drivers and constraints for the energy transition

Description: The energy transition is of major interest to many citizens. Energy modelling and the respective energy data service should therefore provide the possibility for becoming a source of information also for non-professionals and hence ensure that scientific results are communicated in a way that allows for a universal understanding. Indeed, studies emphasise mismatches between the needs of modellers and users, especially in the modelling of social, behavioural and political aspects, the trade-off between model complexity and understandability, and the ways that model results should be communicated [23], [24]. It has been suggested that a better understanding of user needs and cooperation between modellers and a broader public is necessary to truly improve models and unlock their full potential to support the transition towards climate neutrality in Europe. The challenge addressed within this measure is to identify those stakeholders who later on have to be reflected as users of the nfdi4energy platform.

Year	Milestone
1-3	[MS2.1.1] Data collection in three Case Studies (including Use Case 6.3)
3	[MS2.1.3] Testing and evaluation of visualisation in focus groups and workshops (in cooperation with M2.6)
4	[MS2.1.4] Testing and evaluation of gamification elements in focus groups and workshops (in cooperation with M2.5)
	[MS2.1.5] Three case study reports
2-5	[MS2.1.6] Coordination of project reference groups / feedback loops / workshops

Task 2.1.1 Identify relevant stakeholders (local and general)

Description: In a first step, we identify all relevant stakeholders for whom the platform and its outputs might be interesting and useful. We differentiate between local (from the case studies Task 2.1.2) and general stakeholders such as local political decision-makers, local and general public, energy companies, businesses and many more. Regarding the latter two, we will cooperate with TA3.

Deliverable: [D2.1.1.1] List and graphic overview on relevant stakeholders

Task 2.1.2 Identify three relevant and appropriate case studies

Description: Due to the decentralised character of the energy transformation, the local level and its specifics are highly important for successful implementation [25], [26]. Thus, regarding the envisioned research data services, we aim to integrate on the one hand existing knowledge gained via qualitative case studies on local conflicts in the context of energy transition and prosumer projects. On the other hand, to achieve high compatibility with the specific platform requirements, we plan to gather own data in three selected very diverging case studies (most-different-case design). One case will be connected to Use Case 6.3, the other two will be identified at the start of the project considering the local energy transition context at that time.

Deliverable: [D2.1.2.1] Short description of three case study regions or projects.

Task 2.1.3 Conduct qualitative research (field work, interviews, focus groups, and workshops)

Description: We understand that citizens should not only be informed but their preferences should also be considered as part of data platform design and energy modelling activities. Integrating the views, needs and understanding of non-experts (citizens science) will help to assess the boundaries of system modelling and to further work on possible additions to system models that can closely represent public preferences. This will be evaluated with affected citizens and actors in our reference case studies. In this measure, we will apply a transdisciplinary approach and conduct a multi-stakeholder process to foster reciprocal learning and receive input for the nfdi4energy platform. The aim of this measure is to enable an exchange between academics and non-academics through co-creation process, dynamics of stakeholder interactions and the integration of different forms of knowledge in order to improve modelling outputs, communication and public engagement with energy models. By getting insights into the attitudes, perceptions and wishes regarding energy as a common good in social communities, we can integrate social aspects into the platform which are scarcely available via survey data. By this means, we will be able to take the first step in closing the gap between energy system research data modelling by digitalisation experts and energy system experts and social science experts.

Deliverables:

[D2.1.3.1] Transcribed Interview Protocols (intern).

[D2.1.3.2] Transcribed Focus Group protocols and workshop sessions (intern).

[D2.1.3.3] Report on case study analysis

Task 2.1.4 Coordinate project reference group, communication channels

Description: Moreover, by means of the local case studies, we have a reference group with which we plan to stay in close contact during the project time span. In the focus groups and workshops in the case studies, we will use and evaluate communication advices developed in M2.6. This includes tools of gamification and interactive visualisation (Task 2.6.3).

Deliverable: [D2.1.4.1] Joint report on experiences and attitudes towards communication advices with Task 2.6.3.

Task 2.1.5 Manage and obtain regular feedback and input

Description: The feedback and input of the reference groups will continuously feed and guide the data service design and outputs are closely linked with M2.4.

Deliverables:

[D2.1.5.1] Workshop with M2.2 and M2.4.

[D2.1.5.2] Workshop outputs

Measure 2.2 Energy policy regulation, political preferences and logics

Lead: IASS

Contributions: SOFI

Goals: Identify relevant regulatory data for the energy sector and explore different policy logics applied to technological change

Description: Regulation and policy are key determinates of the energy transition. Energy assets, both generation and transportation, are subject to regulations of where which types of assets can and cannot be built, and of which assets can be built or operated by whom under which conditions. Further, without dedicated policy action there would have been no energy transition at all. New technologies are often supported by policy measures, such as subsidies or price regulations, which strongly determine their uptake in the system. Infrastructure is generally very tightly regulated, especially within natural monopolies such as power and gas transmission. Regulations are generally national, adding an additional complication for modelling European energy systems.

However, regulations are typically not adequately, or at all, included in energy models [27]. Optimisation models tend to not include policy drivers at all, beyond a carbon price as a proxy for all energy and climate policy measures: Even simulation models and agent-based models, although they seek to describe actor behaviour, tend to consider policy in rather rudimentary terms, such as assuming rational actors seeking to maximise economic utility. Hence, models may generate irrelevant futures, for example by not considering adequate buffer zones for wind power, by not acknowledging policy preferences for (or against) specific technologies, or by modelling solutions that are not permitted by current regulation (such as pure transit power lines, interconnecting two countries through a third). These regulations thus determine the feasible option space for the future, and models must consider them, generally as constraints, to generate relevant scenarios.

To this end, this measure serves to identify the relevant data from energy policy regulations and political preferences that have to be reflected in setting up both metadata schema as well as ontologies, thus feeding into TA4.

This measure consists of two parts. Firstly, we identify the relevant regulatory data, for Germany and other European countries. The aim of this is first to make the relevant data available for modelling and other policy analysis and, second, to publish time series for regulatory data on the new platform and allow for deeper analysis of what drives regulation and endogenisation of regulations into models. For example, we will draw on data from repositories such as RES LEGAL

Europe project[51]. While this website is about to shut down after the end of the project, we seek to further develop the content and ensuring that the data will be continuously accessible. Secondly, we identify the different policy logics applied by governments and political parties in Germany and other European countries – what do they want to achieve in energy and climate policy, and how do they want to do that applying a joint qualitative and quantitative approach. We will survey political decision makers and conduct focus groups about political logics and their impacts. We will then discuss these findings with our experts in FAIR research data to include this knowledge into the services to be developed in TA4.

Year	Milestone
2	[MS2.2.1] Data collection: qualitative and quantitative data on landscape and environment related regulations collected in exemplary data sets
2	[MS2.2.2] Data collection: qualitative and quantitative data of economic regulations collected in exemplary data sets
3-4	[MS2.2.3] Data of political preferences and logics linked and compared to technological change and public acceptance (M2.1 and M2.3)
4-5	[MS2.2.4] Data set prepared for meta-standard development (M4.3) and internalisation into platform, and policy analysis

Task 2.2.1 Survey environment-related regulations: where can we build what?

Description: Energy production, consumption and transport have substantial environmental effects, and hence all countries regulate which types of energy assets can be built in which locations. In many cases, for example for combustion assets and wind power, there are minimum setback distances between new units and existing or planned buildings; often, different infrastructures cannot be placed immediately next to each other (e.g. tipping distance between wind turbines and roads). In this task, we identify existing and historical regulations for landscape and environmental protection rules for energy assets (production, transmission and distribution) and ground transport (e.g. roads, highways, rail-roads) using a combination of qualitative and quantitative data collection (incl. database scans, workshops and surveys). Because a central aim of TA2 is to not only list regulations but also to understand what drives regulation, we generate time series for Germany and a set of European countries, so as to ensure the necessary variance among the investigated variables. This will include electricity, gas and oil, as well as transport (road and rail; including fuelling/charging infrastructure) sector. The collected data will be

[51] http://www.res-legal.eu/home/

prepared as input for TA4 to ensure appropriate modelling based on metadata standards and domain-specific ontologies.

Deliverable: [D2.2.1.1] Data collection of landscape and environmental regulation for energy assets.

Task 2.2.2 Determine economic regulations: what is supported how?

Description: Policy support has been and remains the major driver of technological change and technology uptake; in most energy transition fields, support has been the prime mover, without which the transition would have ground to a halt. In this Task, we derive time series for support for different technologies, both new (e.g. renewable energy) and old (e.g. fossil fuels), and both supply-side (e.g. electricity) and demand-side (e.g. electric cars) support, for Germany and other European countries. The collected data will be prepared as input for TA4 to ensure appropriate modelling based on metadata standards and domain-specific ontologies.

Deliverable: [D2.2.2.1] Data collection of economic regulations between 2000 and 2020 in Germany and selected European countries.

Task 2.2.3 Identify past energy/climate policy logics of past governments and large opposition parties

Description: Policy interventions following certain policy logics. Some countries focus on wind power whereas others focus on photovoltaic in their renewable energy strategies. There is no clear pattern across windy or sunny countries, but rather countries embark on specific paths depending on national preferences, which tend to be driven mainly by industrial considerations and political narratives of what is “appropriate for our country”. These political narratives, in turn, follow a limited set of governance logics and place the state, the market, or civil society at the centre of the envisioned energy future. In this Task we will identify and capture past energy and climate policy logics applied by governments and political parties in Germany and other European countries. This data will describe the full policy space possible in each country, including the possibility of government change and paradigmatic changes in energy and climate policy. There is a special methodological challenge in identifying the metadata standardisation needs from the collected data. We will address this by delivering input to the experts within the WG Metadata & Ontologies.

Deliverables:

[D2.2.3.1] Data collection of energy and climate policy logics.

[D2.2.3.2] Analysis of policy logics based on survey and focus group responses.

Task 2.2.4 Link policy logics to technological change and public acceptance

Description: In this Task, we will link this data to data on technological change (e.g. market uptake, technology cost) and to acceptance (M2.3.), so as to not only identify “what is” but also which dynamics affect policy preferences, allowing for a degree of internalisation of policy preferences and logics in energy modelling. As before, we explicitly seek to link support types and levels to on-the-ground developments such as technology cost and technology market penetration, but also acceptance factors (M2.3) – and for this time series and data from multiple countries is essential, to ensure the necessary variance among the investigated variables. To this purpose we will ensure regular exchange and conduct workshops for cross reference and integration into the other measures, including data representation and standardisation issues.

Deliverables:

[D2.2.4.1] Develop an analytical framework and set of variables.

[D2.2.4.2] Integration workshop(s) output - contributing findings on policy logics and regulations into other measures of TA2.

Measure 2.3 Acceptance and social trends: determinants and data sets

Lead: SOFI

Contributions: IASS

Goals: Identify factors determining social acceptance, support and opposition of energy transition as well as visions for the future

Description: There is a widespread agreement that public acceptance and engagement play a decisive role in the energy transition – not only because opposition risks halting the transition, but also due to the normative goal of acceptance of societal projects as an aim in itself. Social aspects have become a particular focus of politics in the discourse about a socially just and acceptable transformation of the energy system, in Europe and in Germany [28]. This includes that wishes, needs and values of a broad majority are considered, and respective political measures are perceived by citizens as fair and equitable. Thus, several dimensions of justice need to be addressed, especially distributional and procedural justice [29]. Indeed, with the increasing maturity of renewable energy technologies, the challenges of the energy transition are shifting towards obtaining a “social license for clean energy deployment”. The FAIR representation of these data has some special obstacles, ranging from standardisation to privacy issues. We will address these in close cooperation to TA4.

Year	Milestone
1-2	[MS2.3.1] Data collection: Compilation of empirical data on social acceptance and public attitudes

3-4	[MS2.3.2] Typology of public sentiments towards energy
4	[MS2.3.3] Assessment of future behaviour and attitudes
	[MS2.3.4] Data on public acceptance and social trends linked to data on policy logics and technological change (M2.1 and M2.2)
4-5	[MS2.3.5] Integration into nfdi4energy platform (M2.4)

Task 2.3.1 Identify and compile empirical data on public sentiments about energy and the energy transition

Description: The concept of social acceptance has been extensively studied increasing the amount of empirical data over the last two decades. For example, IASS has developed an extensive knowledge and data base with the Social Sustainability Barometer [30]. Since 2017, the institute collects public sentiments on the attitudes, experiences, perceptions of justice, preferences, and intentions for action of the German population in an annual representative survey [31]. Another important example is the recent consultation of the EU commission on the digitalisation of the energy system[52]. Moreover, it is crucial to include regional differences regarding the implementation of energy transition into the platform. Here, we integrate the connection between the issue of energy transition to local public infrastructure and common goods [32] in general as well as the relevance of place-attachment [33] into the analytical framework.

Deliverables:

[D2.3.1.1] Analytical framework: which aspects should be considered?

[D2.3.1.2] Overview on existing studies, case studies and surveys

Task 2.3.2 Determine acceptance factors and create typology of public sentiments towards energy

Description: Though, despite an overall acknowledgement of the importance of social aspects, they are not explicitly represented in energy models yet. Hence stakeholders increasingly call for making them a prerequisite to make models more relevant for advising and finding solutions to actual energy and climate policy challenges. In this task we identify factors determining public acceptance and support of the energy transition by assessing existing data sets from the last decade in Germany and other European countries. We will explore differences and similarities based on the respective socio-political, cultural, and geographical contexts. We will link our data to M2.2 (Task 2.2.3), describing not only the status quo but also considering dynamic effects in

[52] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13141-Digitalisierung-des-Energiesektors-EU-Aktionsplan/public-consultation_en

the context of policy changes and public mood shifts ensuring meaningful integration of this data into energy modelling. Furthermore, we complement the existing data by qualitative new insights into our local reference cases (M2.1 and Use Case 6.3). The results will serve as requirement input for TA4.

Deliverable: [D2.3.2.1] Typology of public sentiments towards energy

Task 2.3.3 Integrate future behaviour and social trends

Description: To improve energy system models by integrating social and political aspects, it is also promising to provide empirical evidence on social trends [30] and how behaviour and attitudes might change in the future. In this task, we develop and apply a joint quantitative and qualitative method to create data addressing this question. This task is linked with the focus groups of M2.1. Up to now, it is not yet clear what would be a useful representation of this data with respect to standardised research data. We expect though, that at least a metadata-based registration of this data is needed to address the FAIR principles for this data. Use Case 6.3 will derive detailed requirements.

Deliverables:

[D2.3.3.1] Survey on social trends and future behaviour.

[D2.3.3.2] Analysis of future perceptions of focus group and workshop participants as well as survey responses

[D2.3.3.3] Data representation requirements as input for TA4

Task 2.3.4 Link public acceptance to policy logics and technological change

Description: It is very important to link Measures 2.2, 2.3 and 2.4. closely to integrate the compiled data into the platform. Thus, there will be constantly close cooperation between all contributors via frequent meetings and joint research.

Deliverable: [D2.3.4.1] Joint research workshop with M2.2, M2.3 and M2.4.

Measure 2.4 Holistic energy system modelling

Lead: ALU

Contributions: IASS, KIT-IISM, SOFI

Goals: Identify general concepts and guidelines for representing societal and political factors into energy system models and collect, standardise and integrate corresponding data and methods into the data services

Description: Energy system models in general not only integrate technological, physical, and economic parameters and constraints, but also explicitly or often implicitly take into account behavioural, societal, or political factors. These factors cover different scales and levels, ranging, for instance, from macroscopic assumptions on economic growth to urban mobility patterns or the area available for renewable generation capacities. Furthermore, future trends which might impact energy demand and consumption patterns have to be evaluated depending on the narrative underlying the scenario under consideration. Depending on the scope of the model, such factors might be included exogenously or endogenously, serving either as input parameters and boundary conditions, or as dynamic model components. In both cases, energy system models in general rely on literature values, data bases or complementary models as a basis for their assumptions, parameter settings and conceptual choices. Accordingly, to facilitate holistic energy system modelling, an accessible, standardised and extensive registry of modelling concepts and parameter estimations is needed. Building on best practices from the literature and existing data bases as well as results from M2.1 - M2.3, this M2.4 aims to provide standardised concepts and data for representing societal and political factors into energy system models. Thus, this measure will derive requirements for TA4 and TA5.

Year	Milestone
1-2	[MS2.4.1] Existing energy system models evaluated and requirements identified [MS2.4.2] Literature-based preliminary database created
3-4	[MS2.4.3] Database for exogenous representation finalised [MS2.4.4] Database for endogenous representation finalised
5	[MS2.4.5] Databases based on feedback cycles developed and adapted

Task 2.4.1 Evaluate existing energy system models with respect to the representation of societal and political factors

Description: Review, categorise and standardise concepts and data sources incorporated in existing energy system models. In the process, specific parameters suitable for exogenous model integration have to be discriminated from concepts and interactions corresponding to an endogenous representation.

Deliverable: [D2.4.1.1] Preliminary database of parameters and modelling concepts

Task 2.4.2 Identify modelling requirements and blind spots

Description: Through expert workshops focussing on the representation of societal and political factors, modelling challenges and blind spots in this area are identified. This covers not only the determination of necessary modelling concepts or data, but also an assessment of the suitable form of how such information should be made accessible to the community. This interaction will not only provide a valuable input for the initial stages of Tasks 2.4.3 and 2.4.4, but will also provide a feedback cycle throughout later stages of the project. To ensure findability and reusability, the

concepts should be integrated in the relevant domain-specific ontology, mainly developed in TA4. Therefore, a close collaboration with the WG Metadata & Ontologies is planned.
Deliverable: [D2.4.2.1] Requirements for a database of parameters and modelling concepts

Task 2.4.3 Create database for exogenous representation of societal and political factors
Description: In particular in techno-economic optimisation models, parameters like public acceptance, future trends of energy demand or consumption patterns are represented exogenously though input data, parameter settings or boundary conditions. This task aims to provide a database of specific parameters and estimates of such factors, drawn from the evaluation in Task 2.4.1, and in particular operationalising the new findings in M2.1 - M2.3 for energy system modelling. The database should be based on the extensions of domain-specific ontology (Task 2.4.2). The WG Metadata & Ontologies enables this combined work.
Deliverable: [D2.4.3.1] Database of concepts and parameters for exogenous representation.

Task 2.4.4 Provide guidelines for endogenous model representation of societal and political factors
Description: The explicit representation of factors like dynamic consumption patterns, public acceptance or evolving trends of changing energy demand in energy system models is still an emerging field. These approaches call for a model-endogenous integration of dynamic interactions or local rules opposed to model-exogenous input data. This Task aims at supporting future development of modelling methods in this field by providing representational guidelines for key interactions. This task takes the requirements identified in Task 2.4.2 into account, and translates the findings of M2.1 - M2.3 into specific modelling guidelines.
Deliverable: [D2.4.4.1] Integration of modelling guidelines into the *Best Practices* service.

Measure 2.5 Gamification and data collection
Lead: KIT-IISM
Contributions: ALU, IASS, SOFI
Goals: Motivate the generate public and societal actors to share their data on the nfdi4energy platform by using gamification elements.
Description: A detailed description of consumer behaviour and preferences has to be based on corresponding data. An energy data service that engages users is uniquely positioned to be used to collect new data from these users and can become a multiplier for researchers. Therefore, we will develop guidelines to motivate users to share their data by including gamification elements on the platform that challenge users to reveal their preferences and ideas for the energy transition.

This means, while measures within TA4 and TA5 ensure a FAIR representation of energy system research related data, in this measure, we focus on how to engage the public in supporting this concept by generating additional content, thus supporting the transdisciplinary facet of energy system research. In order to be able to provide guidelines for further gamification elements on the platform, we will conduct user experiments and specifically engage in a corresponding use case (see TA6). Finally, we ensure the durability of such solutions and possible addition of further gamified elements by defining technical standards, data requirements and interfaces for researchers to add new gamification elements.

Year	Milestone
2	[MS2.5.1] Potential gamification elements selected
3	[MS2.5.2] Application with gamification elements built
4	[MS2.5.3] User experiments conducted
5	[MS2.5.4] Guidelines for gamification elements developed

Task 2.5.1 Identify gamification potential for energy modelling and data collection

Description: Explore the possibilities of gamification features on the platform. Possible objectives of gamified elements are threefold: (i) allow users to play with inputs of energy system models and provide feedback on effects, (ii) incentivise data and preference sharing by users and (iii) enable citizens to participate in energy system research, e.g., by formulating research questions on the platform (citizen science). Based on the results from M2.1 – M2.4, we will identify applications that have a high potential of being used by the broad public when gamified and will therefore add value to the platform. We will also work together with TA1 to identify data that is useful for the research community that can be collected using gamification features from private users of the platform.

Deliverable: [D2.5.1.1] Use cases for gamification features identified and best practices formulated (report)

Task 2.5.2 Design gamification applications for energy modelling and data collection

Description: Build applications with gamified elements. We will develop selected applications to demonstrate the integration of new data and to provide examples for the data structure and functionality of such applications. These applications are needed for a user evaluation to develop manuals for their design and to serve other researchers as a blueprint to include gamification elements in their demonstrators and models.

Deliverable: [D2.5.2.1] Applications with gamified elements (mockups, prototypes)

Task 2.5.3 Conduct user experiments with developed applications

Description: Test the developed applications with gamification elements in user experiments. In order to be able to provide guidelines and recommendations regarding gamification for energy data applications, we need to evaluate the designed applications with various user groups. We will conduct these experiments corresponding to the results of M2.1 and also rely on the focus groups formed in M2.1. Users with diverse backgrounds and demographics will be included in the experiments.

Deliverables:

[D2.5.3.1] Test setup developed and deployed

[D2.5.3.2] Users from all relevant user groups for testing acquired

[D2.5.3.3] Experiments conducted

[D2.5.3.4] Setup and results of experiment published

Task 2.5.4 Derive technical standards & descriptions of gamification models

Description: Within the task, we want to provide specifications that allow other researchers to include their own applications and data in existing applications on the platform in close cooperation with TA4. Based on the results of the user experiments, we will provide guidelines to the community for including gamification elements in use cases and demonstrators. In those guidelines, the gamification data models and interfaces will be described in detail making the gamification of further elements possible in the future. We expect additional requirements regarding metadata standardisation from this task, thus delivering additional input to TA4 and TA5.

Deliverable: [D2.5.4.1] Written guidelines (manual)

Measure 2.6 Creating outreach protocols: How do we communicate model results to different audiences (e.g. Society, Politics)?

Lead: KIT-IISM

Contributions: ALU, IASS, SOFI

Goals: To identify and operationalise the most adequate visualisation tools for conveying model results to stakeholders from society and politics.

Description: In order to reach a broad audience, it is important to make scientific findings available, findable, and easy to understand for stakeholders in the general public and political spectrum that have been identified in Task 2.1.1. The KIT-IISM has experience in experimental evaluation of visualisations to communicate scientific knowledge to non-expert audiences through the project "Visualisation of the Energy Transition in Baden-Württemberg" (ViEW-BW). In this measure, we will develop and evaluate different visualisations containing interactive elements that are suitable to communicate energy system scenarios. As a result, a set of protocols for energy system researchers will be developed as a guide for the outreach and communication of scientific findings from energy system modelling to a broad audience from society and politics.

Year	Milestone
1	[MS2.6.1] Best practices identified
3	[MS2.6.2] Visualisation alternatives prototypically implemented
4	[MS2.6.3] Visualisation alternatives evaluated
5	[MS2.6.4] Best practices report written and available on the platform

Task 2.6.1 Identify best practices and requirements for scientific result communication through interactive visualisation

Description: We will conduct a structured review of papers and studies in order to identify adequate visualisation techniques and elements for energy system modelling results. In addition, we will draw from results of M2.1 to identify stakeholder-specific requirements for the communication of scientific results from energy system modelling to public audiences.

Deliverables:

[D 2.6.1.1] Structured review (documentation)

[D2.6.1.2] Requirement analysis (report)

Task 2.6.2 Implement prototypical visualisations

Description: During the project lifetime, the most promising of the identified approaches from Task 2.6.1 will be implemented to communicate scenarios from energy system modelling to the identified stakeholders from society and politics. This will include the long-term scenario visualisations from Task 2.6.3 (Use Case 6.2) that allow users to enter certain preferences or policy changes into energy system models and see the resulting changes in energy system scenarios.

Deliverable: [D 2.6.2.1] Implemented visualisation alternatives prototypes

Task 2.6.3 Evaluate the effects of interactive visualisations on stakeholders

Description: Following the implementation of prototypes we will conduct a lab or online experiment with relevant stakeholders. Based on the experiment's results we will evaluate the usefulness of each visualisation technique and element with stakeholders.

Deliverable: [D2.6.3.1] Report of experiment.

Task 2.6.4. Develop a protocol for energy system researchers

Description: On the basis of the requirement analysis and the experimental results we then compile a best practice guide and/or protocol for energy system researchers which they can follow to convey their results to the members of society and politics.

Deliverable: [D 2.6.4.1] Written guide for researchers published within the *Best Practices* service

5.3 TA3: Transparency and Involvement of the Energy-Related Industry

Lead: RWTH

Measure Leads: KIT-IISM, RWTH

Description and Objectives

The involvement of the industry is an important building block for the successful development of community services for energy system research. On the one side, industry partners can contribute with technical as well as business-related data sets. On the other side, industry partners can also be users of the platform and access existing data or services provided by the nfdi4energy platform, e.g. to validate new business models. Therefore, this TA aims to include the industry in the development process. In a first step, M3.1 will establish the communication to different industry partners, extending the IAB, and gather their requirements for platform adoption and data sharing. This will be done by online workshops as well as surveys. Subsequently, M3.2 will develop clear processes for contributing and using data and services on the platform. This is done in close cooperation with TA1, TA4, and TA5, which deal with their implementation. M3.3 deals with substituting and enriching data provided by industry partners. For cases, where data from industry is not available or cannot be shared due to privacy concerns, tools are developed to generate synthetic data or to anonymise personal data.

Task Area 3 targets the following objectives:

- [O3.1] Identify and involve industry partners and gather their requirements for platform adoption
- [O3.2] Develop clear processes to actively involve industry partners in the platform development
- [O3.3] Identify requirements for substituting data and implement a set of tools to generate synthetic data as well as anonymised data

Measure 3.1 Industry requirements for platform adoption and data sharing

Lead: KIT-IISM

Contributions: FhFIT, RWTH

Goals: Develop and implement an approach to actively involve industry stakeholders in the platform

Description: The KIT-IISM has a longstanding and large network of municipal utilities and other energy companies. Leveraging our existing network and those of our project partners, we shall identify and involve a project-specific network of industry partner companies during the development of the platform. This network spans wider than the members of IAB, while including them as well. RWTH and FhFIT will contribute and use their network of industry partners from various research projects. With participants from this network, we will conduct online workshops to jointly identify requirements and enablers of platform adoption and data sharing from an industry point of view. This shall ensure that companies will be ideally involved in the platform and willing to make valuable proprietary data available. The initial set of requirements and guidelines will be expanded and adjusted through ongoing evaluation with workshops and/or surveys/interviews to continuously improve the integration of the industry on the platform in M3.2.

Year	Milestone
1	[MS3.1.1] Initial industry partner network established
2	[MS3.1.2] Design Thinking Workshop conducted
3	[MS3.1.3] First draft of industry requirements and data strategy guidelines shared
5	[MS3.1.3] Finalised requirements validated through workshops, surveys or interviews

Task 3.1.1 Identify and create a network of relevant industry partners

Description: For collecting industry requirements, we first need to acquire relevant industry partners and stakeholders which are interested in an energy community platform. To do so, potentially interested industry partners need to be identified and contacted. This includes, but is not limited to, (municipal) utilities, network operators and IT-service providers. A network of interested industry partners shall then be created which can be beneficially used by the partners to facilitate the exchange among themselves.

Deliverable: [D3.1.1.1] Network of at least 15 relevant industry partners (documentation)

Task 3.1.2 Identify industry requirements for platform adoption and data sharing

Description: The KIT-IISM has expertise in the design and conduction of Design Thinking Workshops, an interactive workshop method. An online workshop will be conducted to create an initial set of requirements for adoption and data sharing of industry partners. This will include expectations of the industry partners regarding the platform usage and the legal environment under which they are willing to share their data. The participants will work together in interdisciplinary teams with the aim of planning and prototyping user-centric designs. By using the method of design thinking we aim to integrate the inputs of all relevant stakeholders from our industry network.

Deliverables:

[D3.1.2.1] Design Thinking Workshop for Industry Partners (report)

[D3.1.2.2] Written, structured list of requirements and data sharing guidelines

[D3.1.2.3] Mock-up of data sharing interface

Task 3.1.3 Validate and improve initial requirements

Description: The requirements identified in Task 3.1.2 will be implemented prototypically as a proof of concept. Throughout the project lifetime, partners from the identified industry network will be involved in the platform development process through accompanying workshops, interviews and surveys to validate and refine the initial list of requirements.

Deliverables:

[D3.1.3.2] Prototypical requirement implementation

[D3.1.3.2] Evaluation of at least 10 workshops, surveys, interviews (report)

Measure 3.2 Development of a moderated process to involve industry partners

Lead: RWTH

Contributions: FAU, FhFIT

Goals: Development of a process that enables industry partners to contribute data, use existing data and access *Simulation* service

Description: After the identification of industry requirements in M3.1, this measure aims to establish a clear process for the contribution and use of the platform by industry partners. There are two paths to consider. On the one side, industry partners can share their data via the platform. This requires the definition of standard data formats. On the other side, industry partners can use existing data sets on the platform and access its services, e.g. for simulation. The management of data and the provision of *Simulation* service is targeted in TA4 and TA5, respectively. Hence, this measure will work closely with both TAs. RWTH will coordinate the work and use its participation in TA5 to establish a link to the *Simulation* service development. FhFIT will be the main contact point to the industry partners and guide their contribution process as well as gather their feedback.

Year	Milestone
2	[MS3.2.1] Process for contributing and accessing data defined
	[MS3.2.2] Process for accessing platform services defined
4	[MS3.2.3] Successful execution of the process with industry partners completed

Task 3.2.1 Develop a process for contributing and accessing FAIR data

Description: Data that is to be shared via the platform is supposed to follow the FAIR principles: Findable, Accessible, Interoperable, Reusable. TA4 provides the registry for FAIR data and defines the technical requirements for data to satisfy the FAIR principles. This task will derive a process for contributing new data. It takes into account the technical requirements from TA4 and describes the required format of new data sets. This includes for example specific data formats and standards as well as metadata, describing the information to be found in the data set or licences for their usage. Task 3.2.1 will represent the requirements of industry partner as collected in M3.1 within TA4 and moderate the process of validation and constant improvement.

Deliverable: [D3.2.1.1] Process for contributing and accessing FAIR data defined and executed with industry partners

Task 3.2.2 Develop a process for accessing community services on the platform

Description: Besides data, the platform will provide services, such as SaaS, which will be developed within TA5. This task aims to represent the industry requirements for accessing and using these services. For this purpose, Task 3.2.2 will be in constant exchange with TA5 and develop a process how industry partner can access services, test them and give feedback for a continuous improvement.

Deliverable: [D3.2.2.1] Process for accessing community services on the platform defined and executed with industry partners

Measure 3.3 Collection and creation of substitute data

Lead: RWTH

Contributions: None

Goals: Implement or reuse existing tools to substitute data that cannot be provided by the industry

Description: TA3 has the overall objective to include data from industry into the platform. However, the data that can be shared by individual industry partners might not be complete. For example, grid data such as topology or line parameters is often times not available. Personal data, i.e. data that reveals information about an individual such as the power consumption of a household, can only be shared and fed into the platform after an appropriate anonymisation. Based on the feedback from industry gathered in M3.1, this measure analyses which data has to be substituted. Moreover, tools for the creation of synthetic data sets as well as for anonymisation of data sets with personal data will be developed.

Year	Milestone
2	[MS3.3.1] Required substitute data identified
3	[MS3.3.2] First release of data sets and tools for the creation of synthetic data
4	[MS3.3.3] First release of tools for the anonymisation of data sets
5	[MS3.3.4] Final release of tools for the creation of substitute data

Task 3.3.1 Identify required substitute data

Description: This task will analyse the requirements of the industry regarding the need for substitute data. For this purpose, the input gathered in M3.1 will be used. The required substitute data will be split in two categories: Missing data, that has to be substituted by synthetically created data, and personal data, that has to be processed and replaced by anonymised data.

Deliverable: [D3.3.1.1] List of required substitute data

Task 3.3.2 Develop tools for the creation of synthetic data

Description: The first category of substitute data is synthetic data. The goal of this task is to provide such data whenever it is missing in the data sets provided by industry users. Such data can be taken from other data sets, such as standard load profiles or historic profiles for photovoltaic generation. In addition, tools, which create synthetic data based on user input parameters, can be used. One example for such a tool is a grid topology generator. Task3.3.2 will gather available data sets and provide tools for the creation of synthetic data. We will reuse as much as possible existing data and tools for this purpose.

Deliverable: [D3.3.2.1] Data sets and tools for the creation of synthetic data

Task 3.3.3 Develop tools for the anonymisation of personal data

Description: The second category of substitute data is anonymised data. Whenever data in the original data set contains personal information, such as individual load profiles, or allows to derive personal information, the data set has to be processed and anonymised. That means that the resulting data set does not allow to derive any personal information anymore. Potential measures to achieve anonymisation are pseudonymisation and aggregation. This task will provide tools for the anonymisation of data sets identified in Task 3.3.1.

Deliverable: [D3.3.3.1] Tools for the anonymisation of personal data

5.4 TA4: FAIR Data for Energy System Research

Lead: OFFIS

Measure Leads: ALU, KIT-IAI, OFFIS, TIB

Description and Objectives

This Task Area will lay the foundations for a collaborative research environment for the energy research community that fosters FAIR and reusable research. To this end, metadata standards and ontologies will be developed and the nfdi4energy research infrastructure will be supported in this aspect with the work in this Task Area. Measure M4.1 addresses the creation of a domain ontology for energy system research, which serves as controlled vocabulary in the development of metadata standards for research data in M4.3 and as the basis for the development of ontologies for scenarios and distributed simulations in M4.2 and M5.2, respectively. With the establishment of the research infrastructure, nfdi4energy takes an extensible approach to manage and share data, publications and other types of DOs in research and their interdependencies from energy system projects. This TA implements a range of core services for this purpose, namely the metadata *Registry*, the research knowledge graph and the terminology and PID services. Together they form a semantic layer for integrating, linking and structuring DOs in research. The function of the semantic layer is to enable interoperability and to integrate the components and standards from this Task Area and TA5 with the nfdi4energy platform developed in TA1. By storing metadata of DOs, including PIDs and links to the repository, the metadata *Registry* will be a means to integrate external repositories and will provide a source for the Open Research Knowledge Graph (ORKG). The ORKG in turn supports interoperable analysis of research (meta-)data, e.g. scenario comparison (Task 4.2.3).

Task Area 4 targets the following objectives:

- [O4.1] Create a domain ontology for energy system research
- [O4.2] Provide a rich set of high-quality community-agreed metadata standards covering a broad spectrum of DOs of energy system research
- [O4.3] Implement a metadata registry for various DOs in research
- [O4.4] Create a PID-based process to register DOs in the metadata *Registry* based on useful metadata standards and terminologies
- [O4.5] Support interdisciplinary work in energy system research based on the developed community services

Measure 4.1 Energy system research ontology

Lead: OFFIS

Contributions: RLI, TIB, UOL

Goals: Build a domain ontology for energy system research that captures the scholarly knowledge within the domain making it explicit, shareable, and reusable

Description: The aim of this measure is to create a domain ontology for energy system research that represents the knowledge of the domain as a set of concepts hierarchically structured by relationships. The development of the domain ontology builds on existing approaches from both research and industrial practice such as the OEO, the CIM, and SARGON (see also Section 4.2). The envisioned result is a modular ontology that is extended and detailed by the ontologies that are developed in M4.2 and M5.2. Using the domain ontology as controlled vocabulary, it will enhance the consistency and quality of the metadata standards built in M4.3. The domain ontology will have rich links to semantic models of other domains and thus promote reusability even between research disciplines. Besides, a Terminology Service (TS) is built for the management and collaborative development of terminology resources.

Year	Milestones
1	[MS4.1.1] Special interest group on metadata standards and ontologies in collaboration with the research community, other NFDI consortia, the international research community and standardisation bodies established
	[MS4.1.2] Ontologies selected for reuse, concepts and relations extracted and imported into the novel domain ontology
2	[MS4.1.3] First working version of the domain ontology finished
	[MS4.1.4] Terminology Service implemented
3	[MS4.1.5] Extended version of ontology based on additional requirements from other measures
4	[MS4.1.6] Richly connected ontology finished, operable with all metadata standards of TA4 and TA5
5	[MS4.1.7] Platform integration of the domain ontology completed

Task 4.1.1 Working group on metadata and ontology modelling

The Working Group (WG) Metadata & Ontologies coordinates all activities related to the management and development of metadata schemas and ontologies for the different services of nfdi4energy. In particular, the WG is responsible for aligning the development of the ontologies and metadata schemas. It is also responsible for organising training activities on semantic technology standards and tools, strategies and best practices for modelling ontologies and metadata schemas. The intention is to enable involved energy system researchers within the nfdi4energy to create high quality ontologies and metadata schemas that meet the community's real needs. In addition, the Metadata & Ontologies WG will foster the active participation of the scientific community and will cooperate with other NFDI consortia to share best practices, harmonise the use tools and services, and promote the inter-linking of research domains.

Task 4.1.2 Requirements for the modular domain-specific ontology

Description: The development of a modular domain ontology must be aligned with the ontology and metadata standard developments of the other measures. Therefore, it is necessary to derive requirements in the form of concepts that need to be ontologically describable for the use within M4.2, M4.3, and M5.2. The coordination and discussion of the requirements are organised within the WG Metadata & Ontologies. Based on the results, current ontologies are assessed and a decision is prepared on an ontology selection, which will be further developed or supplemented in the course of the project. The selected ontologies should be as compatible as practicable and serve the measure’s needs.

Deliverables:

[D4.1.2.1] List of requirements

[D4.1.2.2] List of relevant domain ontologies for energy system research

Task 4.1.3 Development of modular domain ontology for energy system research

Description:

Based on the requirements and the list of relevant domain ontologies from Task 4.1.2, a modular domain ontology should be developed. The modular domain ontology should be used as foundation for M4.2, M4.3 as well as for M5.1 and M5.2. With the WG Metadata & Ontologies an appropriate process is defined to ensure effective ontology development work. This includes establishing appropriate communication channels, transparent consultations and discussion spaces for ontology development. The RLI contributes to the development of this process with the experience gained from its work on ontology development.

Deliverables: [D4.1.3.1] Modular domain ontology for energy system research

Task 4.1.4 Terminology Services for domain-specific ontologies

Description: The Terminology Service (TS)[53] provides a single-point-of-entry and is a repository for terminology resources based on W3C semantic standards, such as the Web Ontology Language (OWL 2). The technical infrastructure for terminology access, curation, and subscription will be implemented in the TS, which provides a central entry point for terminology in

[53] https://service.tib.eu/ts4tib/index

nfdi4energy. Through this entry point, the ontologies can be searched, and the API can be used to retrieve terminology information and apply it in own technical services. TIB is also already maintaining several terminology services for various research communities as extensions to this service. NFDI4Ing and NFDI4Chem are particular examples of these extensions. Within the framework of nfdi4energy, further community-specific terminology services will also be established as extensions of the central service. In addition, the services can be used for registration of ontologies. Ontologies for energy research already registered in TIB TS are e.g. Digital Construction Energy (dices)[54] and OEO[55]. In addition, the ontologies and metadata standards developed in nfdi4energy will be registered and made accessible in the TS. Together with the nfdi4energy community, further relevant ontologies and controlled vocabularies can be identified during the project. In this context, there always has to be evaluated whether the license and format allow an integration into the service. The ongoing development and maintenance of a range of TS will complement this service. The TS is central in the collaborative development of standards and vocabularies in M4.1 – M4.3, and M5.2.

Deliverables:

[D4.1.4.1] Terminology service for nfdi4energy terminologies (service)

[D4.1.4.2] Registry for ontologies from the energy research area (service)

Measure 4.2 Development of standards for long-term scenario representation in the energy domain

Lead: ALU

Contributions: RLI, OFFIS, TIB, UOL

Goals: FAIRification of long-term scenario representations in the energy domain through improvement and creation of domain-specific ontologies

Description: Energy system scenarios are important foundations for designing policies to achieve national and international climate protection goals. It has been observed that long-term scenarios that support the goal of carbon neutrality, although they share common characteristics, are quite diverse with respect to the assumptions as well as the conclusions, and they also provide different formats of inputs and outputs. Published scenarios have different time horizons and sampling years, different delineations of energy sectors, different scopes of considered greenhouse gas emissions, among other things. Their assumptions of, e.g., future developments regarding socio-economic drivers, final energy demand, technological and prices developments vary, and they also differ in which parts are modelled endogenously and what is an exogenous input to the

[54] https://digitalconstruction.github.io/Energy/v/0.5/

[55] http://openenergy-platform.org/ontology/oeo/

model. Besides, scenario descriptions themselves represent DOs in research. This measure supports a better scenario comparison related to inputs, assumptions and outputs. In view of the need to quickly transform our energy systems, easily accessible, understandable and comparable information is of high practical need. Therefore, we first derive requirements for a scenario representation. Furthermore, a schema for scenario representation based on a domain ontology is developed and tested with multiple scenario data. To improve the usability and provide easy access, the scenario representation schema is included into an ORKG.

Year	Milestones
1	[MS4.2.1] Requirements for a scenario representation collected
2	[MS4.2.2] Scenario representation finished
3	[MS4.2.3] First extended version of the scenario ontology with rich references to other ontologies is finished [MS4.2.4] ORKG for energy research scenario implemented
4	[MS4.2.5] Ontology for application to further scenarios extended
5	[MS4.2.6] Open Research scenario representation integrated into platform

Task 4.2.1 Continuous requirement analysis for scenario representation

Description: To enable scenario comparisons, the scenarios need to be described in a formalised machine-readable schema. Many elements for scenario representation and comparison can be identified and addressed at the beginning of the project. Within this TA, the requirements for such a scenario representation should be collected. Based on the general requirements analysis in the energy system research community (TA1) and the Use Case 6.1, requirements for a scenario representation can be derived. Needs for the domain-specific ontology should be communicated with WG Metadata & Ontologies be considered in the ontology development in M4.1. However, the general requirements are derived at the beginning, there is a need to support the ongoing developments through continuous elicitation of the requirements and revision of ontology and representation schema.

Deliverable: [D4.2.1.1] Collected requirements for scenario representation and domain ontology

Task 4.2.2 Development of a scenario representation schema based on a domain ontology

Description: Scenarios need to be annotated with terms of an ontology based on a defined representation schema, which will be developed based on the requirements of Task 4.2.1. The schema builds on the existing works, such as the scenario factsheet of the OEP, which will be extended, revised and improved to better align them with domain ontology developed in M4.1.

The representation will provide the means to structure DO containing scenarios and improve their FAIRness. It will simplify the comparison of scenarios for a comprehensive and clear overview.
Deliverable: [D4.2.2.1] Scenario representation schema

Task 4.2.3 Operability of the developed schema for scenario representation

Description: The scenario representation schema developed in Task 4.2.1 need to be put into practice to assure their operability. Therefore, the scenario ontologies are used. This process is realised through the application to exemplary scenarios, which are chosen to represent a diverse set of underlying sectoral, spatial, temporal or methodological scopes. In this way, both a feedback cycle to the development in Task 4.2.3 as well as preparatory steps to the application of the scenario representation in Use Case 6.2 is provided.
Deliverables: [D4.2.3.1] Application of the scenario representation schema to a diverse set of scenarios

Task 4.2.4 Comparison of scenarios based on the Open Research Knowledge Graph

Description: The Open Research Knowledge Graph (ORKG)[56] is a platform for acquiring, curating, processing, and publishing semantic scholarly knowledge from scientific publications that is human- and machine-actionable. For this purpose, ORKG combines expert-based crowdsourcing and (semi-)automated methods for structuring and linking semantically rich descriptions of research problems and their associated contributions stored in a knowledge graph. The crowd of the ORKG includes domain experts, researchers, librarians, and information scientists who organise and describe the contributions and their scholarly knowledge using ontologies and predefined structures, so-called templates. In this way, the FAIRification of scholarly knowledge and its consistent representation are ensured by following defined terminologies and structures. Based on these representations, the ORKG provides further novel means such as state-of-the-art comparisons, dynamic visualisations, and SmartReviews to interactively explore, process, and analyse the curated scholarly knowledge. Scenarios in energy research are diverse and complex due to several modified versions of their input data and underlying assumptions. Based on preliminary work within NFDI4Ing, nfdi4energy will utilise the ORKG and its features for describing and representing scenarios of the energy domain. By integrating the scenario representation schema developed in Task 4.2.2, the scenario description in the ORKG fulfils the FAIR criteria and simplifies the comparison of scenarios. In this way, the results of energy research can be presented and understood by a broad audience.
Deliverable: [D4.2.4.1] Implementation of ORKG for energy research scenario (service)

[56] https://www.orkg.org/orkg/

Task 4.2.5 Working group on scenario description standardisation

The Working Group (WG) Scenario Description Standardisation addresses one of the specific semantic mismatches in energy system research: While energy system analysts typically talk of scenarios as long-term energy system scenarios, energy system simulation experts reflect the aspect of simulation scenario setup with this term. While both notions of scenarios are understood in the respective community, the interdisciplinary integration leads to misunderstandings and thus inefficiencies in research. With the aim of setting up both metadata standards and an ontological backbone for both notions of scenarios (TA4 and TA5), a harmonisation is needed. The WG Scenario Description Standardisation will coordinate all activities related to this field. In particular, the WG is responsible for aligning the development of the ontologies and metadata schemas in close cooperation with the WG Metadata & Ontologies. In addition, the WG will actively involve relevant researchers from the community (e.g. as members of the Scientific Advisory Board (SAB) to harmonise scenario description.

Measure 4.3 Development of metadata standards for energy research data

Lead: KIT-IAI

Contributions: ALU, IASS, OFFIS

Goals: Develop metadata standards for energy research data

Description: As introduced in Section 4.1, energy system research requires diverse data as input for simulations and generates different data as output, as well. To make research data comply with the FAIR criteria, it necessary to describe them with rich metadata, increasing their findability, accessibility, interoperability and reusability. Within this measure, we will first define requirements for different kind of research data used in energy system research. Second, we will participate in the development of domain-independent metadata to analyse which metadata standards are good to be applied in energy system research. A close interaction and cooperation with other NFDI consortia and existing initiatives (e.g. HMC, EOSC, RDA) is planned. Also, we will analyse existing approaches for metadata schema in the energy domain. As last step, we will design metadata standards for different types of research data in energy research. These metadata standards should inherit elements from general - domain-independent - standards and should use the domain-specific ontology developed in M4.1.

Year	Milestones
1	[MS4.3.1] Requirements for metadata standards for energy system research data collected
2	[MS4.3.2] Overview of domain-independent standards completed
5	[MS4.3.3] Metadata standards for energy research data developed

Task 4.3.1 Identification of requirements for metadata in energy system research

Description: For the development of metadata standards for energy system research, requirements need to be defined. Besides for the development of the metadata standard, some of the requirements are also relevant for the domain ontology as part of M4.1. Therefore, a close collaboration with the WG Metadata & Ontologies is planned.

The requirements will be derived from the diverse use cases in TA6 as well as from the general requirements of the community, which are collected with TA1. Also, we will integrate the findings of TA2 to extend the requirements to support data for energy regulation and to integrate policy logics into the requirements. Additionally, we will look into different international datasets to analyse which kind of metadata standard can be helpful to increase the interoperability of these datasets.

Deliverable: [D4.3.1.1] Metadata requirements (list)

Task 4.3.2 Investigation of domain-independent metadata standards

Description: Section 4.2 introduced multiple general metadata standards. Also, within the different NFDI consortia, e.g. in NFDI4Ing, metadata standards are currently under development. Within this task, we will investigate the different domain-independent metadata standards and analyse if they are adaptable for metadata standards for energy system data. We actively reach out to other NFDI consortia (see TA7) as well as to the NFDI-Section on metadata to discuss our requirements and findings to find the best possible way to design metadata standards for energy system research with high interoperability to other existing standards.

Deliverables:

[D4.3.1.1] List of metadata standards

[D4.3.1.2] Evaluation of the reusability of the general metadata standards for the energy system domain

Task 4.3.3 Analysis of metadata schemas in the energy domain

Description: Within the energy domain, there already exist some metadata schemas which are not used by the whole community, e.g. the metadata schema on the OEP. We will analyse the existing schemas and test their applicability. We will evaluate, if certain elements from these schemas should be inherited to increase the interoperability of our metadata standards.

Deliverables:

[D4.3.1.1] List of domain specific metadata schemas

[D4.3.1.2] List of relevant elements from domain specific metadata schemas

Task 4.3.4 Development of metadata standards

Description: Based on the requirements of Task 4.3.1, we will develop our metadata standards for data in energy system research. For this purpose, the experience and work in the creation of metadata standards from the HMC Hub Energy of KIT-IAI will be incorporated. To synchronise these activities with other tasks, the developments are discussed within the WG Metadata & Ontologies. Also, we want to include the general metadata standards, as result of Task 4.3.2 as well as the overview of useful elements from domain specific metadata schemas of Task 4.3.3. We will carefully analyse for which kind of data a common standard is useful, and where specific standards are needed. Useful value vocabularies, e.g. the domain ontology developed in M4.1, will be included.

Deliverables:

[D4.3.1.3] Metadata standards

Measure 4.4 Creation of registries for data, simulators and scenarios

Lead: TIB

Contributions: OFFIS

Goals: Implement and establish central registries for CPES research data objects in the field of energy research to ensure the publication, discovery, sharing, and exchange of all energy research-related DOs in accordance with the FAIR principle.

Description: To achieve the objective of this measure as described above, ORKG will provide a central entry point for all relevant DOs in the nfdi4energy *Registry* service. In the further development of this central knowledge hub, a federated architecture will be realised (Task 4.4.1) to facilitate the integration and discovery of additional services, tools and services. In this architecture, both the existing PID service and the Leibniz Data Manager (LDM) will be implemented and further developed. The LDM, as a prototypical tool, not only supports managing and accessing heterogeneous research data publications, but also solves interoperability problems between different repositories, and thus provides a unified view of data (Task 4.4.2). In addition, in this measure we will built on the community engagement included in TA1 to drive the development of a software library for accessing the various services and data sources of nfdi4energy (Task 4.4.3.). Based on the already developed TIB PID service, within this measure, domain-specific PID concepts or systems will be developed and implemented (Task 4.4.4), while the Submission Service will support energy researchers in their research work, considering FAIR principles from the beginning (Task 4.4.5). The essence of this measure is that, building on the comprehensive tools and services mentioned above, some of which already exist, we will create a powerful set of community services for the energy system research that supports the transformation of the research and transfer cycle to a collaborative, community-driven open science respecting both public and industry interests.

Year	Milestones
1	[MS4.4.1] First version of the federated search developed
	[MS4.4.2] MVP of the Metadata *Registry* implemented and deployed
2	[MS4.4.2] PID System developed and deployed
3	[MS4.4.3] MVP of the Metadata *Registry* implemented and deployed
	[MS4.4.4] PID Service implemented and deployed
4	[MS4.4.5] Submission Service developed and deployed
5	[MS4.4.6] APIs of the Services developed and deployed

Task 4.4.1 Federated architecture for federated search

Description: A large amount of scientific knowledge is published on distributed scientific infrastructures. In this task, we present the approach for federating scientific infrastructures. First, a federated access to scientific infrastructures for retrieving and integrating the fragmented scientific content via a single endpoint shall be realised [29]. For this purpose, ORKG is to act as a central point for all relevant DOs in the nfdi4energy services and thus as the central knowledge interface. Linking ORKG content with third-party semantic resources (e.g., ontologies from M4.1; metadata standards from M4.2, , M4.3 and M5.2) ensures content interoperability and reusability. By leveraging PID services and PID Graph (from Task 4.4.4) in ORKG comparison (see Task 4.2.3), DOs in energy research can be permanently identified. Thereby, the cross-referencing between artefact metadata and artefact content enables the targeted retrieval of content, especially from different scientific articles. In addition, based on use cases (TA 6), possible search variants will be further tested and developed.

Deliverables:

[D4.4.1.1] Implementation of federated access

[D4.4.1.2] Federated architecture for federated search

Task 4.4.2 Adapt Leibniz Data Manager to provide a metadata *Registry*

Description: The data visualisation and management tool Leibniz Data Manager (LDM)[57] was developed based on the open source platform CKAN (Comprehensive Knowledge Archive Network). The prototypically available tool supports managing and accessing heterogeneous research data publications and helps researchers to select relevant datasets for their respective

[57] https://labs.tib.eu/info/projekt/leibniz-data-manager/

disciplines. A key feature of CKAN is its extensible platform and open interfaces (e.g. DCAT support), which allow e.g. domain-specific adaptation to the needs of science, technology, engineering and mathematics disciplines (where TIB is most active). This tool also allows visualisation of different research data formats, besides generic data formats such as image file formats, simple text formats, also AutoCAD data format, thus supporting "screening" of data sets for their potential use. In nfdi4energy, LDM will be adapted to the specific needs of energy research and support energy research data visualisation. With the help of the LDM, digital repositories are interconnected in such a way that data sets and other scientific DOs remain in their respective repositories and the LDM provides an integrated view of the DOs archived by these repositories. In this way, the LDM will not only maintain metadata, but will also solve interoperability issues across repositories and will provide a uniform data view. Deliverable: [D4.4.2.1] Implementation of the LDM prototype for nfdi4energy relevant research data (service)

Task 4.4.3 Access library to nfdi4energy services

Description: In this task, we develop a software library and APIs that provide applications developers, data scientists or software agents programmatic access to services and metadata of the nfdi4energy platform. This will enable users to not only automate recurrent tasks or perform large-scale analyses, but offers the community to develop further services based on the nfdi4energy platform. The focus is on providing functionality for interaction with the ORKG, federated search, PID graph and the submission service that ensures the publication and archiving of digital research objects. This will be realised also by integrating existing external APIs like the ORKG API and the DataCite GraphQL API for accessing information available in ORKG and the PID graph, respectively. The design and engineering of the platform APIs follows a RESTful API design style and the API first strategy, where API definition precedes service implementation. This involves establishing an effective collaboration with the research community from the beginning to get early feedback on the API design for achieving high quality APIs and optimised user experience of the nfdi4energy platform. For the specification of the REST APIs we will adopt OpenAPI.

Deliverables:

[D4.4.3.1] Initial version of non-public APIs to be connected to the nfdi4energy platform of TA1 (service)

[D4.4.3.2] Final version of APIs, publicly available (service)

Task 4.4.4 PID service

Description: The integration of PIDs such as DOI and ORCID is essential for a sustainable publication culture as part of research data management. Under this task, we will continue work on PID developments for domain-specific content or object types such as software, research tools, data management plans, repositories, and conferences. In this way, the visibility and reusability of research results, as well as the overall trustworthiness of research, will be improved. The PID service for nfdi4energy will implement a well-defined interface to the Metadata *Registry* with the aim of providing an environment in which the PID service, in close collaboration with all other registries, will facilitate interoperability through standardised metadata requirements. Based on the domain-specific requirements and user needs identified from TA4, TA5, and TA6, a domain-specific PID concept or systems will be developed. By integrating and connecting these PID systems via a PID graph [30] reportability and transparency on current and future scientific contributions will be enabled.

Deliverables:

[D4.4.4.1] Implementation of PID Service (service)

[D4.4.4.2] Interface to other registries (service)

Task 4.4.5 Submission service

Description: This task will deliver a submission service, which supports the researchers to publish their research artefacts as FDOs. The service implements a user guided process, which consists of three stages: The FAIRification of DOs; the optional deposition of the FAIRified DOs in selected DO-specific repositories and the registration in a registry.

The FAIRification of DOs starts with the selection and application of artefact- and domain-specific standards (terminology service, Task 4.1.4) established in TA4 and TA5 to describe and interlink DOs. Metrics measure the level of FAIRness achieved and provide the user with feedback in the form of recommendations for possible improvements. In the second stage, by means of the PID service (Task 4.4.4), FAIRified DOs are published in external artefact-specific repositories to ensure long-term data preservation and accessibility and to make DOs discoverable and citable. In the third stage, the FDO is registered with its metadata including PIDs in the metadata *Registry* (Task 4.4.2). The development of the submission service is based on the specific applications that emerge for the different types of DOs in TA4 and TA5.

Deliverables:

[D4.4.5.1] Identification of metrics measuring the level of FAIRness of different DO types (report)

[D4.4.5.2] Identification of repositories for publishing different DO types in the energy domain (report)

[D4.4.5.3] Prototypic implementation of the submission service - limited to the support of a single DO and repository (service)

5.5 TA5: Simulation in Interdisciplinary Energy Research

Lead: FAU

Measure Leads: ALU, FAU, OFFIS

Description and Objectives

Simulation is an important tool for energy research, as introduced in Section 4.1, and is already available in many variants. The overall goal of this TA is to give better support for the use of simulation in the energy domain, both for experts and interested non-experts, supporting the FAIR principles not only with respect to data, but to research software as well. For all these purposes, easy and standardised access is a main issue. In order to approach the field, an ontology of simulation paradigms and available software solutions is needed. Model registries for stand-alone simulation software will be one way to support this objective. For many advanced research questions, it is often necessary to perform distributed simulations. This allows for instance to combine simulation software from different domains (co-simulation for, e.g., energy sectors, markets, IT, and communications, mobility), to combine different abstraction layers (multi-level-simulation for, e.g., a fine grained simulation of a mechanism for households in a neighbourhood, integrated in a larger energy system), or different executables of the same simulation software in order to increase performance (parallel simulations for, e.g., portions of a grid model on different processors, potentially connected remotely). Typically, such distributed simulations require higher coding skills compared with stand-alone simulations and are therefore not easily accessible. Thus, it is a major objective of this TA to give better support for performing distributed simulations in the energy domain, by this additionally supporting interdisciplinarity. A first approach for this is to use ontologies for an assistance in the selection, development and execution of distributed simulation scenarios. A second approach is to improve the use of simulation middleware in order to support the configuration and execution of distributed simulation scenarios. The overall goal of these efforts is to provide Simulation-as-a-Service (SaaS) with the nfdi4energy platform as a front-end. The researchers participating in this TA will actively contribute to the WG Scenario Description Standardisation to harmonise the different conceptions of scenarios (see TA4).

From these ideas, Task Area 5 targets the following objectives:

- [O5.1] Provide an overview of relevant simulation software, models, and methods applied in this field in energy system research as service for the community (*Competence* service)
- [O5.2] Identify best practices in energy system distributed simulation and generate easy-access tutorials for better support on this methodological paradigm
- [O5.3] Assist the simulation workflow on the base of ontologies in selection, configuration, and execution of simulators

- [O5.4] Improve existing simulation middleware to increase its general usability for energy researchers
- [O5.5] Establish a SaaS frontend for the nfdi4energy platform

Measure 5.1 Energy simulation software and methods overview

Lead: ALU

Contributions: FAU, KIT-IAI, OFFIS, RWTH, UOL

Goals: Simulation categories as metadata description (reflecting different types, heuristic approaches vs. optimisation, level of physical detail, spatial, and temporal resolution, control and communication, sectors, visualisation, licence model).

Description: Simulation software can be categorised according to various criteria, including the type of simulation (e.g., whether the agent-based paradigm is used or not, whether uncertainty is considered), whether heuristic rules or optimisation is used (e.g., LP/IP/MIP), a physically detailed or more abstract view (e.g., voltages and currents or energy flows in an electric grid), spatio-temporal resolution (e.g., seconds for a mechanism between households in a neighbourhood or hours in a national level model), control and communication (e.g., latency, throughput and reliability of communication channels or idealised assumptions on it), considered sectors (e.g., electricity, heat, gas), visualisation (from simple plots to advanced animations), and licence model (e.g., from permissive open source licence to proprietary). There are several pieces of literature that categorise the variety of energy modelling software, or energy simulation software in particular, [34]–[36] and there are lists of open-source software[58]. However, each overview or taxonomy categorises the models differently, as they have different scopes and reflect the domain knowledge of the authors. Beside this, the taxonomies are not linked to model registries and open source software, if available. Based on different existing approaches, this measure creates an energy simulation software ontology and a model registry, which provides a structured overview of the variety of modelling approaches. In this way, researchers receive orientation, can locate their own approach based on the ontology and compare it with other possible approaches. To achieve interoperability with the domain-specific ontology developed in M4.1, a close coordination of the work is maintained through the cooperation within the WG Metadata & Ontologies. The ontology attempts to be as broad as possible, but does not necessarily provide the depth in all modelling branches. Instead, it invites experts of the different branches (mainly identified from author lists of survey papers and from community knowledge inside the nfdi4energy community) to fill the details for their branches in the form of a moderated procedure. The ontology is

[58] https://wiki.openmod-initiative.org/wiki/Open_Models

complemented with a registry of model implementations and, if available, test cases or other additional resources provided by the model authors. It also provides easy access to existing implementations of the categorised simulation approaches to enable more efficient sharing and easy discoverability of other work. The model registry will be integrated into the services of TA4.

Year	Milestones
1	[MS5.1.1] Stakeholder engagement process for energy simulation software ontology contributions in place
2	[MS5.1.2] Energy simulation software ontology available
3	[MS5.1.3] Model registry available
5	[MS5.1.4] Agent-based simulation registry available

Task 5.1.1 Derive an ontology of energy simulation software

Description: This task builds an overview of a very wide range of energy simulation modelling approaches at a high level and goes into more detail in some of the sub-branches (e.g., agent-based simulation in Task 5.1.3). In parallel, it invites experts of other sub-branches to contribute their knowledge to the further formulation of the energy simulation software ontology in their respective fields. By this, the ontology achieves more than a single review article, because it combines width and depth at the same time, by combining the expertise of nfdi4energy experts and invited other experts.

Deliverables:

[D5.1.1.1] Stakeholder involvement process for the creation of an energy simulation software ontology

[D5.1.1.2] Energy simulation software ontology

Task 5.1.2 Create a model registry for energy simulation software

Description: In this task, model examples are included in a registry and linked to the energy simulation software ontology developed in Task 5.1.1, to provide quick and easy access to young scientists and experts in the respective modelling domain. The registry is complemented by guidance services (e.g., decision trees with relevant questions related to the research question or field of application) that helps finding the most suitable model examples.

Deliverable: [D5.1.2.1] Access model registry, selected software, and example models

Task 5.1.3 Create a registry for agent-based simulation software

Description: Among simulation models, agent-based simulation is one important sub-class. This task will explore the diversity and possibilities of agent-based models in particular, and provides resources on agent adaptivity and learning capabilities. It fills one of the branches in the model registry (Task 5.1.2) down to a high level of detail, which should also serve as an example for other sub-branches of energy modelling approaches addressed at the higher levels of the energy simulation ontology.

Deliverable: [D5.1.3.1] Extension of the energy simulation software ontology and model registry with respect to agent-based simulation and agent learning

Measure 5.2 Ontologies for distributed simulations in the energy domain

Lead: OFFIS

Contributions: KIT-IAI, RWTH, UOL

Goals: Ontology-based approach for integrated development of energy system simulation scenarios

Description: Ontological integration of semantics and domain knowledge in the process of planning, execution, and evaluation of interdisciplinary energy system simulations is required due to the complexity and multitude of domains and models in energy system scenarios[59]. In this measure, we will develop and provide the ontological structures for the modelling of energy system simulation scenarios integrating specialised HIL and laboratory testing. Our approach for ontologies for distributed simulations in the energy domain is based on an information model formalising relations and properties of simulation models and components [19] as well as references to external model- and component-registries from M5.1 and the domain-specific ontology of M4.1. To coordinate with other ontology developments, a collaboration within the WG Metadata & Ontologies is planned.

The main motivation for an ontology-based approach is a process for integrated development and evaluation of energy system simulation scenarios to assist the collaboration of simulation and domain experts in providing components and expertise for an energy system simulation. Simulation experts may be software experts familiar with a given simulation framework and several programming languages or simulation software, but may only have limited knowledge about all domains included in a targeted simulation. The domain experts on the other hand

[59] In the following, we differentiate energy system scenario and simulation scenarios to overcome the semantic problems with the term scenario. Within nfdi4energy, a specific working group is set up to harmonise these conceptions based on common ontologies, see Section 3.4.

possess crucial domain expertise but may have no background in semantic web technologies from computer science or software development (for efficient distributed simulations) in general.

Therefore, an important requirement for our approach is to facilitate the participation of domain experts in the modelling without previous knowledge of semantic web technologies. Thus, a semantic diagram-based approach in form of a mind map is envisioned for modelling the information model. Objects in the mind map can also be annotated directly with additional information (references to external ontologies, e.g. CIM, or the context of future energy system scenarios). While other methods for knowledge modelling with graph-based structures of concept maps exist [37], we argue that a tree-based mind map is sufficient and superior in terms of flexibility for involving non-computer science experts.

For the ontological representation of the modelled information, a base ontology representing the information model structure has been developed at OFFIS [38]. Both RWTH and OFFIS bring in previous experiences and initial data models for the description of laboratory components and coupling from the ERIGrid project[60]. This is complemented by a representation of laboratory infrastructure in the scope of Hardware-in-the-Loop real-time simulations and existing European databases about smart-grid research infrastructure.

Further experience in this area comes from the KIT-IAI. In the Energy Lab 2.0 project, simulators from different domains and real systems are linked together. There is a great need for such ontologies here. In Use Case 6.1, the ontologies developed here are applied and tested in Energy Lab 2.0.

Year	Milestones
1	[MS5.2.1] Identification of domain concepts and narrative relations completed
2	[MS5.2.2] Hierarchical structure of concepts and relations included
3	[MS5.2.3] Formal description of concepts developed
4	[MS5.2.4] Query-based process descriptions and templates evaluated
5	[MS5.2.5] Platform integration completed

[60] https://erigrid2.eu/

Task 5.2.1 Identify and harmonise existing domain ontologies

Description: Existing domain-specific ontologies must be identified. A close cooperation with M4.1 and M5.1 is achieved through the collaboration within the WG Metadata & Ontologies. The partners have significant experience with CIM, IEC 61850, SensorML, CityGML, and own developed ontologies.

Deliverable: [D5.2.1.1] Registry of existing/usable domain ontologies

Task 5.2.2 Integrate and extend domain-specific concepts and relations

Description: The domain-specific ontologies will have to be expanded by concepts and relations (especially from the TA6 use cases) and then integrated into the formal model. There is initial work on this at KIT-IAI, RWTH and OFFIS. This requires the inclusion of middleware specific concepts into the ontology to facilitate an automated simulation setup and execution. By discussing preliminary concepts in the WG Metadata & Ontologies, a close connection to M4.1 will be realised.

Deliverable: [D5.2.2.1] Integrated nfdi4energy simulation scenario ontology

Task 5.2.3 Design and specify (query-based) processes for development and evaluation of energy system simulation scenarios

Description: Based on the requirements from Use Case 6.1, the prototype of a system is built here, which enables the automated configuration and instantiation of simulations and processes. Use Case 6.1 will evaluate the applicability of the ontology in a real-world scenario and provide direct feedback for the ontology development process through the WG Metadata & Ontologies.

Deliverable: [D5.2.3.1] Process specifications/templates

Measure 5.3 Simulation middleware for the energy domain

Lead: FAU

Contributions: OFFIS, RWTH, UOL

Goals: Provide easy access to simulation middleware to support different kinds of distributed simulation, either as a direct approach or as a result from the ontology-based assistance.

Description: Simulation middleware is needed for the coupling of two or more single simulations. A traditional approach is the high-level architecture, initiated in the 1990ies and still relevant in various fields (including military). A well-known approach in the energy domain is mosaik for a close coupling of single simulators. Mosaik follows a conservative (deterministic) discrete event-based scheduling approach with a central scheduler orchestrating the distributed simulation scenario. A more optimistic and loosely coupled publisher-subscriber-middleware approach may increase performance but may necessitate more sophisticated transaction mechanisms (e.g., rollback, which may not be supported by all simulation components out of the box). The loose coupling approach has initially been suggested in the mobility domain and is based on a topic-based publish-subscribe mechanism for the combination of single simulators and other software such as data sources and analytics components. Topics allow for the orchestration of the distributed simulation scenario, for the interaction between single simulations and also for the provision of data between them. All kinds of distributed simulation described in the first paragraph can be realised with the topic-based framework.

We will focus on three middleware variants based on close and loose coupling, respectively. The first one based on close coupling is mosaik because it is already well established in the energy domain and comes with existing wrappers for various simulation software. It also provides time services for conservative synchronisation. The second is a decentralised approach [39] in which services such as orchestration, interaction and data provision are realised by publishing and subscribing to topics. The topic structure is derived from predefined data-models describing the submodel's worldview [40]. The coupling concept can be implemented efficiently by data stream processing platforms such as Apache Kafka, comes with time services, and can connect to other components such as data sources as well. The last coupling variant is based on strict peer-to-peer exchange of electrical interface quantities for use in distributed real-time simulations where the latency and a deterministic timing are the key requirements [41]. The approaches will be compared and extended while considering performance, scalability, persistence, and traceability of the simulations. Finally, the optimised service will be accessible from the nfdi4energy platform and execute distributed simulations for use of the CPES community.

Year	Milestones
1	[MS5.3.1] Requirements analysis completed
3	[MS5.3.2] Simulation middlewares extended
5	[MS5.3.3] SaaS for the energy domain realised

Task 5.3.1 Conduct requirements analysis

Description: Based on the different use cases from TA6 a requirements analysis must be carried out as a first task in this measure. The question of what kinds of coupled simulations should be realised in the context of this project needs to be answered. This spawns across several dimensions, e.g., how many different submodels shall be coupled concurrently, what are the run-time constraints, or what modelling paradigms need to be combined. The methodical decisions of the following tasks depend on this outcome.

Deliverable: [D5.3.1.1] List of requirements

Task 5.3.2 Extend co-simulation framework mosaik

Description: One of the key frameworks for distributed (Co-) simulation and a quasi-standard in the field is mosaik[61] [42], which will be extended to support the ontology-based design and validation processes of simulation scenarios as well as the use cases and their respective submodels. Aside from integration, the appropriate submodels there are some extensions to the framework necessary in order to integrate it with the nfdi4energy activities as well as the platform concept.

Deliverable: [D5.3.2.1] Ontology-based simulation framework features (software artefact)

Task 5.3.3 Extend existing topic-based publish-subscribe framework

Description: In the scope of this task, an existing framework for loosely coupling different simulators is extended to meet the requirements from Task 5.3.1. Therefore, a concept needs to be developed as well as implemented. Although the framework was designed in a general way, its primary use was in the mobility domain. Therefore, one issue is the adaption to the modalities of the energy sector. The approach also provides SaaS capabilities, which shall also be extended to fit with the intended use cases of TA6.

Deliverables:

[D5.3.3.1] Concept for framework extension (software architecture)

[D5.3.3.2] Implemented features within framework (software artefact)

Task 5.3.4 Extend co-simulation framework VILLAS

Description: In this task the existing co-simulation framework VILLAS[62] should be extended to assist the users with software for the automatic configuration of a distributed network of VILLASnode gateways via a central web-based interface. The generation of gateway configuration files should be based on the ontology developed in Task 5.2.2 and be supported by a web-based graphical editor to design a simulation topology. These advancements provide the user with a global view of lab and component interconnections while still keeping data-flows local to the devices and laboratories where possible by avoiding a single broker-based exchange point. Existing features of the framework should be used for deploying and controlling gateway instances.

Deliverable: [D5.3.4.1] Web-based UI for framework VILLAS (software artefact)

[61] https://mosaik.offis.de

[62] https://fein-aachen.org/en/projects/villas-framework/

Measure 5.4 Platform integration

Lead: FAU

Contributions: ALU, KIT-IAI, OFFIS, RWTH, UOL

Goals: Create the link between TA5 and the overall nfdi4energy platform.

Description: In order to enable the use of the services developed in TA5, it is necessary to offer ways to integrate them into the overall platform. Therefore, the results of the three previous measures must be made available on the nfdi4energy platform, developed in TA1. This includes 1) the categorisation, interfaces or links to simulation frameworks, and model registry, 2) the ontology-based assistance to prepare, configure and execute distributed simulations, and 3) the chosen middleware approaches. To embrace the functionality of the given measures, an API needs to be designed and implemented within the services. In this way, we allow the direct use of the *Simulation* service by nfdi4energy users. The service will be carefully tested by the use cases in TA6.

Year	Milestones
3	[MS5.4.1] Interface definition finished
5	[MS5.4.2] Integration of components completed

Task 5.4.1 Develop external service interface

Description: The question of how to encapsulate the model registry (M5.1) and the three simulation middlewares (M5.3) needs to be answered. As a result, interfaces are designed. There will be either one global interface that offers all services and allows access to these different components in a homogeneous way, or dedicated interface definitions for the model registry and the simulation execution part.

Deliverable: [D5.4.1.1] External service interface definitions (software documentation)

Task 5.4.2 Integrate model registry with platform

This task deals with a link between M5.1 and the overall platform. As a first step, based on the findings of Task 5.4.1 a mechanism is implemented in order to provide access to the collected information. This includes the developed guidance service of the registry. As a second step, interested researchers should gain the possibility to not only consume information from the registry, but also extend it with their knowledge.

Deliverable: [D5.4.2.1] Implemented model registry integration (software artefact)

Task 5.4.3 Integrate mosaik with platform

Description: Based on the ontology from M5.2 design (model selection and coupling/interfacing) and validation (sub-model interoperability and quality of results) for mosaik will be implemented via a platform front-end that facilitates a guided design process. The process will generate a mosaik configuration file that can be used to instantiate simulations.

Deliverable: [D5.4.3.1] Implemented mosaik framework integration (software artefact)

Task 5.4.4 Integrate topic-based publish-subscribe framework with platform

Description: This task deals mainly with implementing the binding between developed interface and the existing framework for loosely coupled distributed simulations. Besides, there should be the possibility for easy testing and performing demonstrations without being dependent on the outcome of other TAs. Therefore, at least a prototypical frontend is built on top of the interface.

Deliverables:

[D5.4.4.1] Implemented publish-subscribe framework integration (software artefact)

[D5.4.4.2] Prototypical frontend for demonstrations (software artefact)

Task 5.4.5 Integrate VILLAS framework with platform

Description: In this task, the VILLASnode simulation-data gateway should be extended with new interfaces required for its integration into the middleware as well as its use in the Use Case 6.1. In particular an integration into the mosaik middleware as well as data registries from TA4 are to be pursued to enable the use of the VILLASnode gateway as a data sink / source for recording and playback of results in a real-time simulation scenario.

Deliverables:

[D5.4.5.1] Implemented platform integration (software artefact)

[D5.4.5.2] Implemented interfaces for TA4 data repositories

5.6 TA6: Use Cases for Community Services

Lead: ALU

Measure Leads: ALU, KIT-IAI, OFFIS

Description and Objectives: While TA1 to TA5 develop the necessary community services of nfdi4energy, the main objective of TA6 is to define additional requirements from energy research examples and to apply the provided services to specific use cases which reflect core needs of the scientific energy system research community. Thus, the role of TA6 within nfdi4energy is threefold: (1) In order to demonstrate the usability of the developed services as the ontologies and middlewares, the use cases from TA6 are implemented based on these developments. (2) Additionally, new requirements from the use cases must flow into the work in TA1 to TA5, with a special focus on TA2, as the integration of society still shows methodological weaknesses in energy system research and therefore will receive a focus here. (3) Additional visibility for the developed services within the community is generated and, thus, is strengthen the user group activities (TA7).

The use cases are examples of the main different types of projects within energy system research with respect to involved disciplines, research data and simulation needs. Therefore, they will lay the ground for the future expansion of the research data collected and provided in energy research. Use case “Energy lab & simulation coupling” (M6.1) provides a setup which, in addition to simulators, also links real laboratories. The services developed from TA4 and TA5 can therefore be used and tested in a complex simulation scenario. Use case “Long term energy system scenarios, society and energy politics” (M6.2) will provide a detailed energy system scenario comparison, building on developments in TA4. By using methods from TA2 the results will be brought to a broader audience reaching from the public to decision makers. Finally, the use case “Distributed simulation for distributed energy systems” (M6.3) addresses self-organisation with autonomous agents based on distributed simulations. This use case also includes methods from TA4 and TA5, applies best practices from TA1 and includes industry data as result from TA3.

A central element of TA6 is to showcase the potential of the FDO registries developed in TA4 and to feed back additional requirements in view of the practical experience made throughout the implementation of the use cases. An iterative feedback cycle between the use cases and the platform development in TA1 will be established for this purpose. Also, the use cases of TA6 deliver best practice exampling, showing how to use the developed services of nfdi4energy in small research projects. These best practices can be included into the platform developed in TA1.

Summarising, Task Area 6 will in particular contribute to the following objectives:

- [O6.1] Deliver additional requirements for TA1 to TA5
- [O6.2] Apply best practices to address social challenges in future energy system concepts from TA2
- [O6.3] Show how the processes of industry involvement from TA3 can be applied to research examples
- [O6.4] Use standardised scenario description from TA4 (reflecting harmonised scenario conceptions from WG Scenario Description Harmonisation) to make energy system scenario results accessible, understandable and comparable to the public and to support decision makers.
- [O6.5] Test the developed methods to couple distributed simulators and real laboratories from TA5
- [O6.6] Deliver best practices examples and guidelines for TA1

Measure 6.1 Use Case: Energy lab & simulation coupling

Lead: KIT-IAI

Contributions: RWTH

Goals: Automatable configuration and execution of a coupled simulation of a user-supplied ontology-based scenario description

Description: Use Case 6.1 provides an adapted scenario from distributed simulations and real laboratories, with the help of which the developed concepts, ontologies and services from TA4 and TA5 can be applied. The scenario should also include the use of industrial data as a further characteristic. A tutorial for the coupling and use of distributed simulations and real laboratories emerges from this application, which is played back into the community in TA1 to TA3.

As an application example, an element from EnergyLab 2.0 is chosen. EnergyLab2.0 is a living laboratory as well as a simulation platform for the development of the energy system of the future[63]. RWTH will be linked into the scenario by acting as a data provider, representing the role of an interconnected laboratory. This demonstrates the capabilities of the ontology-based approach to involve third parties.

For this purpose, a scenario has to be identified first, which serves as a demonstrator. The scenario must contain various simulation components that are to be configured and coupled in an automated manner and must also contain real components. The EnergyLab 2.0 comprises

[63] https://www.elab2.kit.edu

many real components, such as photovoltaic systems, battery storage systems, Power2Gas systems, gas turbines, and so on. In order to be able to automate the different components of the scenario, the components have to be described in a standardised way. For this purpose, the ontologies developed in TA4 and TA5 are used to describe the components. This includes the description of the configuration, their control, the description of input parameters as well as a description of input and output data. For the description of the data, a suitable metadata format provided by the ontology from TA4 and the *Simulation* service from TA5 are used. Active participation in the WG Scenario Description Standardisation will be given.

Year	Milestone
1	[MS6.1.1] Description of the scenario for the demonstrator completed
2	[MS6.1.2] Collection of the component descriptions finalised
3	[MS6.1.3] Overall model using the ontologies from TA4 and TA5 completed
4	[MS6.1.4] Implementation of component interfaces and controllers finished
5	[MS6.1.5] Demonstration and tutorial published

Task 6.1.1 Identify use case scenario

Description: The first task is to identify a scenario from EnergyLab 2.0 and RWTH Aachen that is suitable as a demonstrator. For this purpose, the required components must be identified and the necessary documentation and descriptions must be recorded and collected in order to develop a description of the scenario.

Deliverable: [D6.1.1.1] Description of the scenario (report)

Task 6.1.2 Model selected scenario using ontology

Description: The second task is model building. The goal is to create a model of the scenario using the ontologies from TA4 and TA5. Existing modelling of individual components must be collected, integrated into an overall model, and transferred to the ontology. Exchanged data with the third party will be prepared.

Deliverable: [D6.1.2.1] Model of the scenario using the ontologies from TA4 and TA5 (report)

Task 6.1.3 Implement coupling for use case prototype

Description: For the realisation interfaces must be developed conformal to the ontology (according to the modelling). After selecting a suitable framework (TA5), the components are integrated into a complete system with the help of the framework. The result is a first prototype of coupling simulators and real laboratories.

Deliverable: [D6.1.3.1] Coupling distributed simulations and real laboratories (report, demonstration)

Task 6.1.4 Create documentation and tutorial

Description: The developed demonstrator is documented and published and serves as an example for further applications. A tutorial will be created through which the results will be published in the community (TA1 - TA3).

Deliverable: [D6.1.4.1] Tutorial for coupling simulators and real laboratories

Measure 6.2 Use Case: Long term energy system scenarios, society and energy politics

Lead: ALU

Contributions: IASS, KIT-IISM, RLI

Goals: Provide transparent and open comparative information and data on long-term energy system scenario results

Description: Since the recent change in the German climate protection act that prescribes the goal of becoming carbon neutral until 2045, several larger energy system scenario studies have published their extensive results, and even more scenario results are expected to be published in the coming months and years. As each study takes a different approach, it is difficult to compare results quantitatively, and to draw overall conclusions about consensus and controversies in the findings [42]. Ideally, outcomes would be made easily comparable, and key aspects would be visualising for making it intuitively accessible to policy makers and other interested stakeholders. In view of the need to quickly transform our energy systems, this easily accessible and understandable information is of high practical need. For this use case, a detailed scenario comparison with additional visualisation features will be done for long-term energy system scenarios for Germany published in recent and ongoing studies from various research institutes.

Year	Milestone
1	[MS6.2.1] Suitable energy scenarios screened and selected
2	[MS6.2.2] Energy scenarios annotated with suitable vocabulary or ontology
3	[MS6.2.3] Scenario comparison concept developed
4	[MS6.2.4] Scenario visualisations are implemented, first experiments conducted

Task 6.2.1 Define scope and requirements

Description: In this task, the ontology developed in M4.3 is applied for scenario comparison. Suitable scenarios and comparable parameters have to be identified, analysed and selected. Selected parameters need to be embedded in a sound comparison concept that integrates various scenario DOs. The parameters need to be annotated with reasonable ontology terms to enable effective comparisons across different scenarios and to lay the groundwork for quantitative automated scenario comparison. Based on feedback from Task 6.2.3, the chosen scope and parameters will be reassessed using insights from the energy community.

Deliverables:

[D6.2.1.1] Stakeholder workshop on energy system modelling

[D6.2.1.2] Standardised energy scenario description concept

Task 6.2.2 Adapt the open platform for energy scenarios

Description: Based on existing initiatives such as the OEP, the service developed in TA4 is adapted for and filled with long-term energy system scenario data for the specific case of climate neutral energy scenarios for Germany in 2045. The task builds on existing concepts to bring together a variety of artefacts for scenario description in a meaningful way. Previous projects, such as SzenarienDB, laid the groundwork by introducing scenario factsheets or suitable metadata strings, but did not address their comprehensive comparison. Therefore, this task focuses on connecting existing scenario descriptions to facilitate easy-to-use and meaningful scenario comparisons, facilitating a machine-readable and automated process that builds upon existing vocabularies, ontologies and services.

Deliverables:

[D6.2.2.1] Standardised scenario description for selected scenarios

[D6.2.2.2] Scenario comparison implementation and report

Task 6.2.3 Develop and validate draft visualisations

Description: In order to reach a broad audience, the results of energy scenarios must not only be comparable, but also need to be communicated in a way that is informative, engaging and understandable for non-experts. In this task, target groups from the public will be selected based on results from TA2 and drawing from M2.6 and requirements for communicating scientific results will be applied to visualise the energy system scenarios that are made comparable in Tasks 6.2.1 and 6.2.2. As a result, several visualisations with interactive and gamified elements will be developed to address the respective target groups' interests and needs. Such features will allow to clarify trade-offs between different factors in the scenarios, illustrate sensitivities, or translate user preferences into parameters covered by the scenario ontology. The different elements will be integrated on the platform and tested in the long term during the project period to analyse the usage behaviour and preferences through surveys and interviews with participants from the identified target groups. By applying the methods and concepts drawn from M2.1 and 2.6 to the specific use case of long-term energy system scenarios, this use case also provides a valuable feedback cycle to TA2.

Deliverables:

[D6.2.3.1] Mock-ups of scenario visualisations with interactive and gamified elements

[D6.2.3.3] Surveys and interviews (report)

Task 6.2.4 Involve the public & decision-makers

Description: The energy transition is a societal task and hence of great interest to the broader public including policy makers and business stakeholders. However, there is a mismatch between the needs of modellers and users, and the wider audience in the ways that model results are communicated. In this task, we will draw on the public engagement work of TA2 and stakeholder mapping process. We will conduct focus group processes with selected target groups, e.g., local government representatives, state government representatives etc. to test the visualisation tools and gamified elements developed in 6.2.3. The focus group feedback will provide useful insights for TA2 and beyond. In close collaboration with TA2, the results will be summarised and documented in form of a communication guide for modellers targeting specific audiences.

Deliverables:

[D6.2.4.1] Summary report from focus group sessions

[D6.2.4.2] Communication guidelines

Measure 6.3 Use Case: Distributed simulation for distributed energy systems

Lead: OFFIS

Contributions: FAU, SOFI, UOL

Goals: Provide requirements for the standardised representation of flexibility and the integration of co-simulation systems based on distributed simulation using standardised interfaces, elaborate best practices on the integration of acceptance studies

Description: Due to the increasing integration of renewable energies, the interaction and coordination between all actors in the system is becoming more and more important in order to efficiently jointly manage the high volatility of generation and grid congestions at all grid levels. Market mechanisms for the use of flexibilities require closer cooperation between both grid operators and private actors delivering flexibility options on lower voltage levels. Self-organisation using autonomous agents as technical foundation within automation systems is key to adaptive and self-healing systems, especially in future application areas of redispatch based on market principles. Research in this field leads to new requirements regarding energy system simulation (e.g., regarding co-simulation including communication simulation) and management of research data. Social challenges (e.g. acceptance) for the implementation of new concepts are reflected as well and thus should optimise the research and development process. As such, this use case delivers requirements to TA1, TA2, TA4 and TA5.

Year	Milestone
1	[MS6.3.1] Use case exemplary process defined
2	[MS6.3.2] Requirements for standardised flexibility representation defined

	[MS6.3.3] Requirements for co-simulation derived
4	[MS6.3.4] Best practices on the involvement of society to enhance social acceptance in early research phases deduced
5	[MS6.3.5] Exemplary results transferred to platform in standardised format

Task 6.3.1 Derive a model of distributed flexibility

Description: The modelling of flexibility for new applications in future multi-modal energy systems has been an important research area in the last decade. In this task, different flexibility modelling concepts are evaluated based on literature studies in prior projects, with an additional focus on user preferences modelling. From this, requirements will be deduced for the specific use case of self-organised redispatch on the distribution level regarding standardised representations of flexibility as input for *Best Practices* (TA1).

Deliverables:

[D6.3.1.1] Requirements for standardised flexibility representation as input for TA1 (*Best Practices*) (report)

[D6.3.1.2] Tutorial on flexibility modelling as input for TA1 (tutorial)

Task 6.3.2 Develop self-healing flexibility aggregation

Description: Autonomous systems of distributed artificial intelligence (DAI) are a core research direction in energy system research. In this task, an exemplary application of DAI in energy system research is shown to reflect the specific requirements of this research direction early in the platform development (TA1).

Based on the open-source framework “mango”[64], intelligent and autonomous software agents are developed, which are assigned to individual decentralised small plants and can manage and forecast their flexibility or redispatch capability (see Task 6.3.1). Based on suitable methods from organic computing, these software agents will be combined into a self-organised, controllable flexibility pool that offers aggregated flexibility to the grid operator. A dedicated observer/controller agent [43] assumes the role of a flexibility aggregator, which acts as a dispatcher in case of a redispatch request and monitors the compliance with the promised flexibility provision during operation. Furthermore, self-healing mechanisms are developed by which the self-organised system can respond at the algorithmic level to disturbances, such as communication impairments or the failure of plants.

Deliverables:

[D6.3.2.1] Requirements regarding coupling of simulators as input for TA5 (report)

[64] https://gitlab.com/mango-agents/mango

[D6.3.2.2] Resulting research software as open-source software, to be integrated in registry (TA4/ TA5) based on recommendations regarding metadata standards (TA4) (research software)

Task 6.3.3 Analyse self-healing mechanisms for redispatch pools

Description: The robustness of distributed agent-based optimisation methods for self-organising redispatch will be developed based on prior research activities [44] and is investigated in a co-simulation. This task is closely coupled with the integration of the communication network simulation (Task 6.3.4).

Deliverables:

[D6.3.3.1] Requirements for the integration of autonomous systems based on DAI as input for TA5 (report)

[D6.3.3.2] Exemplary results of self-healing redispatch using distributed autonomous agents (research data)

Task 6.3.4 Conduct communication network simulation

Both centralised as well as decentralised control strategies in the energy sector rely on the quality-of-service (QoS) of the underlying communication network, i.e., latency, throughput, loss probability, as well as network reliability. Communication networks as a part of an energy system can be modelled at various abstraction layers: the most direct approach is to use a packet-level communication network simulator such as OMNeT++ or ns3 based on the discrete-event paradigm, as this allows for studying protocol details and also mutual dependencies between the energy system and the communication network; it however requires co-simulation capabilities in order to couple the other simulators(s) with the network simulator. As an alternative approach the QoS characteristics can be represented inside another simulator by its statistical properties, possibly derived by using machine learning [45]. Impairments of the network QoS such as link disruptions, increase of delay, etc. can be investigated with both approaches. TA5 will provide simulation middleware for the easy access and configuration of distributed simulations. Therefore, the results of TA5 will be used in this Use Case 6.3 and it will also be a benchmark for the results of TA5. FAU has provided the well-known open-source framework Veins [46] for connecting communication network simulations (OMNeT++) with microscopic traffic simulations (SUMO), similarly SGsim (connection of OMNeT++ and distribution system simulator DSS)[47] and has also provided a topic-based publish-subscribe framework [18] for distributed simulations. The work in this task will be based on those results.

Deliverables:

[D6.3.4.1] Requirements regarding the need for communication simulation in Use Case 6.3 as input for TA5 (report)

[D6.3.4.2] Configuration of distributed simulations for studying communications in the Use Case 6.3 as well as requirements for this field for TA5 (report / *Best Practices*)
[D6.3.4.3] Example results of the simulations of Use Case 6.3 (to be transferred to platform (TA1)) (research data)

Task 6.3.5 Implement aggregation-based management of flexibility

In order to orchestrate decentralised assets for providing grid flexibility demands such as needed for redispatch either aggregation of the individual asset constraints or optimisation models are possible. The approach chosen in Task 6.3.1 will be reflected here as follows: Aggregation is scalable but typically not able to respect all individual constraints whereas optimisation can consider them but has scalability problems when used for centralised control of a large set of individuals. An aggregation/disaggregation concept has been suggested which takes into account all individual charging constraints (with respect to power, energy, and time) of electric vehicles of a larger fleet and can efficiently compute the ability to provide flexibility over time without violation of any individual constraint ("FlexAbility") [48]. It is intended to adapt this approach in terms of assets (besides electric vehicles also stationary batteries of households can be considered), bidirectionality (currently charging is restricted to be unidirectional), uncertainty (instead of deterministic demands random profiles of the individual components), combination of centralised and decentralised control (a regular central computation alternating with decentralised operation), and resilience (operation under impairments of the communication). The resulting aggregation can be handled as one actor in Task 6.3.1 to validate the chosen approach and show its applicability for hierarchical and holonic settings. It will be investigated how this approach works in Use Case 6.3 and which requirements result for TA5.

Deliverables:
[D6.3.5.1] Requirements for simulation settings using hierarchical aggregation concepts as input for TA5
[D6.3.5.2] Exemplary results: Test of the control approach compared to decentralised control for integration in research data repository (research data)

Task 6.3.6 Conduct case study on social challenges of local implementation

Description: This task is closely connected to TA2 and serves there as a local case study. Since the success of the implementation of new technologies and devices like autonomous agents for self-healing redispatch is determined by social and political acceptance and support, we aim to analyse the perceptions and concerns of people potentially in contact with this new technology. Thus, we will select a local case study where we find people who are already engaged in the issue of energy for example via own solar panels or shared energy supply as well as people who are not experienced in this field so far. The effects of an adapted flexibility modelling including user preferences is one of the aspects in this case study. The results of this qualitative case study gained via interviews and focus groups are an integral part of TA2.

Deliverable: [D6.3.6.1] Best practices to include aspects of social acceptance in early energy system research phases as input for TA1 and TA2 (report)

5.7 TA7: Organisation & Management

Lead: UOL

Measure Leads: TIB, UOLB

Description and Objectives

TA7 comprises the tasks for the overall project organisation and management. It ensures a successful and efficient internal project management, external communication and of course a good integration of nfdi4energy in the NFDI landscape, as well as equal opportunity measures. The main project management is done by the Project Office (PO), as introduced in Section 3.4.

Task Area 7 targets the following objectives:

- [O7.1] Efficiently manage and govern the nfdi4energy consortium
- [O7.2] Ensure proper accounting and compliance with legal obligations
- [O7.3] Organise internal and external communication and information infrastructure for the project
- [O7.4] Ensure quality of the whole work within the project
- [O7.5] Support the integration of nfdi4energy in the NFDI landscape

Measure 7.1 Overall management and governance

Lead: UOL

Contributions: All

Goals: Set-up of the overall management, governance structure and advisory boards

Description: Within M7.1, the organisational structure described in Section 3.4 “Organisational structure and viability” should be set up. This includes the steering committee (SC), the scientific advisory board (SAB) and the industry advisory board (IAB). The governance structure should be operational over the whole project.

Year	Milestone
1	[MS7.1.1] Set-up of the SC completed
	[MS7.1.2] First meeting of SC conducted
	[MS7.1.3] Set-up of SAB completed
	[MS7.1.4] Set-up of IAB completed
2-5	[MS7.1.4-7] Annual meetings of SAB conducted
	[MS7.1.8-11] Annual meetings of IAB conducted

Task 7.1.1 Support work of Steering Committee (SC)

Description: The management of all TAs is coordinated within the SC. Therefore, directly at the beginning of the project, the SC should be brought to life. Within the SC, the PO supports and assists the task leaders in organising meetings, writing reports and adding contributions to the media channels. The SC ensures proper work in all TAs and moderates in cases of conflict.

Deliverables: [D7.1.1.1-5] Annual Report of the work of the SC

Task 7.1.2 Support work of Scientific advisory board (SAB)

Description: The scientific advisory board brings a broader scientific perspective to nfdi4energy. The PO is responsible for setting up the SAB and organise the annual meetings. Possible new members could be identified by the group of the SAB members. The PO moderates the process to be handled by the SC.

Deliverables: [D7.1.2.1-5] Report of the annual SAB meetings

Task 7.1.3 Support work of Industry advisory board (IAB)

Description: The industry advisory board brings the industry perspective to nfdi4energy. The PO is responsible for setting up the IAB and organise the annual meetings. Within this work, the PO is depending on the network of the SC members and will support the SC in identifying, informing and including possible IAB members.

Deliverables: [D7.1.3.1-5] Report of the annual meetings

Task 7.1.4 Coordinate recruitment for nfdi4energy

Description: Recruitment for technical positions can be difficult. Therefore, the project partners want to support each other by having a common overview of openings, which should also be synchronised with the NFDI website. This overview should help to identify and direct candidates towards matching positions within the consortium. Job openings from nfdi4energy will be reviewed regarding equal opportunity for all partners.

Deliverable: [D7.1.4.1] Overview of openings, communicated internally and externally

Task 7.1.5 Support equal opportunity within nfdi4energy

Description: Equal opportunity for minorities and female researchers should be aimed within nfdi4energy. The ratio of women within the project including student researchers should be regularly reviewed. Based on the recommendations of the DFG[65], the members of the consortium will discuss and develop strategies to increase the number of women in the project. The consortium holds members highly active in equal opportunity measures in different committees, thus adding a lot of experience in this field to the consortium. The PO will be in charge of making the respective activities prominent within the whole consortium.

Deliverables: [D7.1.4.1-5] Annual report on gender equality and diversity

Task 7.1.6 Coordinate future project extensions

Description: Within the long project time, new developments in the field of research data management as well as in the energy domain are expected. Therefore, the PO will follow these developments and coordinate possible extensions to nfdi4energy.

Deliverables: [D7.1.6.1-5] Annual report on possible project extensions

Measure 7.2 Accounting and contract management

Lead: UOL

Contributions: All

Goals: All funds should be correctly assigned to the partners and a correct spending should be ensured

Description: Within nfdi4energy a consortium agreement needs to be negotiated to arrange the financial distribution within the consortium. Funds should be correctly distributed every year. Additionally, contracts with RLI and FhFIT should regulate their integration into nfdi4energy.

Year	Milestone
1	[MS7.2.1] Consortium agreement signed
	[MS7.2.2] Subcontracts with RLI and FhFIT signed

Task 7.2.1 Finalise consortium agreement

Description: The consortium agreement lays the foundation for nfdi4energy. It needs to be negotiated, agreed and signed by all partners. The agreement includes the legal rights and obligations between the partners. This task will build upon prior experiences within other NFDI consortia.

Deliverable: [D7.2.1.1] Consortium agreement

65 https://www.dfg.de/download/pdf/foerderung/grundlagen_dfg_foerderung/chancengleichheit/fog_empfehlungen_2020.pdf

Task 7.2.2 Subcontracting partners

Description: The RLI and the FhFIT are included as partners in the consortium. Their contribution is regulated by subcontracts which need be set up appropriately.

Deliverables:

[D7.2.2.1] Subcontracts with RLI

[D7.2.2.2] Subcontracts with FhFIT

Task 7.2.3 Distribute annual budget to co-applicants and partners

Description: The funds need to be distributed annually to all partners as agreed in the consortium agreements. All usage of the funds needs to be reported, so a common spending report for the DFG can be created.

Deliverables: [D7.2.3.1-5] Common annual spending report

Task 7.2.4 Distribute and manage variable funds

Description: The project includes variable funds to financially support additional projects, to address unforeseen events and to react to risks and other developments. The PO manages these funds and coordinates its usage with the SC. Additionally, the variable funds will be used for speedboat projects for research management for energy system research, as defined by the NFDI4DataScience consortium. The PO will discuss on the process for implementation of the projects with NFDI4DataScience to learn from their experience.

Deliverables:

[D7.2.4.1] Speedboat implementation concept documentation

[D7.2.4.2-6] Annual report on variable funds

Measure 7.3 Marketing, information and event management

Lead: UOL

Contributions: All

Goals: Ensure good communication and information sharing within the project and the community

Description: A common information and communication infrastructure should support the developments within nfdi4energy. It enables an easy access to all information within the project and improves the overall collaboration. Besides the online infrastructure, there will be yearly open meetings with the whole consortium and quarterly meetings within each TA.

To continuously communicate and engage with stakeholders, a variety of communication and networking channels will be used, including events in different formats offline and online (webinars, community events, project website), as well as social media (especially Twitter and

LinkedIn). With these communication channels, nfdi4energy involves and informs people outside the consortium about the progress of the project. IAB and SAB play an important role as multipliers within the community. Specific formats will be developed for these groups to realise a continuous feedback process.

Year	Milestone
1	[MS7.3.1] Communication and information infrastructure set-up completed
	[MS7.3.2] Public website online
	[MS7.3.3] Social media channels started
2-5	[MS7.3.4-7] Quarterly updates for the website performed

Task 7.3.1 Operate communication platform for nfdi4energy

Description: For cooperative projects, good communication between all project partners is fundamental. Therefore, an instant-messaging infrastructure with integrated video conferencing is set up, so communication between all co-workers is the project is supported and simplified, reflecting privacy and GDPG regulations.

Deliverable: [D7.3.1.1] Initial set-up of instant-messaging infrastructure

Task 7.3.2 Maintain information space and project documentation for nfdi4energy

Description: Within the nfdi4energy consortium, documents and data as well as source code will be shared. To support this exchange and collaborative work, an information infrastructure will be set up and a common practice to work on the infrastructure is formulated.

Deliverable: [D7.3.2.1] Initial set-up of information infrastructure

Task 7.3.3 Maintain project glossary

Description: Within nfdi4energy, researchers with different backgrounds come together. To create a common understanding, a common glossary with important terms and their definition is developed by the members of nfdi4energy. The glossary will continuously be improved during the project and can also be used for the development of the domain-specific ontology in TA4.

Deliverable: [D7.3.3.1] First version of project glossary

Task 7.3.3 Organise annual open community events and the meeting of the GA

Description: To coordinate within the consortia and to include the community, nfdi4energy will host a yearly two-day event. The PO will organise these events, to which all members of nfdi4energy will contribute. Attached to the open event, the GA will hold an internal meeting.

Task 7.3.4 Organise quarterly project meetings in each Task Area

Description: To coordinate the activities within the TAs, in each quarter all members of each TA should meet together. To reduce carbon emissions and realise equal opportunity measures, every second TA meeting will be hold online, while every other meeting will be a face-to-face meeting. The PO will support the task leaders in coordinating these meetings and ensure proper documentation.

Task 7.3.5 Maintain a project web presence

Description: To get attention in the community and to inform about the project, a web presence should be developed. The web presence should include general information about the different tasks, like goals and contact persons. The website should also contain project news and information on the annual open community event. The PO is responsible to regularly add new content and updates on the project to the website. Later on, this web presence should also include the platform, which is developed in M1.3.

Deliverable: [D7.3.5.1] Set-up of web presence

Task 7.3.6 Social media activities and outreach

Description: nfdi4energy also aims to interact actively with the public. Therefore, social media accounts (especially Twitter and LinkedIn) should be set up for a broader audience. The social media content should include regular updates from the different TAs and their developments. To coordinate the social media and website activities within the consortium and with partners, a social media strategy should be developed. The goal here is not to replicate the diversity of existing content, but to link, connect, integrate and improve accessibility for the groups involved. Thereby, nfdi4energy supports the NFDI Directorate in their announced initiative for NFDI-wide cross-cutting online engagement and networking.

Deliverable: [D7.3.6.1] Social media strategy

Measure 7.4 Quality management

Lead: UOL

Contributions: All

Goals: Ensure a constant reporting to identify risks and problems at an early stage

Description: While most of the work in nfdi4energy is done within the TAs, there exist some critical dependencies between the TAs. Also, the goals of the project should be reached till the end of the project. Therefore, the overview on the progress of the project is tracked to ensure that all goals can be achieved. The tracking is supported by an annual progress report. Based on the progress report, deviations from the project plan should be discussed and solutions should be developed.

Year	Milestone
1-5	[MS7.4.1-5] Annual progress reports submitted

Task 7.4.1 Monitor project progress

Description: The PO continuously monitors the progress of the project. It tracks the status of the consortium and the ongoing developments. It requests regular reports from all TAs and summarised them for the SC. In case of deviations, it discusses possible solutions with the task leaders and informs the SC.

Deliverables: [D7.4.1.1-5] Annual project summary reports

Task 7.4.2 Coordinate reports and reviews

Description: To monitor the progress and the current state, the consortium will write annual progress reports. These reports are also used as reporting to the DFG and NFDI. The PO and collects the reports from the TAs.

Deliverables: [D7.4.2.1-5] Annual project progress reports

Measure 7.5 Cooperation and engagement within NFDI and beyond

Lead: TIB

Contributions: All

Goals: Create a network of nfdi4energy both nationally and internationally with existing NFDIs, services, projects, stakeholders and initiatives from all research fields relevant to energy research (including in particular computer science, engineering, social sciences, etc.) and beyond.

Description: The success of scientific research is based on the creative collaboration of people. To ensure purposeful collaboration, nfdi4energy plans to work closely bilaterally with a number of other NFDI initiatives to address the challenges of energy system research in a domain-specific and interdisciplinary way. In addition, the members of nfdi4energy will be actively involved in the various NFDI communities and NFDI boards (Directorate, Sections) and participate in the development of international initiatives, such as the EOSC.

Year	Milestone
1 - 5	[MS7.5.1-5] Annual coordination and cooperation with NFDI consortia and with NFDI boards

Task 7.5.1 Manage bilateral cooperation with other NFDI consortia

Description: The NFDI consortia that have been funded so far are working on joint solutions to individual problems in a wide range of fields - from cultural sciences, social sciences, humanities and engineering to life sciences and natural sciences. In this context, cross-consortium exchange is the basis for the success of NFDIs[49]. nfdi4energy has many areas of overlap with NFDI4Ing and NFDI4DataScience, and a close exchange with them already exists. The bilateral cooperation with these NFDIs will continue to be intensified and expanded.

- With its expertise in semantic technology, TIB has already contributed to the development of a semantic framework in NFDI4Ing for the engineering sciences[66]. Within nfdi4energy, TIB will also contribute its expertise in this area, intensify the bilateral cooperation with NFI4Ing in the development of the semantic framework in order to crystallise new connection points between the two NFDIs and support the data retrieval and data generation processes of energy system research.
- Computer science plays an essential role in energy research, so a close cooperation with NFDI4DataScience is indispensable, since this is a consortium operating in computer science, for computer science and in applications. TIB makes an important contribution to NFDI4DataScience with its good global networking in the development of specialist communities from computer science and beyond. nfdi4energy plans to work closely with in order to better network with the specialist community from computer science, as well as with practitioners from the community, and to continuously involve them in energy research.
- Socio-technical aspects also play an important role in CPES research, which is why nfdi4energy will also seek to network with KonsortSWD to identify further potential for collaboration.
- With the third funding round in NFDI, basic consortia will be funded as well. nfdi4energy is explicitly motivated to cooperate with these consortia and to reuse their results, as well as to contribute to the requirements analysis process of these consortia (see also Section 3.3).

Deliverables: [D7.5.1.1-5] Annual report on any further cooperation activities relevant to nfdi4energy and documentation of the results of the cooperation measures.

[66] https://nfdi4ing.de/archetypes/ellen/

Task 7.5.2 Coordinate with NFDI Sections

Description: Cross-cutting topics, which affect several NFDI consortia, have already been identified: Examples of cross-cutting topics are the joint modelling of metadata schemas and ontologies, joint infrastructure services and services on the topic of research data management, legal and ethical issues surrounding the sharing of research data, or even the establishment of citation of research data in scientific publications [49]. These should be processed in future in the NFDI association in so-called Sections. nfdi4energy will actively participate in the consortium meeting with its spokesperson and seek collaboration of the cross-cutting topics with the Sections [50]. In addition to cooperation in Task 7.5.1, nfdi4energy will also work intensively on cross-consortium standards and solutions related to the above-mentioned cross-cutting issues in order to prepare the foundation for collaboration in the consortium meeting and coordination with the NFDI Sections.

Deliverables:

[D7.5.2.1] Identification and documentation of potential cross-cutting topics

[D7.5.2.2-6] Annual reporting in consortium meetings and in Sections

Task 7.5.3 Coordinate with NFDI Directorate

Description: In order to actively support the work and tasks of the NFDI directorate, nfdi4energy will organise and coordinate regular meetings with the NFDI Directorate with our spokespersons to realise a regular exchange regarding strategic, organisational issues around nedi4energy. For the content-related exchange, the professional staff of nfdi4energy will proactively participate in established events organised by the Directorate in various formats (e.g. strategy workshops) to discuss cross-cutting issues and other strategic topics, as well as to help shaping the cross-consortium exchange.

Deliverables: [D7.5.3.1-5] Annual presentation and documentation for the NFDI Directorate

Task 7.5.4 Foster cooperation with European and international partners

Description: The global success of nfdi4energy is based on the cooperation with European (e.g. EOSC) and international partners (e.g. RDA). The consortium is already in close contact with many relevant stakeholders and plan to work closely with them. By continuously observing the highly dynamic environment regarding research data (management), Open Science, CPES research to identify emerging projects and initiatives (with a focus on Germany and Europe) and nfdi4energy will get in touch with them to discuss potential collaborations. At the same time, nfdi4energy will continue to intensify existing collaborations with our partners.

Deliverable: [D7.5.4] Report on existing research partners and cooperation agreements

6 Overall Funding Request

Description and Summary of Contributions by (Co-) Applicants

UOL. Prof. Dr.-Ing. Astrid Nieße as spokesperson of nfdi4energy will dedicate a significant share of her time to coordinate the tasks of UOL within the consortium, as well as to integrate the consortium's contributions as a whole. With her expertise in energy system research, she will especially support the stakeholder-driven process in the CPES research and transfer cycle and the use case driven requirement deduction within the field of selfhealing and selforganising systems. Her experience in research data and software platform development as well as energy system modelling and simulation from prior projects will support the overall aspiration of the nfdi4energy consortium. The University of Oldenburg will provide laboratory facilities in the context of digitalised energy systems, including labs for automation systems, hybrid co-simulations, and distributed energy management systems. These labs are a joined lab infrastructure of OFFIS and UOL. Meeting rooms for GA meetings and other project management facilities for meetings up to 200 persons will be provided. Accounting and contract management will be performed by UOL as an in-kind contribution which is a crucial part for the viable structure of the consortium. Personnel from related projects within the context of FAIR research data and software at about 2 fulltime equivalents (FTE) will be integrated into nfdi4energy for synergetic effects with related initiatives.

ALU. Prof. Dr. Anke Weidlich will dedicate a noteworthy amount of time to coordinate the use cases of nfdi4energy in TA6, particularly Use Case 6.1. There, she contributes by establishing links to her scientific network and beyond in the field of energy system modelling, and by providing her experience from previous work in this field, in order to provide a meaningful application of the community services developed within nfdi4energy. She uses activities in other boards to involve further stakeholders, and she provides here simulation experience in the developments of TA5, especially in the energy simulation taxonomy and model catalogue. ALU will also contribute time resources from one university-financed postdoctoral researcher throughout the project lifetime, as well as meeting and research facilities. Software products and datasets that ALU has developed will also be brought in (e.g., agent-based simulation model flexABLE, data pre-processing software for European energy and emission-related data).

FAU. Prof. Dr.-Ing. Reinhard German as a co-spokesperson of nfdi4enrgy will dedicate a significant share of his time to coordinate FAU´s efforts in nfdi4energy. With his experience in simulation in areas such as computer networking, smart energy, connected mobility and in approaches for distributed simulation he will especially support the simulation activities in nfdi4energy. He and his group will give a focus on TA5 and will contribute to simulation middleware in order to allow for an easy access to simulation services (SaaS).

FAU will also contribute with the simulation framework i7-AnyEnergy (agent-based energy simulation library), SGsim (communication network simulator OMNeT++ and distribution system simulator openDSS), Veins (microscopic traffic simulator sumo and OMNeT++), and the publish-subscribe framework from the “virtual mobility world” project for loose simulator coupling. Expertise from related projects and from the collaboration with Monash University will be added as well.

IASS. Prof. Dr. Johan Lilliestam as co-spokesperson of nfdi4energy will dedicate a significant share of this time to coordinate IASS‘ efforts in nfdi4energy. Through his expertise in energy policy and energy modelling, he will specifically support TA2 to integrate policy and societal needs in the nfdi4energy development. His insights especially from the SENTINEL (H2020) and TRIPOD (ERC) projects will contribute to better understand the needs of modellers and users, especially in the modelling of social, behavioural and political aspects, the trade-off between model complexity and understandability, and the ways that model results should be communicated. The IASS will further contribute information from their Social Sustainability Barometer as a basis for acceptance and public sentiments data. In addition, IASS will provide infrastructure to conduct stakeholder workshops and project meetings at its facilities.

KIT-IISM. Prof. Dr. Christof Weinhardt as co-spokesperson of nfdi4energy will dedicate a significant amount of his time in the management of the KIT‘s contributions to nfdi4energy. Through his extensive expertise and experience with incentive and platform design, he will be able to support the consortium in the development of an interactive and engaging user design on the platform for all targeted stakeholders. His previous work on gamification and visualisation will support the feature design of the platform. Furthermore, with his current focus on digital citizen science, he and his group will contribute to the engagement of the general public on the platform and thereby increase its reach beyond the research community. In this context, he will contribute 1 FTE that will support the citizen science efforts of the consortium and help to establish the necessary corresponding infrastructure. Furthermore, he will contribute 0.2 FTE of technical support for the establishment of the research data infrastructure. The KIT-IISM will further contribute the KD2 Lab to the project, which can be used to conduct user experiments in a protected setting. The KIT-IISM will contribute corresponding resources to prepare and conduct experiments in the project context.

KIT-IAI. Prof. Dr. Veit Hagenmeyer as co-spokesperson of nfdi4energy and Dr. Wolfgang Süß will invest a significant amount of their time in the management of the KIT‘s contributions to nfdi4energy. KIT-IAI will also bring in its expertise in energy system design, modelling, and simulation. KIT-IAI has further expertise in the area of metadata and data management. With the EnergyLab2.0, the KIT-IAI brings a simulation platform and real laboratory into the project, with the help of which the applicability of the developments of nfdi4energy can be verified. KIT-IAI coordinates the HUB Energy of the Helmholtz Metadata Collaboration (HMC). Personnel from HMC Project within the context of FAIR data and software at about 2 FTE will be integrated into nfdi4energy for synergetic effects with HMC.

OFFIS. Prof. Dr. Sebastian Lehnhoff as co-spokesperson of nfdi4energy will dedicate a significant share of his time to coordinate OFFIS‘ efforts in nfdi4energy. With his expertise in digitalised energy system modelling and co-simulation he will support respective areas in nfdi4energy. Additionally, he will use his position as speaker of UOL‘s strategic research area Future Energy as well as his position as board member of the Energy Research Centre of Lower Saxony (EFZN) to actively disseminate the nfdi4energy activities to generate participation within the community. Internationally, he will use his position as Steering Committee Chair of the E-Energy conference as well as his leading position at ACM‘s SIGEnergy for multiplication. OFFIS will provide access to his energy labs, including labs for automation systems, hybrid co-simulations, and distributed energy management systems. These labs are a joined lab infrastructure of OFFIS and UOL. Personnel from related projects within the context of FAIR research data and software at about 2 FTE will be integrated into nfdi4energy for synergetic effects with related initiatives.

RWTH. Prof. Monti as co-spokesperson of nfdi4energy will dedicate significant amount of his time to coordinate the participation of RWTH while also establishing the link with FhFIT. He brings contributions first of all in the area of power system modeling with specific reference to real time simulation and hardware in the loop technology. Furthermore, Prof. Monti is a recognised leader in the design and implementation of data platform for power grid automation as in the case of the SOGNO project, part of the Linux Foundation Energy. Thanks to the cooperation with FhFIT, RWTH will have a unique position in linking the effort of nfdi4energy to industry. Furthermore, Prof. Monti is active in several committees at European level and within IEEE and these will be also significant opportunity of dissemination of the work performed in this project.

SOFI. Prof. Dr. Berthold Vogel as co-spokesperson of nfdi4energy will invest a significant share of his time to coordinate the contributions of SOFI in nfdi4energy. With his expertise on common goods, social places and qualitative methods of empirical social research he will support and coordinate SOFIs empirical work on social local conditions and implementations. Moreover, he will use his position as board member of the Energy Research Centre of Lower Saxony (EFZN) to promote and disseminate nfdi4energy activities and results. The position of the scientific coordinator of the Cross-Cutting Research Area on Social Sciences of the EFZN is based at the SOFI with one fully-funded FTE. These synergies regarding networks and expertise are going to be included into the nfdi4energy. Moreover, a junior research team of the Research Institute Social Cohesion (FGZ) located at the SOFI focusses on the issue of public goods. This personnel with about 2 FTE will be integrated into the nfdi4energy for synergetic effects. In the context of the focus on its socio-ecological orientation, the SOFI is willing to support the ambitions of nfdi4energy via its main budget. SOFIs societal research included into the nfdi4energy draws on its tradition on energy transition research established by Rüdiger Mautz since the 1990s.

TIB. Prof. Sören Auer as co-spokesperson of nfdi4energy will dedicate a fair share of his time for the TIB efforts in nfdi4energy. TIB will also bring in its substantial software and service portfolio comprising the Open Research Knowledge Graph, AV-Portal, TIB’s GitLab for NFDI, the Leibniz Data Manager and the VoCol/Terminology Service, which is also further developed and maintained independently from the nfdi4energy budget. In addition, TIB will leverage horizontal functions such as its subject specialists, PID services, long-term archiving and marketing department for the aims and goals of nfdi4energy.

Abbreviations

ALU	Albert-Ludwigs-Universität Freiburg
CIM	Common Information Model
CKAN	Comprehensive Knowledge Archive Network
CPES	Cyber-physical energy system
D	Deliverable
DAI	Distributed Artificial intelligence
DCAT	Data Catalog Vocabulary
DO	Digital Object
DOI	Digital Object Identifier
EFZN	Energy Research Centre of Lower Saxony
EOSC	European Open Science Cloud
FAIR	Findable, Accessible, Interoperable, Reusable
FAU	Friedrich-Alexander-Universität Erlangen-Nürnberg
FDO	FAIR Digital Objects
FhFIT	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. - Institut für angewandte Informationstechnik
FTE	Fulltime Equivalent
HMC	Helmholtz Metadata Collaboration
IAI	Institute for Automation and Applied Science
IASS	Institute for Advanced Sustainability Studies e.V.
IEC	International Electrotechnical Commission
IISM	Institute of Information Systems and Marketing
KIT	Karlsruher Institute of Technology
LDM	Leibniz Data Manager
M	Measure
MS	Milestone
NUC	nfdi4energy user community
OED	Open Energy Datamodel
OEM	Open Energy Metadata
OEO	Open Energy Ontology
OEP	Open Energy Platform
OFFIS	OFFIS e.V.
openmod	Open Energy Modelling

ORCID	Open Researcher and Contributor ID
ORKG	Open Research Knowledge Graph
PID	Persistent Identifier
PV	Photovoltaic
QoS	Quality-of-service
RDA	Research Data Alliance
RLI	Reiner Lemoine Institut
RWTH	RWTH Aachen University
SaaS	Simulation-as-a-Service
SARGON	Smart energy domain ontology
SCL	Substation Configuration Language
SOFI	Soziologisches Forschungsinstitut Göttingen (SOFI) e.V.
TA	Task Area
TIB	Technische Informationsbibliothek
TS	Terminology Service
UOL	Carl von Ossietzky Universität Oldenburg
WG	Working Group

Appendix

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