Energy HUB

PhD Programme on Integrated Energy Systems on the Norwegian Continental Shelf

REPORT FROM PRE-PROJECT

NTNU
Norwegian University of
Science and Technology

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FOREWORD BY NTNU ENERGY

The Norwegian government's ambitions to reduce climate gas emissions by 55% by 2030 can only be achieved through the massive electrification of sectors that today use fossil fuels. The offshore oil and gas sector is one of the sectors responsible for a major portion of Norway's national climate gas emissions.

In general, climate gas emissions can be reduced by producing hydrogen with carbon capture and storage (CCS) for export, or by the electrification of the offshore power systems. The latter can be achieved by using electricity from onshore hydropower or wind power, or by producing offshore wind power to be used on offshore platforms.

The challenge of using onshore renewable electricity will be a lack of sufficient electricity in the future. CCS has the potential to reduce offshore climate gas emissions in the future when a hydrogen infrastructure and market have been developed.

An interdisciplinary pre-project with experts in technology, economics and social sciences from NTNU has proposed a combined offshore power system using gas turbines, onshore electricity and offshore wind power, due to its great potential to reduce climate gas emissions on offshore installations.

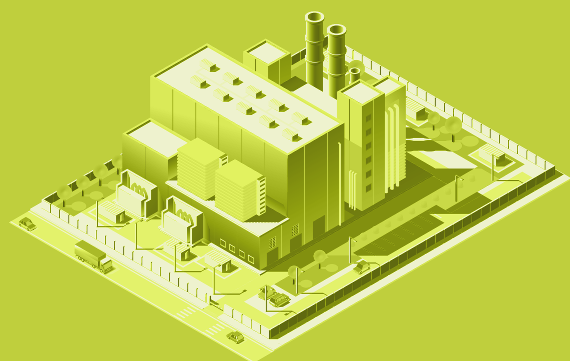
The project proposed in this report will explore this idea by having students look into concrete offshore systems. It includes a variety of stakeholders from the oil and gas industry, energy companies, regulatory authorities, and companies responsible for power grid development. The project aligns well with the Norwegian government's ambitions to produce 30 GW using offshore wind.

An interdisciplinary approach is necessary to solve the various challenges of such a concept. Particularly challenging is the variability of wind power calculations in different time scales and forecasting how the wind power should be utilised, combined with onshore power and power from gas turbines, in an optimal way. The power needed for gas processing, compression and transport, as well as for pressure support in reservoirs, needs to be carefully taken into account.

NTNU has a long tradition of building new interdisciplinary competences in the maritime domain coupled to disciplines in cybernetics and information and communication technologies, including the BRU21 programme: Better Resource Utilization in the 21st century.

For NTNU, this project will be of utmost importance for developing competence across disciplines in the future energy system. The increased capacities for building new competences for PhD, Master and Bachelor students will be important for future workforce recruitment for the involved stakeholders.

Johan Hustad
NTNU Energy



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COLLABORATION ACROSS BOUNDARIES IN THE ENERGY TRANSITION

Equinor aims to be a leading company in the energy transition, and has strengthened its ambition to reduce net group-wide operated emissions by 50% by 2030, while also focusing on medium-term actions consistent with the goals of the Paris Agreement and a 1.5-degree pathway. Although the onshore grid in Norway is well regulated, the offshore grid is, in 2023, still a work in progress, with several oil and gas electrification projects and offshore wind development having just started. On the other hand, Statnett has forecast electric energy shortages and peak load challenges from 2027, partly due to the intermittency of the emerging wind and solar energy systems.

This journey towards a net-zero energy system is therefore already showing its dilemmas and trade-offs. Equinor's long-term goal is to develop the NCS as an energy province. The plan is to continue sustaining a strong cashflow from a highly focused, carbon-efficient oil and gas business to fund the transformation, while at the same time scaling up investments in renewables to create value from the existing portfolio and a high-quality project pipeline. This includes developing and deploying the industrial value chains of the future in wind, solar, hydrogen, and carbon capture and storage (CCS) to enable other industries to decarbonise their activities.

In parallel, the plan is to continue to work with the universities, suppliers and customers, host governments and civil society to develop the business models, policies and frameworks that will enable the world to achieve net zero by 2050. This transition process heralds an increase in collaboration across boundaries, the integration of energy management across companies, businesses and technical disciplines, and engagement with stakeholders in the wider society.

We describe this transition as a function of the new challenges with an increased complexity of the energy mix, coupled with increased technical and organisational complexity in energy management. Organisational complexity denotes an increasing integration across boundaries – whether these boundaries are companies, vendors, professional disciplines, regulatory regimes/bodies or businesses – and across numerous societal stakeholders.

New practices must be developed, made legitimate and institutionalised across these boundaries. Only parts of this complexity can be mitigated technically – e.g., by use of batteries, mixing energy systems, and simulation and forecasting tools. Many challenges must be mitigated with legitimated societal and institutionalised governance practices, on many levels. New systems and practices must also be transparent – not only for the industry and the authorities, but they must also be acceptable and just for society at large. Energy companies, vendors, government bodies and others must develop operating models for this new situation.

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Print by NTNU Grafisk Senter

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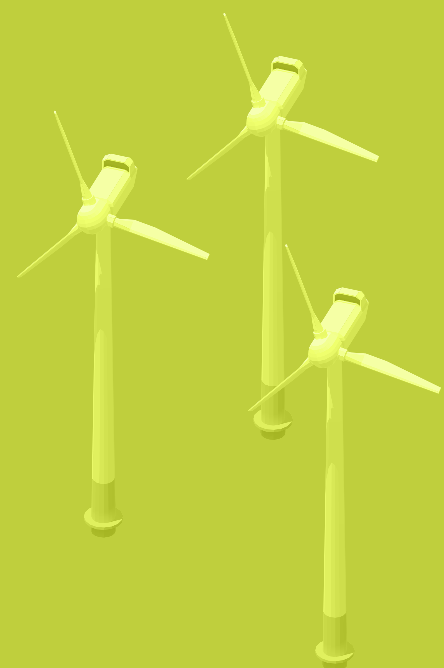

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EXECUTIVE SUMMARY

The Norwegian electricity system is gradually being expanded and integrated with activities and assets on the Norwegian Continental Shelf (NCS) with the aim of electrifying and decarbonising assets in the oil and gas industry. This move entails multiple challenges in terms of technology roll-out and integration between different types of systems and organisations, and opens for important debates about how societies such as Norway's collectively prioritise how scarce renewable energy resources are managed. The process has major implications for the oil and gas industry, the electricity sector, and for the Norwegian and European societies at large. The outcome will be key to shaping the future of Norway over the next 50-100 years.

The aim of this report, which is the main deliverable in a project initiated under a Memorandum of Understanding between Equinor and NTNU, is to survey interest and research challenges from industrial stakeholders and to define a multidisciplinary PhD programme, the NTNU Energy HUB, for investigating integrated energy systems on the Norwegian Continental Shelf core areas and to educate PhD and Master students. This report forms the basis for the decisions of stakeholders to fund and be involved in the programme.

A key part of the process of defining the PhD programme was the conducting of interviews with industrial stakeholders to better understand their challenges in this area. This was done by posing three central questions to each potential stakeholder:

1. What challenges does your organisation face in today's and tomorrow's energy system on the Norwegian Continental Shelf?

2. What are the research questions of interest for your organisation in this regard?

3. How can NTNU help you to address these challenges?

The results of the interviews, together with a literature review of the current state-of-the-art research, were sorted into the three overlapping and cross-disciplinary areas of 1) Technology, 2) Economics, and 3) Politics and society. A multitude of research questions were raised, including the development of new methods and tools, and more applied research.

To solve this, an operating model based on multidisciplinary PhD clusters is proposed, consisting of PhD teams supervised by NTNU professors and co-supervised by industry representatives, and complemented with Master thesis students. The PhD programme is designed as a use-case driven research activity. This means that the stakeholders have a direct influence on the research theme selection.

October 2023

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BACKGROUND AND AIMS

BACKGROUND

The Norwegian electricity system is gradually being expanded and integrated with activities and assets on the Norwegian Continental Shelf (NCS) with the aim of electrifying and decarbonising assets in the oil and gas industry. This move entails multiple challenges in terms of technology roll-out and integration between different types of systems and organisations, and opens for important debates about how societies such as Norway's collectively prioritise how scarce renewable energy resources are managed. The process has major implications for the oil and gas industry, the electricity sector, and for the Norwegian and European societies at large. The outcome will be key in shaping the future of Norway over the next 50-100 years.

An important part of the future vision for the NCS electricity supply is to ramp up offshore wind production to serve correlated offshore structures. The oil and gas installations on the NCS traditionally depend on their own power supply, which derives from gas turbines. Nowadays, the energy demand is increasingly covered by the onshore grid or from offshore wind power. The shift in how electricity from land is being used, how power is supplied offshore and the associated integration of the offshore energy system in the larger Norwegian electricity system has multiple important implications with strong associated research needs.

This integration implies the interconnection and interdependencies, and hence increased complexity, of previously independent entities. First, there is a scarcity of renewable energy to cover new offshore and onshore demands in the near and long-term future. Moreover, combined with high CO_2 prices, CCS and increased focus on hydrogen, the integration of energy systems with multiple energy vectors becomes increasingly important. This makes the forecasting and shared utilisation of energy and information essential across different energy vectors, time scales and organisational boundaries, and between companies that usually compete.

The change in the energy landscape on the NCS is also evident from the announcement from the Norwegian government that the Petroleum Safety Authority Norway is changing its name with effect from 1 January 2024 to the Norwegian Ocean Industry Safety Authority, and that the Norwegian Petroleum Directorate will be renamed at the same time. Through these name changes, a wider area of responsibility is reflected including the development of CO_2 transport and storage and offshore wind.

It is of central importance to ensure that the new developments are democratically legitimate, and that key concerns within environmental and energy justice are addressed so that future conflicts and polarisation over the production and use of electricity and other energy carriers are minimised. Energy HUB will therefore involve different disciplines and research areas to cover this wide scope and to ensure a just and transparent energy system for the larger Norwegian society.

THE NORWEGIAN CONTINENTAL SHELF CORE AREAS

A closer look at the progress of electrification on the Norwegian Continental Shelf reveals the following picture: on the one hand, Utsira High is powering up offshore installations from a 200 MW cable from the onshore grid via Johan Sverdrup, as shown in Figure 1. On the other hand, in Hywind Tampen, wind energy will provide renewable energy to supplement existing gas turbines at Gullfaks and Snorre. This will supply as much as 20-30% of the energy demand, depending on the wind conditions. Looking towards 2030, future deployment of offshore renewable energy sources is projected to be integrated, comprising a variety of technologies and sectors, such as subsea installations, windfarms, onshore usage of offshore electricity surplus, and conversion to hydrogen.

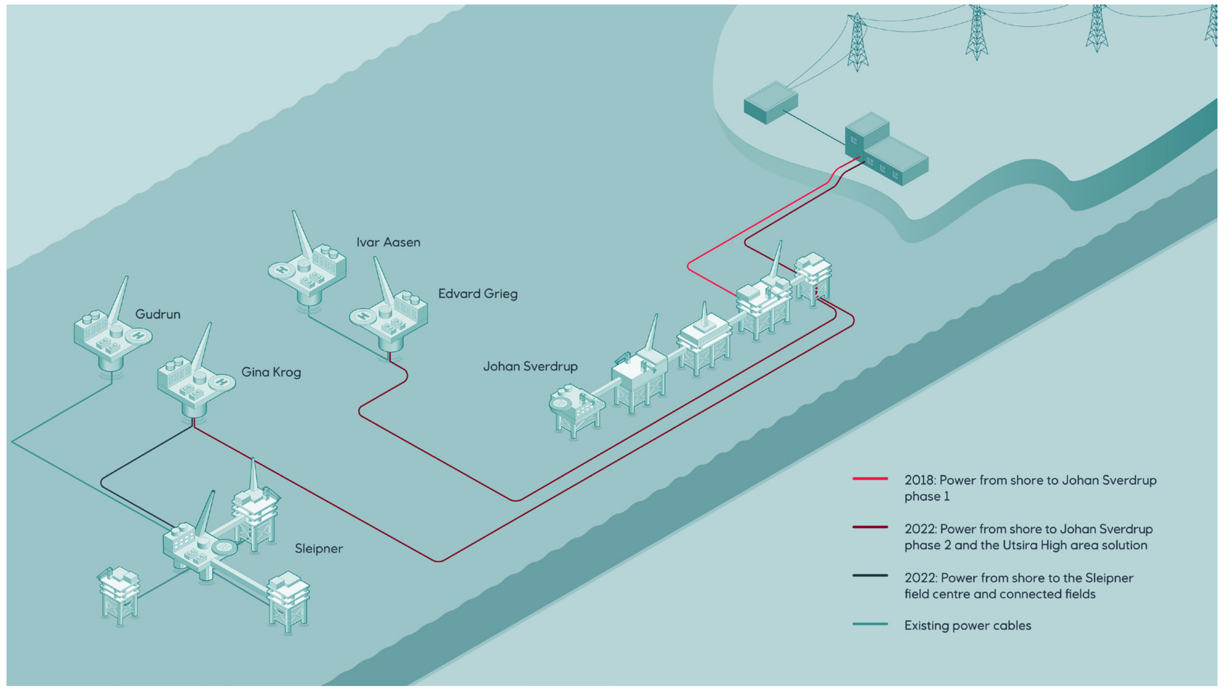


Figure 1. The Utsira High Electricity grid. With permission from ©Equinor.

Figure 2 illustrates the integration of a floating wind farm into the offshore system of Hywind Tampen, comprising the fields of Snorre and Gullfaks. The variable nature of wind power necessitates balancing services, which means that, during low wind speeds, the electricity demand must be covered by another power source. This could be a gas turbine, a battery, a re-electrification of stored hydrogen via a fuel cell, or a power cable supply that covers the intermittent supply gaps.

In contrast, at peak wind times, surplus energy should be stored or transported on shore to diminish the curtailment of renewable electricity. This intermittent phenomenon of offshore wind infrastructures necessitates new energy management strategies, such as Power-to-X, battery storage or smart electricity management by the operator, in addition to improved wind and demand modelling and control in order to minimise the balancing needs.

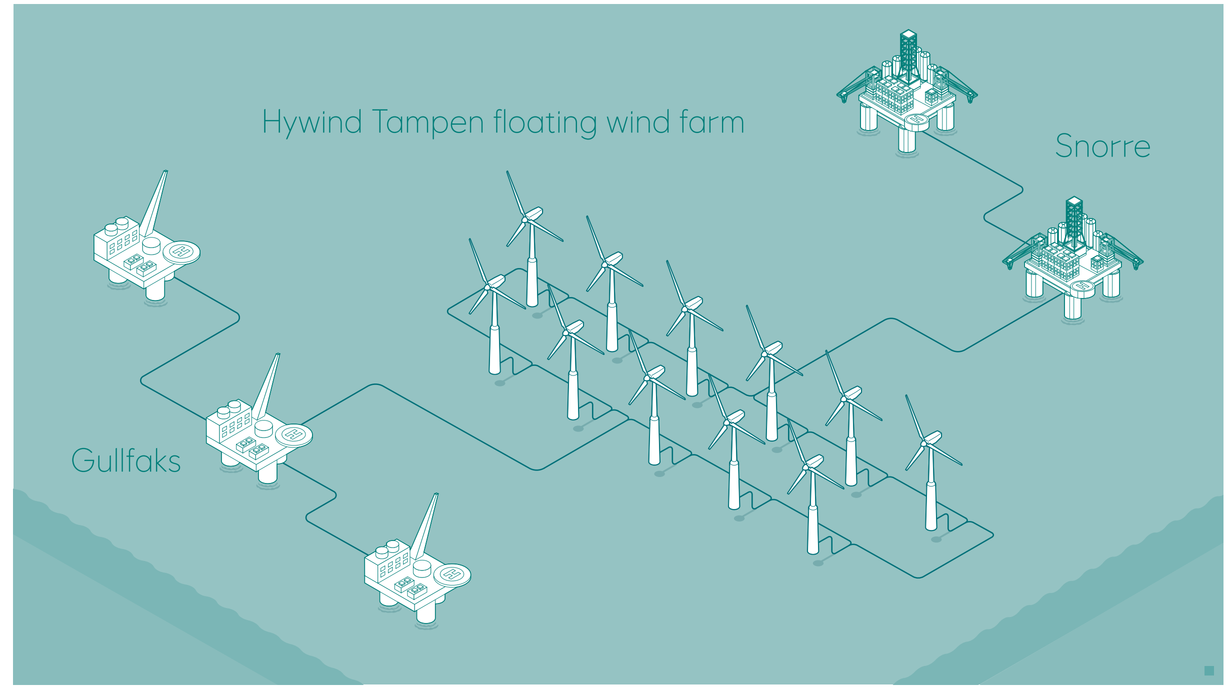


Figure 2. Hywind Tampen connected to Snorre and Gullfaks. With permission from ©Equinor.

Figure 1 and Figure 2 showcase the current situation of the offshore installations around Utsira High and Hywind Tampen. These are two examples of the efforts to strive towards a more sustainable future in the offshore industry that have been undertaken by the main industry partner, Equinor. However, Utsira High and Hywind Tampen are two isolated cases in an industry where assets powered by fossil fuel must be decarbonised. In the future, the energy systems will be more integrated, as presented in Figure 3. The involvement of many technologies leads to diverse system dynamics and control structures, which must be temporally modelled, planned, scheduled and optimally operated.

Furthermore, the quantification and utilisation of energy storage systems must be analysed, and – owing to the complexity of the new picture – there is an urgent need for the understanding and forecasting of different conditions and interdependencies. Control centres for the new technologies and their combined operation must be developed and optimised. Overall, the island configuration of offshore platforms will disappear, and the onshore to offshore connections will increase over time. This new trend will lead to novel interconnections between different sectors and domains by impacting the research community in multidisciplinary approaches. The future energy is envisioned to be connected, converted and transported via energy hubs.

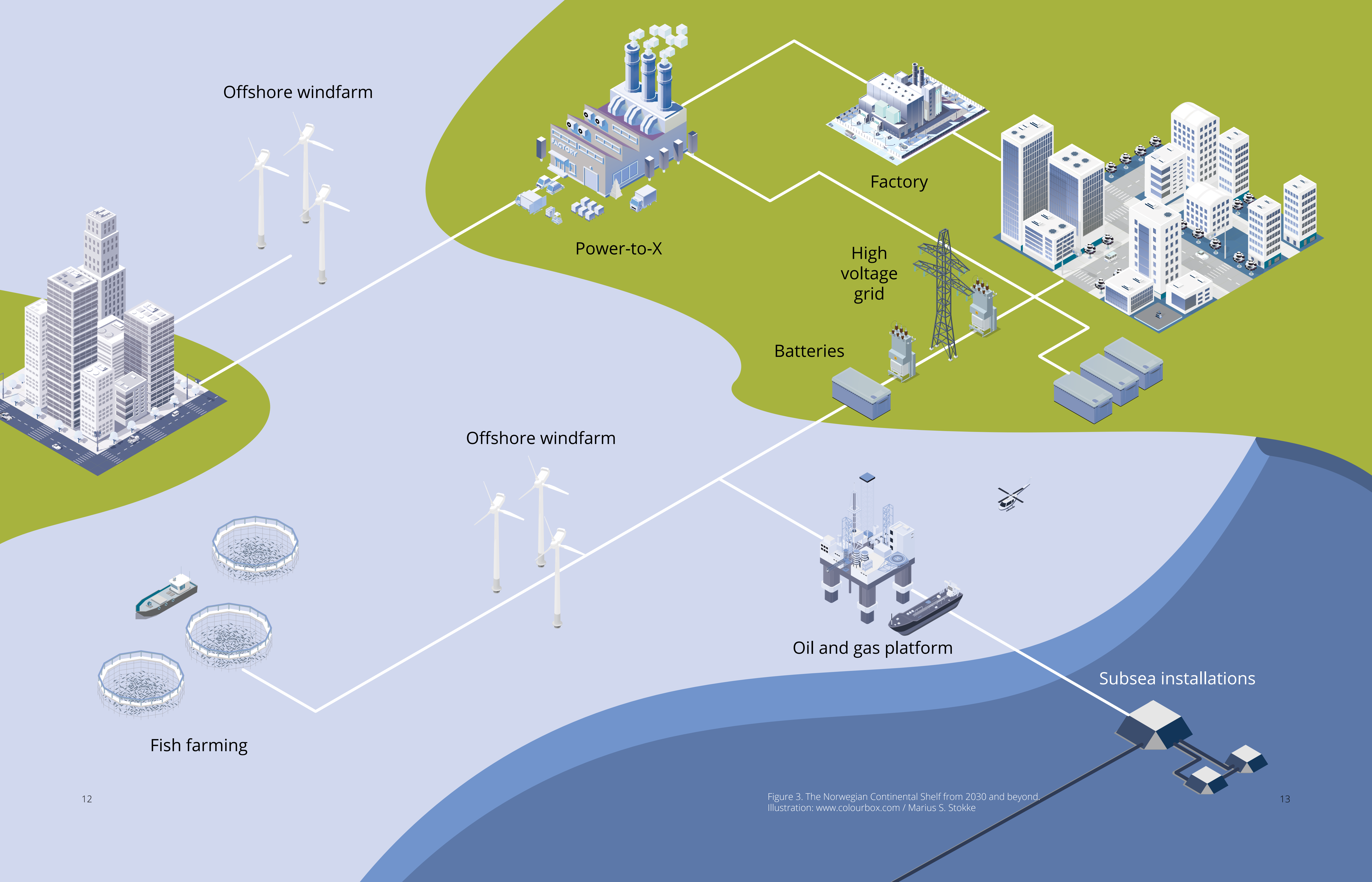


Figure 3. The Norwegian Continental Shelf from 2030 and beyond.
Illustration: www.colourbox.com / Marius S. Stokke

WHAT IS AN ENERGY HUB AND ANALYSIS OF INTEGRATED ENERGY SYSTEMS?

An energy hub is a physical interlinkage point where multiple energy carriers are connected, converted and transported[1]. It includes the integration of renewable and other energy sources and carriers with energy storage and different types of demand that are flexible and adaptable, while ensuring a high security of supply and resilience. The energy hub is characterised by large amounts of energy exchange and transmission between multiple local points, energy storage to overcome the variable nature of renewables, and an overall flexible energy system. It will require a control centre that continuously coordinates the energy system in response to their availabilities, capacities, and to the forecasted energy supply and demand. An energy hub can be seen as an enabler for an integrated energy system.

Integrated energy system analysis is “an approach in which researchers consider a multi-system energy challenge holistically rather than looking at each of the systems in isolation”[2]. Simulating and analysing integrated energy systems in a holistic way, makes it possible to benefit “from the synergies between heating, cooling, electricity, renewable energy and fuel pathways at all scales”[3].

The description that follows is divided into four main categories:

1. Energy resources
2. Energy demand
3. Energy carriers and storage
4. Societal dimensions of energy hub development

Each category is further divided into subgroups.

1 Zhang, H., et al. (2022). Modelling and analysis of offshore energy hubs. *Energy*, 261, 125219.
2 https://www.nrel.gov/grid/integrated-energy-system-simulation.html
3 https://eera-esi.eu/about/what-is-eera-esi/

ENERGY RESOURCES

Offshore wind:

Offshore wind power harvests the wind energy resources on the Norwegian Continental Shelf. This technology can be crucial for the green revolution towards a more sustainable electricity generation market with a high potential in the North Sea region.

Onshore wind:

To a lesser extent than its offshore counterpart, onshore wind power ensures renewable and emission-free electricity generation on the shore regions of the NCS. It is well suited for large-scale deployment and is economically more attractive than offshore wind farms. However, area conflicts make the potential for onshore wind in Norway uncertain.

Solar:

Solar energy is experiencing a strong boost in the world in general as well as in Norway. The price of photovoltaic panels has experienced a strong decrease over time. The full potential of solar energy for electricity and heat generation is yet to be upscaled and integrated into the Norwegian economy. At the NCS, floating PV could be a promising supplement to offshore wind.

Wave energy:

Less developed than offshore wind turbines and smaller in scale, wave energy can contribute to the storage of energy and production of electricity. Floating buoys could be connected to a turbine via a cable to generate electricity, or used to deploy underwater gravity energy storage.

Hydropower:

Hydropower is the reliable backbone of the Norwegian electricity generation system. In contrast to other renewable energy sources, hydropower is less variable and highly flexible in its operation patterns due to the large reservoirs. Hydropower provides a stable base supply and offers flexibility, thereby supporting all electrification projects. However, the further expansion of the hydropower system is limited, as most resources are already highly utilised.

Gas turbines:

Gas turbines fuelled with natural gas or with decarbonised fuels such as hydrogen or ammonia, and combined with steam cycles for increased efficiency, can play an important role in the future offshore energy mix, especially when combined with renewable energy resources. As a flexibility asset, they could contribute to overcoming fluctuations in the electrical grid due to intermittent renewable energy sources. CCS combined with gas turbine cycles could also be a key factor in the achievement of climate targets.

ENERGY DEMAND

Surface and subsurface operation:

The offshore surface operation includes the power supply to all its offshore production fields and assets. Whilst the energy transition enforces a gradual reduction of oil and gas production, these primary energy carriers will remain in the portfolio in the coming decades. The subsurface operation includes the provision of electricity to its underwater operating assets and drilling units. As the need for clean electricity increases, the necessity to have a predictable and stable power supply remains urgent.

Production of hydrogen and fuels of the future:

Hydrogen, together with other sustainable fuels such as ammonia and green methanol, could become the key energy carrier in a future clean and dispatchable energy portfolio. It is seen as one of the most promising secondary energies to replace primary fossil fuels in the near to medium term. The high gravimetric energy density of hydrogen can be used to store and convert electricity. Moreover, there are big plans and large expectations for future industrial use of hydrogen derived from electrolysis and from natural gas with CCS.

Gas network:

The gas network in Norway ensures that the energy carrier natural gas, or hydrogen, is supplied timely on a daily basis to the demand side via pipelines. It ensures dispatchability and energy storage through line-packing of the natural gas and includes not only transport but also gas processing facilities.

CCS:

In a future electricity system, it might be essential to include carbon capture and storage (CCS) in the energy portfolio. It is an enabler for CO_2 emission reductions. CCS requires energy to capture, transport and store the CO_2.

Onshore user:

The onshore user is the collective term for the energy demand on the shore or inland of Norway. A user can be the buildings sector, the commercial sector, or the industrial sector.

ENERGY CARRIERS AND STORAGE

Electricity:

Electricity as an energy carrier is produced by various primary energy sources. It is acknowledged that electricity is the most important energy carrier, and its significance will further increase over time with continued electrification of the industry and transport sectors.

Natural gas:

Natural gas primarily contains methane and has historically been produced by extraction in natural gas fields. It is the fossil fuel that has the lowest carbon footprint. It can be reformed to produce blue hydrogen with CCS.

Hydrogen and fuels of the future:

Hydrogen is currently mostly produced by the reforming of methane, but for many it constitutes the hope for a clean and dispatchable energy carrier. Hydrogen in its pure form cannot be extracted but must be produced (e.g., via electrolysis, requiring electricity) and then stored in a compressed or liquid form, before ultimately being re-electrified in mobile or stationary fuel cell applications. Ammonia, green methanol and other fuels of the future are also vital.

Batteries:

Batteries are the most widespread technology for electricity storage. The high efficiency in storing energy electrochemically is used in many applications, and is a driving force in the green shift due to its dispatchability and help in overcoming fluctuating and intermittent renewable energy sources, such as solar energy and wind power.

SOCIETAL DIMENSIONS OF ENERGY HUB DEVELOPMENT

Societal dimensions in brief:

The development and large-scale implementation of energy hubs on the NCS will have wide-ranging implications for Norwegian society and beyond. The Energy HUB programme will mobilise social science competence to analyse such aspects, with a key goal being to develop critical and constructive recommendations for societal engagement. Examples include the following themes.

Energy justice:

In the implementation of energy hubs, it is key to ensure a) Distributional justice (i.e., a fair distribution of burdens and benefits), b) Procedural justice (i.e., ensuring an inclusive and participatory decision-making process with clear and transparent governance), and c) Recognitional justice (which entails actively ensuring the inclusion of marginalised voices in such processes).

Legitimation:

It is key to ensure that energy hubs are legitimate. Legitimation processes typically entail working with a) Social acceptance (the acceptance of local publics, policy makers and markets), b) Stakeholder engagement (engaging diverse stakeholders, including industry, government, academia and civil society to legitimise innovations by incorporating different perspectives and addressing concerns), c) Policy alignment (aligning technological advancements with relevant policies and regulations to ensure legal and ethical compliance), and d) Narrative shaping (crafting a narrative around innovations helps to shape public perception and fosters trust, contributing to their overall legitimacy in the eyes of the society).

Trust:

Succeeding with energy hubs requires the development of trust between actors who may have radically different interests, or who might be competing with each other. Exploring the conditions for such cross-organisational, cross-sectoral and societal-wide trust will be key.

Network expansion:

Building trust and legitimacy hinges on developing strong networks and sharing knowledge among stakeholders. This helps in cross-pollinating ideas, accessing resources and building a supportive community, as well as understanding the drivers and barriers to the network development.

Learning:

The development of energy hubs might serve as a platform for learning, experimentation and adaptation, where the involved actors can refine their technologies based on feedback and real-world testing over time. Exploring and understanding such processes of learning are important for the Energy HUB programme.

Technology use:

The energy hub concept entails the implementation of a series of new technologies (e.g., control rooms and associated control systems). Their success requires the successful integration in everyday worklife, which is mediated by existing practices, cultures, ways of communicating, etc. Understanding how new design interacts with staff under difficult conditions is important for the Energy HUB programme.

Temporal logics:

The energy hub concept requires the integration of technologies, organisations and actors working and operating on different temporal logics. Understanding how these temporal logics play out across domains, and what can be done to align and harmonise them in a meaningful way, is a key challenge in the Energy HUB programme.

Energy trading:

An energy hub is normally connected to one or several markets for different energy vectors, with different time horizons and with different purposes in terms of providing energy, peak power or other types of flexibility. These markets require design that promotes fair and efficient resource utilisation in both the short and the long term.

AIM OF THE REPORT

The aim of this report, which is the main deliverable in a project initiated under a Memorandum of Understanding[4] between Equinor and NTNU, is to survey interest and research challenges from industrial stakeholders and to define a multidisciplinary PhD programme, the NTNU Energy HUB, for investigating integrated energy systems on the Norwegian Continental Shelf core areas and to educate PhD and Master students. This report forms the basis for the decisions of stakeholders to fund and be involved in the programme.

4 https://khrono.no/files/2021/10/07/07.10.2021-MOU-Equinor-NTNU.pdf

Illustration: www.colourbox.com

INVOLVEMENT OF STAKEHOLDERS AND IDENTIFICATION OF RESEARCH GAPS

STAKEHOLDER INVOLVEMENT

Between May and September 2023, a total of 15 industrial stakeholders were interviewed to identify their research challenges and interests. The feedback was positive and generated a lot of interest with various stakeholders. Further stakeholders will be contacted in the upcoming months. The following organisations were contacted in the first round:

- ABB Norway
- ABB Corporate Research
- Aker BP
- Aker Horizons
- CorPower Ocean
- Equinor
- Gassco
- Google DeepMind
- Kongsberg
- NVE
- OKEA
- RWE
- Statkraft
- Statnett
- Xera

During the interviews of the stakeholders, three questions were posed:

1. What challenges does your organization face in today's and tomorrow's energy system on the Norwegian Continental Shelf?
2. What are the research questions of interest for your organization in this regard?
3. How can NTNU help you addressing these challenges?

In addition, two thematic workshops were conducted with various stakeholders, as well as six project workshops involving NTNU and Equinor:

- Thematic workshop as part of the 2023 NTNU Energy Transition week: *Renewable energy systems on the Norwegian Continental Shelf: Resources, use and sharing.*

- BRU21 conference workshop: *Electrification & decarbonisation of the NCS: Radical reduction of CO_2 emissions.*

- Workshops with Equinor with the following aims:

  - To communicate the interests of other industrial stakeholders
  - To explore different research topics related to the Energy HUB programme
  - To analyse research questions of interest
  - To build knowledge and trust

SYNTHESIS OF THE RESEARCH GAP ANALYSIS

In this section, a synthesis of the research gaps identified by industrial partners and by a literature review is presented, and key outcomes are described. The research gaps are further detailed in the following two sections. Figure 4 summarises the three cross-disciplinary areas that are covered.

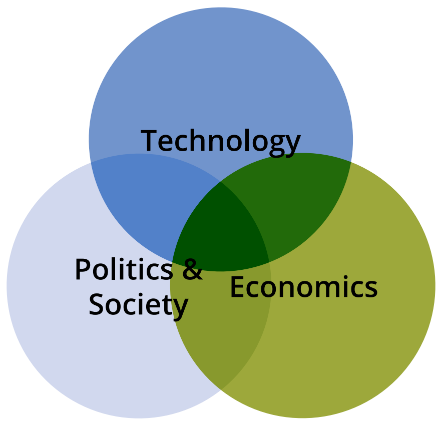


Figure 4. Three research fields identified by the gap analysis, with a strong interlinkage and cross-disciplinarity between the areas.

TECHNOLOGY

1. The renewable revolution on the NCS necessitates methodologies that include sustainability approaches alongside technological innovation and design. Life cycle assessments must therefore be integrated to better analyse the environmental impact of upcoming technologies, such as offshore wind, hydrogen, Power-to-X, CCS and offshore DC grids.

2. Such a shift towards new green and low-carbon technologies on the offshore field must be optimised, both in its design and in its operational patterns, and must be flexible and adaptable while also ensuring secure supply and resilience. Thus, quantification of energy needs and energy storage for balancing provision must be evaluated.

3. The interplay between supply and demand actors must be enhanced by smart and digital tools. On a small, granular scale, the control and optimisation measures must deal with uncertainties in renewable power generation by integrating economic aspects and ensuring energy efficient solutions for an optimal synergy of the energy system units.

ECONOMICS

1. The operation of the offshore assets needs to be integrated with the onshore energy system and markets. The technology transition towards renewable energy sources on the NCS must be technologically viable and economically favourable, in terms of both cost and potential for value creation. Therefore, modelling and optimisation tools must be focal points in order to analyse design and operation of the energy hubs and the interlinked generation, storage and conversion technologies.

2. Energy forecasting and technology deployment rates must be assessed to facilitate the integration of renewable and low-carbon energy sources.

3. Analysis of the market values of upcoming renewable and low-carbon energy carriers must be performed, as it enhances the feasibility of the energy transition and enables institutions to make the right decisions at the right time.

POLITICS AND SOCIETY

1. Further investigations must address uncertainties regarding CO_2 taxes and underlying emission goals for Norway and Europe to enforce a green revolution on the NCS.

2. Analysis of how decarbonisation pathways on the NCS can ensure a legitimate reorientation of the industry and society, and of what it would mean to roll out the energy hub concept on the NCS based on principles of energy justice and just transition. This entails understanding existing governance structures, and how these can be strengthened through new forms of collaboration between public institutions across scales, key industrial actors and relevant groups of the public.

3. Mobilising concepts such as energy citizenship, public engagement and social acceptance to analyse emergent controversies across scale, and to identify social potential to advance the transition. This includes developing competences and leadership skill sets throughout the PhD programme and beyond to build capacities for the actors (industry, public sector, NGOs) that are key developers of sustainable energy systems and societies.

RESEARCH GAPS RESULTING FROM THE INDUSTRIAL STAKEHOLDER INTERVIEWS

In this section, the knowledge and research gaps identified by the industrial partners are provided. First, the **technology** gaps are summarized and classified into three fields: a) offshore energy resource utilisation, b) electrical infrastructures and markets, and c) hydrogen and other alternative energy carriers.

a) Offshore energy resource utilisation

The future of oil and gas as energy resources on the NCS field is uncertain due to the climate goals. The increase in renewable energy sources in the power generation sector is, in addition to the government's climate goals, due to cost reductions of specific technologies using solar and wind resources. The potential and realistic capacity deployment of offshore wind power needs to be analysed and forecasted by considering market needs and future power market designs:

- How much capacity of offshore wind power will be deployed in the future?
- Which type of network will be used to connect other markets and between them?

The interplay between gas turbines, either fueled with hydrogen or complemented with CCS, and intermittent offshore wind farms needs to be assessed on a system, process, and component level by considering wind variability and speeds. Techno-economic studies incorporating sustainability aspects need to quantify whether it is technologically viable and economically attractive on a large scale.

On a process level, control systems need to be efficient, reliable and cost-optimised on a practical use-case basis. Different timescales and different layers of failures must be implemented (real-world adaption). It is necessary to design specific controls as economically and practically as possible, and to design use-case related control and automation aspects.

Further, a control centre will be vital for the energy hub concept:

- How should a control centre for a future energy hub be designed and operated?

It must provide data protection and autonomy to the different businesses it serves. The structure, ontology, standardisation and algorithms underlying the control centre need to be investigated and developed.

b) Electrical infrastructure and markets

The continuing integration of renewable power systems and the need to decarbonise offshore platforms on the NCS drive the discussion on how the new power market should be ideally established and how the electrical distribution grid should be designed:

- What type of electrical network do we foresee?
- What form will the connections onshore to offshore take?
- As there are many different operations, what are the technological and operational models for gradually expanding the offshore grid?

The latter can be designed in a manifold of ways including a connection offshore to onshore in a radial grid structure, such as, planned in Sørlige Nordsjø II and Utsira Nord or as a part of a more integrated offshore grid structure:

- How could the future distribution grid for integrated energy systems be designed?
- What are the implications on the grid design for ratings, functionalities, safety and carbon footprint, and what are the gaps in the current offerings?

Once the integration of land-based and offshore infrastructures is in place, questions need to be answered regarding the interplay of the electricity system:

- What form will the interplay regarding the electricity system and balancing provision take?

Furthermore, the quantification of balancing needs must be calculated in order to capture possibilities and synergies between onshore and offshore assets and where excess energies can be transported to avoid renewable energy curtailment.

c) Hydrogen and other alternative energy carriers

Connected to the offshore energy resource utilisation and the future picture of power markets, a possible way to overcome energy curtailment could be the integration of Power-to-X strategies such as the production of hydrogen and other sustainable energy carriers onshore or offshore. The fuels of the future for different sectors and purposes are yet to be defined:

- Which sustainable fuels are represented in the future power system?
- What are the hurdles involved in shipping green molecules?
- Europe needs green hydrogen and Norway does not have the power surplus.
  How can this be resolved?

Future work addressing where the power surplus for such energy intensive conversion processes can come from must be assessed. Ultimately, the interface between electricity and other energy carriers must be imposed and optimised by multi-energy carrier analyses.

From an **economics** perspective, the green energy transition must be economically optimised across multiple sectors to unveil the pathways for sustainable power markets on the NCS and Norway for the upcoming decades. The tools and analytical models to achieve these results need to be evaluated:

- What are the most economically attractive decarbonisation routes?
- Which analytical models and tools should be used or developed for such an analysis?

In the near-term transition toward green energy technologies, the economics of back-up gas turbines for periods when renewable energy is lacking must be assessed and the cost and benefit allocation of shared offshore assets need to be evolved. Furthermore, the NCS power market needs to be integrated into the larger European electric power system. The connection and extension to continental Europe must be designed and analysed such that the utilisation of new grid infrastructures in an energy hub are maximised:

- How can the utilisation of (new) grid infrastructures in an energy hub be maximised?

Related to the new power market design and forecasting, the following questions are raised:

- What form will the institutional setup take with regard to how electricity is managed?
- Who are the buy and sell actors of the future trading models, and how can this be optimised?
- What form will the future energy markets take?

Overall, different methods must be implemented or developed in the assessment of future offshore energy hubs including a) techno-economic optimisation of offshore and renewable energy systems, b) future market penetration and market value analysis of energy carriers such as hydrogen and renewable energy technologies, c) multi-objective optimisation of a complex system taking into account climate targets, institutional capacities, societal dimension and public perception alongside economic and technologic indicators.

From a **politics and society** point of view:

Tied to the economic aspect and implied economic modelling tools, further analyses must assess emission goals of Nordic countries and Europe considering environmental consequences and roadmaps how to achieve the targets. The future policies need to address CO_2 emission thresholds and enforce deployment of offshore wind islands, and the green revolution on the NCS areas must be analysed and investigated. A central aspect of this programme and in need to be further studied is:

- How can policy institutions ensure a just and fair transition in an energy hub?

Furthermore, policies need to undermine the integration of the NCS electrification with the onshore grid while guaranteeing stable electricity prices and assuring public acceptance and societal payoffs. In this regard, a plan to educate the public and a communication strategy must be laid out explaining why such a green transition on the NCS area is necessary and beneficial for the larger Norwegian society:

- What policies and standards do we need in order to integrate the NCS electrification with the onshore grid?
- How can we avoid creating issues in the onshore electricity prices?
- What is the public communication strategy?

New challenges arise when implementing offshore energy hubs with national, regional and European legislation linkages. The reorganisation of the electricity system must be standardised by ensuring cybersecurity on an energy hub. To deal with the stochastic nature of renewable energy sources, the implementation of new business models for flexible demand response for balancing provisions to the grid can be developed. In addition, several open questions within this cross-disciplinary area remains to be answered including:

- How can decision tools such as eco-technoeconomic analysis be used to evaluate the economic and environmental impacts of different solutions when applied in practice?
- What form will the life cycle assessment (LCA) of hydrogen technologies take, and how should their deployment be coupled with offshore energy hubs?

RESEARCH GAPS RESULTING FROM THE ACADEMIC LITERATURE

In the following paragraphs, the research gaps resulting from the literature review of the state-of-the-art research are discussed.

Several national[5,6], and international[7,8], research projects have investigated different offshore grid concepts and how to integrate wind farms and oil and gas platforms to an offshore and onshore power grid. The general conclusions are that a higher level of integration has economic benefits in terms of better resource and infrastructure utilisation, while leading to more complexity in terms of planning, operation, market interaction and cost-benefit allocation. Recent developments in international research point towards different concepts for offshore energy islands[9,10], including cross-border connections and integration to hydrogen energy subsystems[11] in the form of pipeline networks of hydrogen ships.

Zhang et al.[1] studied how clean offshore energy hubs interrelate with efficient offshore wind power generation and distribution, energy supply for maritime transport, oil and gas recovery, and offshore farming, while also enabling the conversion and storage of liquefied decarbonised energy carriers for export. Durakovic et al.[12] investigated the deployment of hydrogen technologies coupled with offshore wind power for the North Sea area. They concluded that the inclusion of the energy hub empowers the deployment of offshore wind in the North Sea. Furthermore, the deployment of green hydrogen can significantly lower the renewable energy curtailment.

Similar work has been done[13] that emphasises that, by deploying offshore wind power in synergy with hydrogen on the NCS, Norway could fortify its position as a clean energy country and become the largest clean fuel exporter in Europe. Woznicki et al.[14] performed a techno-economic analysis of offshore wind farms paired with hydrogen electrolysers, and Zou et al.[15] revealed that the integration of offshore wind energy in oil and gas platforms improves the economy and the environmental impact of that specific field because of the avoidance of gas turbines.

Balancing of power from wind energy is necessary and will have growing importance due to large variations in wind and sea conditions; in fact, atmospheric flow physics are considered one of the grand challenges in wind energy[16]. Recently, lab-scale measurements have shown to replicate the diverse conditions in the field, enabling testing of turbines in varied wind conditions to improve forecasting of power output and turbine degradation[17].

Work by Yang et al.[18] shows that the environmental and energy life cycle emissions of offshore wind farms are still inferior to those of their onshore counterparts. Riboldi et al.[19] compared three power structures for the Utsira High area: solely gas turbine-driven operation for fossil fuel platforms, full electrification of the oil and gas assets, and a hybrid approach by partial electrification and gas turbine cycles. The outcome of the study showed that the economic attractiveness of full electrification is very limited, even considering a strong European commitment towards high CO_2 emission prices.

Roussanaly et al.[20] focused on decarbonising offshore assets via a CCS route. They concluded that the offshore CCS concept offers significant potential for decarbonising the oil and gas industry in a cost-efficient manner.

The development of digital twins will be important for optimal control and asset management of an offshore wind farm. The predictive digital twin[21] is envisioned to give real time decision support either autonomously coupled directly to energy systems or to the personnel in the control room. Furthermore, by implementing digital twins from design through production and operation until decommissioning one can achieve a holistic insight of operation and maintenance cost, and best practice that are useful for the design of future energy systems.

Overall, the literature about offshore energy hubs and their integration and synergies with the shore is fairly limited. The main findings and research needs based on the literature review are summarised and listed within each of the previously identified cross-disciplinary areas. This list will be further developed and detailed to be part of PhD position descriptions for the first batch of candidates in 2024.

5 Kristiansen, M. (2019). Multinational transmission expansion planning: Exploring engineering-economic decision support for a future North Sea offshore grid. PhD thesis NTNU.

6 Korpås, M., et al. (2012). A case-study on offshore wind power supply to oil and gas rigs. *Energy Procedia*, 24, 18-26.

7 Decker, J.D., & Kreutzkamp, P. (2011). OffshoreGrid: Offshore Electricity Infrastructure in Europe. Report.

8 Flament, A. et al. (2014). NorthSeaGrid: Offshore Electricity Grid Implementation in the North Sea.

9 Tennet. North Sea Wind Power Hub. URL: https://www.tennet.eu/about-tennet/innovations/north-sea-wind-power-hub. 2016.

10 Cutululis, N.A. et al. (2021). The Energy Islands: A Mars Mission for the Energy system. Report.

11 Gea-Bermúdez, J., et al. (2023). Going offshore or not: Where to generate hydrogen in future integrated energy systems? *Energy Policy*, 174, 113382.

12 Durakovic, G., del Granado, P. C., & Tomasgard, A. (2023). Powering Europe with North Sea offshore wind: The impact of hydrogen investments on grid infrastructure and power prices. *Energy*, 263, 125654.

13 Meier, K. (2014). Hydrogen production with sea water electrolysis using Norwegian offshore wind energy potentials: Techno-economic assessment for an offshore-based hydrogen production approach with state-of-the-art technology. *International Journal of Energy and Environmental Engineering*, 5, 1-12.

14 Woznicki, M., et al. (2020). Far off-shore wind energy-based hydrogen production: Technological assessment and market valuation designs. In *Journal of Physics: Conference Series* (Vol. 1669). IOP Publishing.

15 Zou, X., et al. (2021). Sustainable offshore oil and gas fields development: Techno-economic feasibility analysis of wind–hydrogen–natural gas nexus. *Energy Reports*, 7, 4470-4482.

16 P. Veers et al. (2019) Grand challenges in the science of wind energy. Science, 366 (6464).

17 L. Li, R.J. Hearst, et al. (2020) The near-field of a lab-scale wind turbine in tailored turbulent shear flows. *Renewable Energy*, 149:735-748.

18 Yang, J., et al. (2018). The life-cycle energy and environmental emissions of a typical offshore wind farm in China. *Journal of Cleaner Production*, 180, 316-324.

19 Riboldi, L., Völler, S., Korpås, M., & Nord, L. O. (2019). An integrated assessment of the environmental and economic impact of offshore oil platform electrification. *Energies*, 12(11), 2114.

20 Roussanaly, S., et al. (2019). Offshore power generation with carbon capture and storage to decarbonise mainland electricity and offshore oil and gas installations: A techno-economic analysis. *Applied Energy*, 233, 478-494.

21 San, O., Rasheed, A., & Kvamsdal, T. (2021). Hybrid analysis and modeling, eclecticism, and multifidelity computing toward digital twin revolution. GAMM-Mitteilungen, 44(2).

TECHNOLOGY

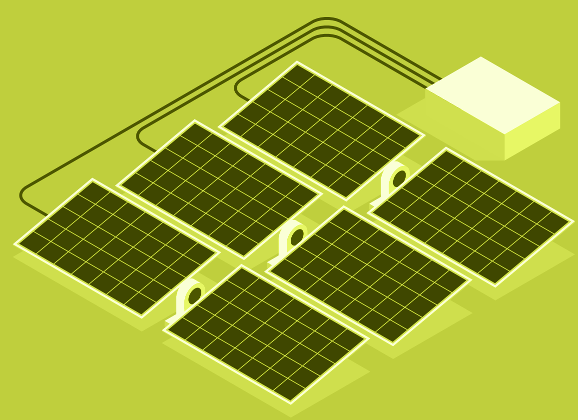
- Control and optimisation of offshore platforms integrated with wind energy or electrification from shore.
- Maximising utilisation of available wind energy: A stepwise approach from single platforms to a fully integrated offshore DC grid with link to hydrogen subsystems.
- Targeting specific solutions needed for arctic environments and energy systems in the North (offshore and connection to the onshore grid).
- Analysis on offshore AC and DC solutions on a local and expanded level.
- Utilisation of other renewable energy sources: Wave energy, floating PV and expansion of onshore power generation.
- CO_2 capture: Blue H_2 and power generation from gas (offshore and at coastline) including endogenous hydrogen and power demands on a Norwegian and pan-European level.
- Creating offshore energy solutions that strengthen the onshore grid, instead of exerting more strain on it.
- Offshore network topology and representation of the onshore power system of the future.
- Digital twins and data-driven methods for offshore power systems and specifically offshore control rooms.
- Analysis of optimum provision of balancing services to support variable renewable energy sources through integration of the onshore and offshore power systems.
- Interplay between the offshore energy system and the European energy system, analysing both capacity expansion and operations.
- Understanding the atmospheric flow physics interacting with wind farms and how they influence power production, energy forecasting, and wind turbine degradation.

ECONOMICS

- An economic dispatch model to improve profitability of offshore wind assets combined with various storage solutions and grid connections.
- Investment planning strategies for integrated energy systems on the NCS.
- Techno-economic analysis of sustainable fuels (e.g., ammonia, methanol, hydrogen, etc.) for shipping, storage and energy carrying on the hub.
- Optimisation models and operational models incorporating uncertainties related to offshore-deployed technology strategies.
- Retrofitting of offshore energy infrastructures to take part in the energy transition, for example, switching to hydrogen and CO_2 pipelines.

POLITICS & SOCIETY

- National and European policy strategies to foster offshore wind deployment and decarbonisation of oil and gas platforms.
- Socio-technical studies on the transition of oil and gas business towards sustainable renewable energy systems on an energy hub.
- Life cycle assessments of the new energy solutions offshore.



THE PHD PROGRAMME

AIM OF THE PROGRAMME

The aim of the PhD programme is to examine research questions related to integrated energy systems on the Norwegian Continental Shelf, as illustrated in Figure 5. The PhD programme's mission is:

> Energy forecasting and utilisation across temporal, professional and organisational boundaries for NCS core areas.

The multidisciplinary programme will ensure a broad coverage of all research questions, with the overall goal of advancing industry-relevant and use-case related research. Furthermore, the PhD candidate will study specialised courses and undergo training to be best prepared for future challenges in the energy sector, especially for the NCS and for possible recruitment by industrial partners.

We aim for a PhD programme with a flexible yet more focused scope than the large FME research centres (Centres for Environment-friendly Energy Research). We will educate candidates at Master and PhD level, while conducting research on industry-relevant use-cases. The scope of the project integrates renewable energy systems with the oil and gas industry to enable stepwise development of sustainable energy systems on the NCS.

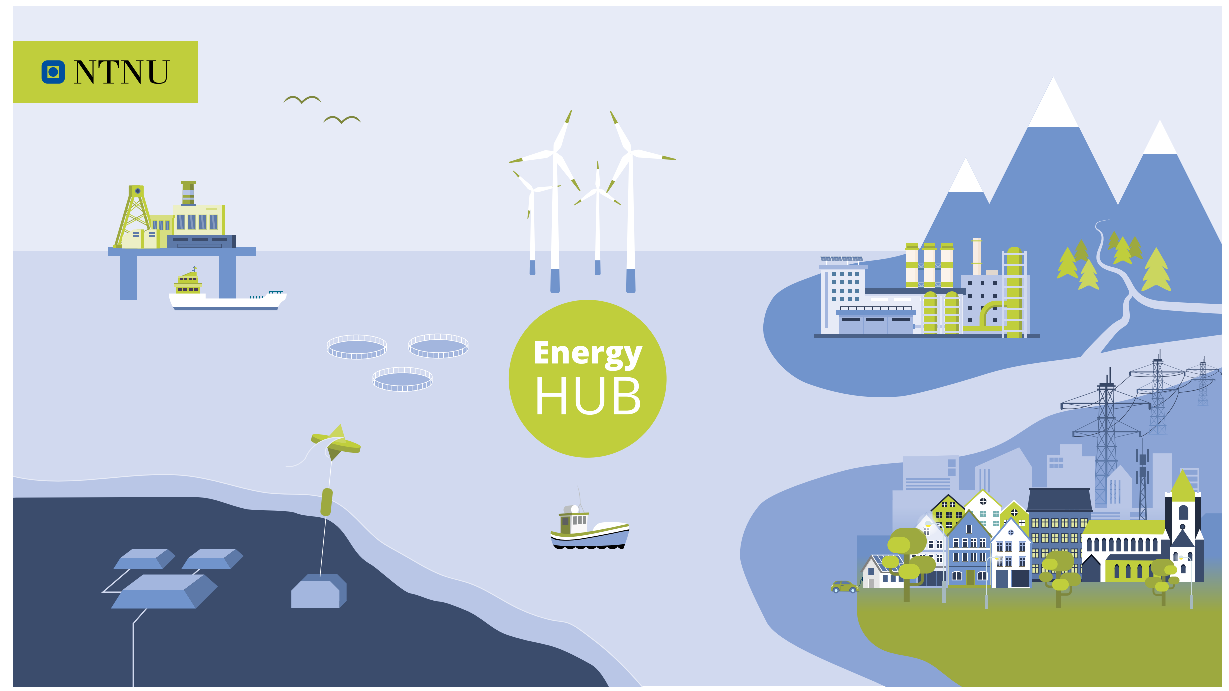


Figure 5. Illustration of the NTNU Energy HUB.

Illustration: www.colourbox.com

Illustration: Tora M. T. Mæhle

SYNERGIES WITH OTHER RESEARCH CENTRES

There are many research centres that NTNU is involved in that have interesting synergies with the Energy HUB PhD programme. The focus in this section is on existing centres and initiatives, and describing synergies between the centres and this programme.

The NTNU Energy Transition is an umbrella research initiative dealing with the transition and best strategies towards future energy systems. Methodologically, this research project initiative includes both social sciences and technology, but focuses on transition. Regarding modelling approaches, the initiative has research groups within long-term energy system design and capacity expansion, integrated assessment models, energy system operations, markets and market design, and more. This initiative is broader than the Energy HUB project, as it focuses on all aspects with the transition. In addition to research, its main purpose is to facilitate cooperation among different axes, such as: a) between industry, policy makers and academia, b) internally across disciplines at NTNU, c) between FMEs and other centres, and d) between NTNU and leading international research groups. NTNU Energy Transition Initiative has established an organisation and platform for facilitating innovation, communication and dissemination. The Energy HUB project provides a more detailed understanding of the challenges that are present at the NCS. There is a large potential for synergies with the NTNU Energy Transition Initiative.

The FME research centre NTRANS analyses energy systems in the context of the decarbonisation of energy sectors, industry and transport towards a zero-emission society. It delineates transition pathways for a more sustainable future energy market. It combines insights from social, economic, technical and environmental sciences, and the outcomes of NTRANS will be useful in the creation of a fair and transparent NCS energy market and in achieving its integration with the onshore energy market. This research scope can enhance the collaboration with the Energy HUB programme, and many synergies in the field of social sciences will result in facilitating a fair and transparent transition on the NCS.

The FME research centre NorthWind focuses on the deployment of wind energy in diverse areas for a sustainable future power market. The research goals of this initiative are to reduce the costs of wind energy installations, to increase their efficiency, and to diminish the negative environmental impact of these assets. The synergy with Energy HUB is found in the investigation of wind energy on the power production side. One of the work packages of NorthWind focuses on digital twins adapted to wind power generation, thereby predicting load basis and performances.

The research programme BRU21: Better Resource Utilization in the 21st century focuses on achieving increased efficiency and safety, and a reduced environmental footprint of oil and gas production, through digital and automation technologies. From the energy perspective, the BRU21 programme focuses on optimising energy demand in oil and gas installations including drilling, reservoir, production and maintenance. It also conducts research on energy management as well as economic and investment analysis for complex offshore energy systems, including the electrification of oil and gas installations. The BRU21 leadership has indicated that they will collaborate with the Energy HUB programme through joint projects and synergies in relevant areas.

The LowEmission research centre focuses on a variety of technologies to reduce CO_2 emissions on the NCS, and has several potential synergies with the Energy HUB programme. On the one hand, regarding energy resources, synergies can result in the field of gas turbine cycles that are fired with carbon-free sustainable fuels. On the other hand, multiple collaboration opportunities might arise in the development of cost-efficient offshore power distribution networks and energy management solutions for the offshore field.

The FME research centre NCCS covers many aspects of carbon capture and storage, and there are thus natural synergies with the Energy HUB project on the energy demand side. This research centre embraces the whole CCS value chain, from the CO_2 capture process to the ultimate disposal of CO_2 in geological formations and reservoir management. Synergies between the two initiatives will primarily result in the interplay between point source CO_2 capture in thermal power plants and renewable energy systems, but also in the field of CCS deployment on oil and gas platforms. Furthermore, cooperative objectives can be found in hydrogen-fuelled gas turbines for clean and efficient energy conversion on the NCS.

The FME research centre HYDROGENi looks at many aspects of hydrogen and has synergies with Energy HUB on the energy carrier side. The NCS field will present specific challenges and opportunities that are not investigated in HYDROGENi – for example, regarding how to build and operate hydrogen components and subsystems suited for offshore environments, exploring offshore subsurface hydrogen storage, and different pressurised hydrogen storage solutions.

The overall objective of the research project Ocean Grid is to develop new solutions of offshore grid technologies in Norway to enhance the capabilities and potential of offshore wind energy. The outcomes of Ocean Grid will be useful in addressing the issues of electric energy transmission on the NCS, which is important for the Energy HUB programme.

OPERATING MODEL OF THE PROGRAMME

DESIGN OF THE PHD PROGRAMME

The PhD programme is designed as an industry-relevant use-case driven research activity, and envisions a direct influence on the research theme selection and evaluation by the industrial stakeholders. In comparison to other research initiatives, this will allow the building of a more dynamic research environment, where the PhD candidate adopts research inputs from the companies on a real use-case basis. The research topic is not static but evolves dynamically in time, and its scope is focused on real-world application and conceptual topics to enable a sustainable transition on the NCS. In other words, the typical bidirectional composition of general PhD programmes will be extended to a triangular situation involving the academic supervisor, PhD student, and company co-supervisor or mentor.

Furthermore, specific training and education will be provided to the PhD candidate in order to enhance personal assets and capabilities in the field of integrated energy systems. To enhance collaboration and knowledge-building, a list of common courses covering the core knowledge necessary in the Energy HUB initiative, secondments in industry, workshops including those organised by the PhD candidates, and summer school or winter school, will be important parts of the PhD programme.

Figure 6 presents the multidisciplinary PhD programme with several research themes and PhD students. Under each research theme, several (here, as an example, displayed as three) PhD students are involved in a research team, including the co-supervision of at least two Master students. The multidisciplinary clusters enable the mapping of a large research field, allowing several PhD students to work in groups, with knowledge exchange across different disciplines. A third dimension in the PhD cluster is time where we envision that PhD candidates towards the later years of the education works together with PhD candidates in their early years.

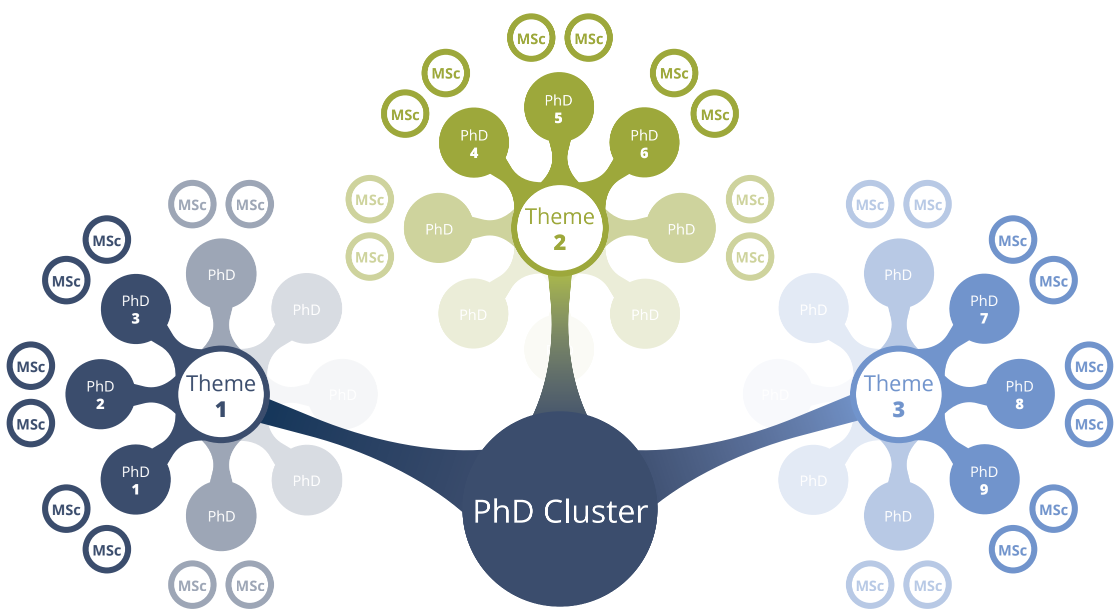


Figure 6. PhD clusters with multidisciplinary teams working on selected research themes.

CORE VALUES

The programme will follow the core values of NTNU, summarised by the slogan "Knowledge for a better world". Furthermore, the key values of the programme are:

1. Multidisciplinary research collaboration

   The participants of the Energy HUB programme will undertake to use the multidisciplinary expertise present in the consortium, and collaborate and strive for research excellence by learning and adopting the methods and concepts recommended by experts in the different fields covered by the project. This will require an unusual effort from the researchers but will ensure impeccable research outcomes.

2. Fairness in energy transition

   The transition towards a sustainable energy system must be fair and transparent. This programme will make sure that the change takes place in a transparent manner for the energy companies but also for the wider Norwegian society.

3. Sustainability in energy resource utilisation

   This programme drives the industry to a sustainable resource utilisation and enhances the energy efficiency of the system overall. Critical resources and technologies are assessed, with the main goal being to enable the shift towards renewable energy sources.

4. Respect in communication enhancement

   This programme is an initiative that will bring academic and industrial experts together to enhance the research landscape and project future research topics.

5. Openness in research representation

   By default, the programme will promote open research. The aim is to provide open-source software, open-access research publications and open research data.

GENDER AND EQUALITY

Although the listed NTNU key personnel consists of only males, the project owner and several department leaders are female. This research initiative strongly supports gender equality and fairness between all involved entities. If two applicants are on the same educational and professional level, the female candidate is prioritised.

NTNU ENVIRONMENTS IN THE PLANNED PROGRAMME

Faculty of Engineering

Department of Energy and Process Engineering

Terese Løvås
Head of department

Department of Geoscience and Petroleum

Ute Mann
Head of department

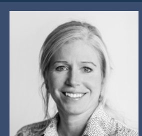
Faculty of Economics and Management

Department of Industrial Economics and Technology Management

Marielle Christiansen
Head of department

Faculty of Humanities

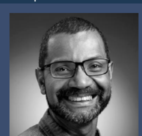
Department of Interdisciplinary Studies of Culture



Guro Korsnes Kristensen
Head of department

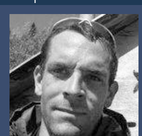
Faculty of Information Technology and Elecrical Engineering

Department of Computer Science



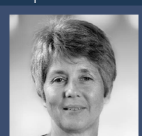
Heri Ramampiaro
Head of department

Department of Engineering Cybernetics



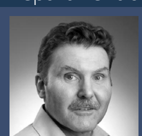
Sebastien Gros
Head of department

Department of Electric Energy



Anngjerd Pleym
Head of department

Department of Mathematical Sciences



Einar Rønquist
Head of department

KEY NTNU PERSONNEL

The pre-project of the NTNU Energy HUB has Head of Department Terese Løvås as project owner and Benjamin Mitterrutzner as project manager. The key personnel included eight professors from the departments represented in the project:

Sebastian Gros
Department of Engineering Cybernetics

Eric Monteiro
Department of Computer Science

Tomas Moe Skjølsvold
Dept. of Interdisciplinary Studies of Culture

Lars O. Nord
Department of Energy and Process Engineering

Trond Kvamsdal
Department of Mathmatical Sciences

Alexey Pavlov
Department of Geoscience and Petroleum

Magnus Korpås
Department of Electric Energy

Asgeir Tomasgard
Dept. of Ind. Economics and Tech. Management

It is envisioned that the key personnel from the pre-project will continue their involvement in the PhD programme. Further, new upcoming professor positions, financed by the academic agreement between NTNU and Equinor, will be linked to the programme. This includes a professorship in the Department of Engineering Cybernetics on Energy System Integration.

The aim is that the programme will be managed by an externally financed person with strong connections in the Norwegian industry.

INTERNATIONAL ACADEMIC COLLABORATIONS

The collaboration with leading universities will be based on NTNU's established collaborations, including *Nordic Five Tech* and the *Enhance Alliance*.

The *Nordic Five Tech* consists of the following institutions:

- Chalmers Tekniska Högskola
- Danmarks Tekniske Universitet (DTU)
- Kungliga Tekniska Högskolan (KTH)
- Aalto University
- Norges Teknisk-Naturvitenskapelige Universitet (NTNU)

The *Enhance* network unites 10 international universities:

- Chalmers Tekniska Högskola
- Eidgenössische Technische Hochschule Zürich (ETH)
- Politechnika Gdańska
- Norges Teknisk-Naturvitenskapelige Universitet (NTNU)
- Politecnico di Milano
- Rheinisch-Westfälische Technische Hochschule Aachen (RWTH)
- Technische Universität Berlin
- Technische Universiteit Delft
- Universitat Politècnica de València
- Politechnika Warszawska

There is also potential for collaboration within IEA, as exemplified by the initiative involving DTU Wind and Energy Systems, the Danish Energy Agency, and IEA Wind TCP on Offshore Energy Hubs[22]. This will be a networking and collaboration forum for researchers and industry professionals who work with these subjects.

Moreover, the collaboration with Massachusetts Institute of Technology (MIT) in Energy HUB will be coordinated under the umbrella of the newly signed MoU[23] between MIT and NTNU on the topic of sustainable energy systems.

STEERING COMMITTEE

A steering committee should be established with a mix of industrial and academic members. The steering committee is, in collaboration with the project owner, responsible for the overall direction and follow-up of the project.

22 https://iea-wind.org/2022/11/22/offshore-energy-hubs-super-power-of-the-future/
23 https://nyheter.ntnu.no/ntnu-og-massachusetts-institute-of-technology-mit-undertegner-samarbeidsavtale-innen-energi/

DOCTORAL CANDIDATE RECRUITMENT STRATEGY

INTEGRATED MASTER-PHD SCHEME

To recruit talented Master candidates to the PhD programme, NTNU is envisioning an integrated Master-PhD scheme. The goal of this scheme is to give a seamless transition from Master studies to PhD studies. The scheme is a model whereby the candidate is partly accepted for a PhD programme and starts the PhD education during the last year of the Master studies.

INDUSTRIAL PHD SCHEME

The Research Council of Norway has established the Industrial PhD Scheme to boost research efforts and long-term competence-building for Norwegian trade and industry through the recruitment of doctoral candidates. The scheme is also intended to promote closer cooperation between the business sector and research organisations as a necessary step in promoting knowledge transfer from researchers to society at large.

JOINT ANNOUNCEMENT FOR PHD POSITIONS

To create more publicity and generate interest for PhD position applications, joint announcements of multiple PhD positions should be part of the recruitment strategy. The admission to a PhD position follows NTNU's requirements and standards.

FUNDING OF THE PROGRAMME

The research funding will initially be based on direct industry contributions, and will later be complemented by national and international (EU) public funding. The national funding could include schemes such as: a) Industrial PhDs, b) SFI (Centres for research-based innovation), c) KSP (Collaborative and knowledge-building project) and d) IPN (Innovation project for the industrial sector). The EU funding could include MSCA doctoral networks and various topical Horizon calls.

We foresee three industrial membership levels with different levels of commitment and effective influence on the research topic:

1. Gold: Full funding of one or several PhD candidates
2. Silver: Partial funding of a PhD candidate - Contribution to a PhD pool
3. Bronze: In-kind funding

The cost of one PhD student per year is estimated to be MNOK 1.5 plus MNOK 0.1 for programme management. This means a cost of MNOK 4.8 for a 3-year PhD candidate. The rate will increase annually based on the increase of rates for funding of research fellowships from the Research Council of Norway.

RIGHTS TO RESULTS

The rights to results will be handled in the consortium agreement and will not be covered in depth in this report. In general, the results are owned by the party that generates them. In case of joint ownership of results that were jointly developed in the project by two or more parties, and when it is not possible to separate such results for the purpose of applying for, obtaining or maintaining the relevant patent protection or any other intellectual property right, the parties shall have joint ownership of such results and define this in a separate joint ownership agreement.

TIMELINE

The overall goal of the one-year pre-project was to establish a roadmap for a PhD programme that promotes industry-relevant research in the field of integrated energy systems. Within this scope, the pre-project is intended to help the involved partners to identify the specific knowledge and research gaps, and to achieve the green transition on the NCS core areas.

Regarding the PhD programme, a doctoral education at NTNU usually lasts from three to four years, but the intention is to extend the programme further with multiple batches of PhD candidates. The goal is to start up the programme by Q3 2024, according to the following steps:

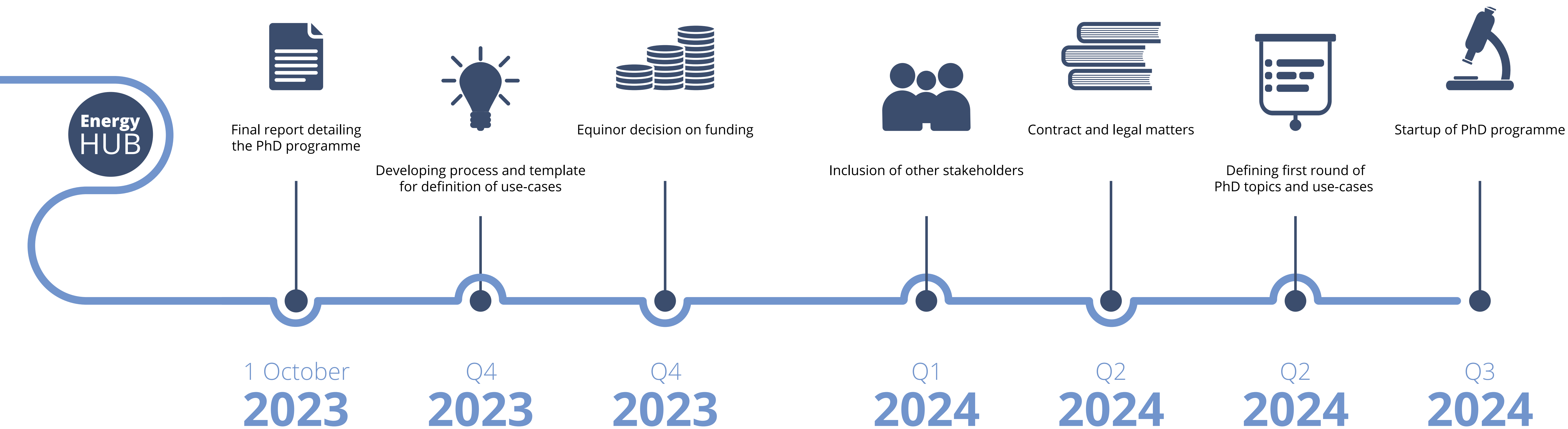


Illustration: Marius S. Stokke

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