Netherlands Organisation for Scientific Research

Section 1 - Application details

Title of the proposal*	North Sea in Transition: an integrated approach for a balance between economy and ecology
Main applicant	Prof.dr. H. Brinkhuis
E-mail	secretary@nioz.nl
Correspondence preference	☐ Dutch ☒ English
Primary NWA route applicable to the research proposal	**Blue route** (1)
Secondary NWA route(s) applicable to the research proposal	Energy (5), Circular (3), Sustainable food (4), Environment (9), Big data(25).
Keywords (max. five)**	North Sea, energy, food, nature, integration
Budget range requested budget	☐ 0.5 – 2 M€ ☐ 2 – 5 M€ ☒ 5 – 10 €M

Section 2 - Research proposal

Summary
The coming decennia will mark a dramatic change in our North Sea, constituting more than 60% of the territory of The Netherlands. Driven by the need for an energy and food transition and bound by pressures from fisheries, shipping, oil, gas and sand extraction and marine protection, a balance between technology, economy and ecology in a complex system must be struck. Billions of Euros are going to be invested presenting a unique opportunity to create and exploit a healthy North Sea ecosystem by combining the major transitions: energy, food and nature. In this project we aim to integrate novel energy research with ecosystem, marine food and social research in a changing natural environment to establish an optimal transition pathway.
In a consortium with 83 partners from 42 organizations we will investigate the development and effects of floating solar panels and islands, wave converters and conversion of peak energy into useful fuels. We will assess whether the ecological carrying capacity of the North Sea system is sufficient to sustainably support multifunctional use of the Netherlands Continental Shelf, also in an international context. We will investigate the potential for new forms of food production including farming of lower trophic levels and optimization of traditional fisheries in a changing environment, including effects of climate change and plastic pollution. Our social, economic and legal research aims at a timely identification of potential hurdles for the transitions, and the development of strategies for 'value creation' in all three transitions. Special attention will be given to the topics in the Research Agenda of the North Sea Strategy 2030 of the Netherlands government.
This project addresses the game changers of the NWA 'Blue Route', water as source, water as blue pathway and living on water and matches the questions and broad aims of many other NWA routes.

2.1 Project description

Scientific and societal breakthroughs
In this North Sea in Transition (NWA-NiT) proposal we research the possibilities and effects of the major transitions: energy, food and nature. The consortium integrates novel energy with ecosystem and marine food research in a rapidly changing North Sea environment (Figure 1). We aim at establishing directions towards optimal transition pathways in this complex system. We include research into the carrying capacity of the North Sea system in a changing climate and the assessment of socio-economic factors and legal aspects and solutions. We address issues in spatial planning and management of sustainable solutions and the use of smart financial instruments. The NiT-project will lead to critical new insights in the transitions of energy, food and ecology on the North Sea and lead to new avenues in conservation, food production, health, and ecosystem dynamics. Furthermore, the programme investigates judicial and societal aspects of these transitions; in short, all aspects of sustainable North Sea Blue Growth.

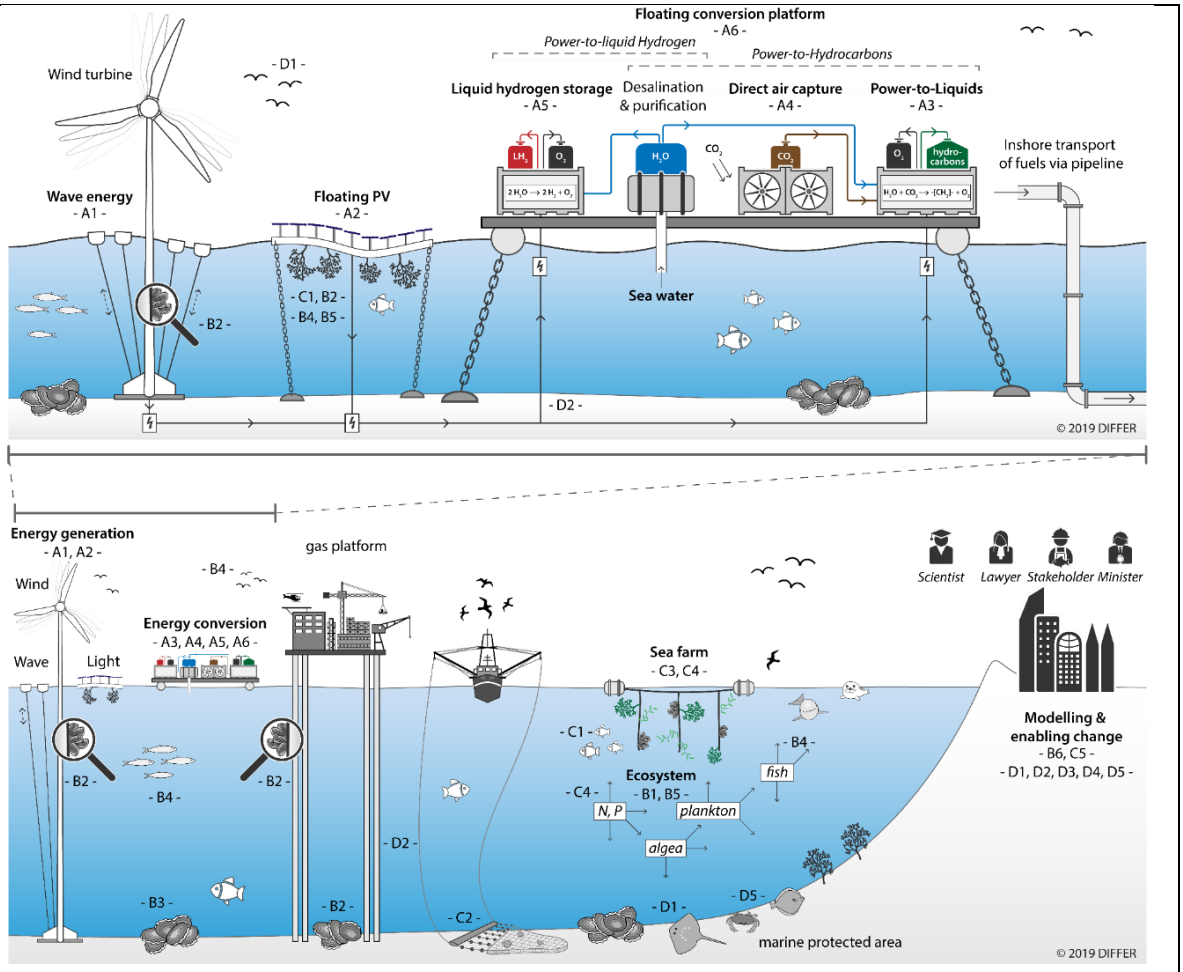

Figure 1: Artist impression of a busy North Sea with many changes. The numbers refer to the different Work Packages in this NWA-North Sea in Transition (NWA-NiT) proposal.

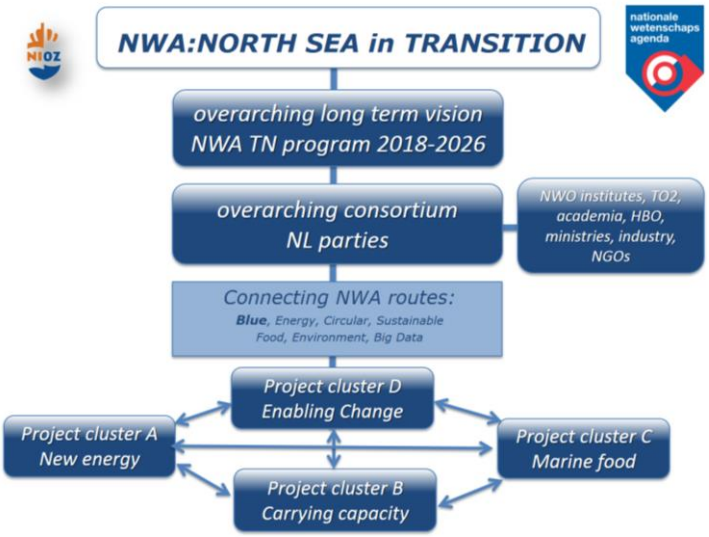

Figure 2: The set-up of this NWA-NiT proposal with an overarching consortium and 4 research clusters

Breakthroughs and innovations
The proposed research goals are highly ambitious and we anticipate to generate a number of major breakthroughs that will have a decisive impact on the sustainable development of the Netherlands part of the North Sea. Through the close overarching cooperation between the different partners and disciplines we create an integrated approach for scientific research of the different aspects of the coming transitions. The research of the 83 partners is organized in 4 clusters. New technological developments addressed in cluster A will create new Man Made Structures that enable organisms to settle on these hard substrates (cluster B). In turn these plants and animals will compete with other uses like fisheries and mariculture for scarce nutrients (cluster C). Models will help to predict the limits to growth both in space and in ecosystem functioning. There will be increasing competition for space in the North Sea and the outcomes of this research will enable a more multi-functional approach for the different users. Social, legal and economic aspects often hamper an optimal combination of the new developments and cluster D is set up to better enable the transitions.

The breakthroughs per cluster include:
Cluster A: New Energy
Cluster A undertakes an integrated approach of Offshore Energy Parks (OEPs). Wind Turbines (WTs), Wave Energy Converters (WECs) around the OEP, and Floating Solar Platforms (FSPs) between WTs generate renewable energy. WECs also reduce waves within the OEP. Pumped-Hydro Storage (PHS) as part of the WECs provides short-term storage and balancing power. The energy is converted onsite into sustainable hydrocarbon fuel for aviation and shipping with CO2 from Direct Air Capture (DAC). For seasonal storage, hydrogen from electrolysis is stored onsite as Liquefied Hydrogen (LH2). An Artificial Hybrid Island (AHI) with reclaimed and floating parts houses electrical and process equipment as well as fuel and LH2 tanks and DAC units. Fuel and LH2 reach coast by ship or pipeline. Steady power electricity is exported by cable. Scientific breakthroughs for the OEP concept are foreseen by (i) development of integrated OEP system model (**A1**); (ii) mathematical description of widely adaptable WEC power take-off using non-linear control technologies (**A1**); (iii) mathematical modelling of flexible FSPs with fabric-like failure modes (**A2**); (iv) novel electrolyte/electrode architecture for fuel synthesis (**A3**); (v) DAC with significantly reduced desorption energy (**A4**); (vi) new materials for bulk LH2 storage (**A5**); (vii) modelling of AHI including interaction between parts and with wave and current fields (**A6**).The societal breakthroughs facilitated by Cluster A are (i) sustainable, 100% CO2-neutral fuels for heavy transport; (ii) sustainable hydrogen for heating - saving tremendous investments into electrical grid; (iii) short-term buffering and seasonal storage OEP, contributing to national energy security; (iv) providing a stepping stone for hydrogen economy; (v) creating jobs in the maritime and energy sector; (vi) technological leadership and export opportunities in clean energy. Along with these breakthroughs, economic benefits to the Blue Economy are foreseen: (i) drastic reduction of expensive electricity transportation to the coast; (ii) hub for energy conversion, storage, bunkering, energy transport, and marine food production; (iii) security of energy supply from indigenous source; (iv) Dutch jobs and export opportunities in novel maritime and offshore technology. The solar platform project will deliver the world's first scientific field observations on the interaction of floating solar farms with the local ecosystem. It will provide necessary data to calibrate simulations that can predict effects of large scale floating solar farms, which are necessary for such innovation to make the next step to commercialization.

Cluster B: Carrying Capacity
Cluster B provides integrated knowledge of processes, interactions and especially the effect of upcoming changes in the geophysical, chemical and ecological environment at different temporal and spatial scales. These relate to unprecedented large-scale changes in exploitation of the North Sea, including the potential designation of 25% of the Netherlands Continental Shelf to offshore wind. New insights lie in: (**B1**) spatially explicit information on potential changes in primary production and hence carrying capacity for the North Sea food web; (**B2**) assessment of the potential contribution of Man-Made Structures (MMS) as new habitats and their effect on biomass, biochemical cycles and biodiversity; (**B3**) assessment of the added value of MMS on recovery of seafloor integrity due to the exclusion of seabed disturbance, both for soft sediment communities, as well as the re-establishment of biogenic reefs; (**B4**) scale-dependent food web interactions between pelagic fish and seabirds around offshore structures; **(B5)** assessment of temporal changes in the microbial and micro-algal composition as a consequence of anthropogenic changes and the microbial enrichment and degradation of man-made particles (e.g. microplastics) and its impact on the food web and (**B6**) identifying the limits beyond which large-scale MMS cause fundamental physical and ecological system changes by understanding ecosystem effects and cumulative interactions in a spatially explicit context. This allows stakeholders to assess the feasibility of current policy objectives regarding the energy, food and nature transitions, taking into account autogenic trends such as climate change and the projected reduction of anthropogenic nutrient input. By showing how objectives interact, how impacts may accumulate and how functions can be restored, cluster B helps to evaluate options and set priorities towards a sustainable use of marine resources. Its knowledge is essential for a safe implementation of the activities in clusters A and C. Close interaction with cluster D ensures that assessments for a 'North Sea in Transition' (NiT) links

directly to policy directives and ambitions. It aims to ensure that these ambitions do not compromise the objectives set by the EU Marine Strategy Framework Directive (MSFD) for Good Environmental Status (GES).

Cluster C: Marine Food
Cluster C provides understanding of the potential and limits of the North Sea for future marine food production. New insights include: (**C1**) optimisation of off-shore mussel and seaweed farming and evaluation of the ecological implications of such farms in order to stimulate the development of a sustainable and economically viable aquaculture sector in the North Sea; (**C2**) an integral approach of effects of closed areas on fish (sustainable fish stock development and migration) and a sustainable fishing industry; (**C3**) seaweed culture practice options positively affecting chemical content of seaweed such as protein for human consumption; (**C4**) essential modelling techniques and information on the potential yields and environmental limitations of combined wind, shell fish and seaweed farms to establish sustainable carrying capacity for these activities in the North Sea; (**C5**) determination of scenario's for future marine production on different scales and locations and for single or combined farming activities including ecological impacts and ecosystem goods and services.
The outcomes of cluster C will give answers to societal questions concerning food production at sea: what is the ecological footprint of marine food production and how does marine food production contribute to climate adaptation and circular economy.
This will pave the way for stakeholders, policy makers, and the public to assess the feasibility of current policy objectives regarding sustainable food production.

Cluster D: Enabling changes
The cluster of social, economic and legal research is overarching and aims at identifying which social, economic and legal challenges as well as opportunities are relevant to the energy, food and nature transitions in the North Sea. This very innovative integrated approach will provide possibilities to address drivers and barriers (**D1, D2**), and adapt an ecosystem based approach leading to salient, credible and resilient solutions (**D3, D4**). Multidisciplinary scientific overview articles will be written on ecosystem functioning, marine nature in the Anthropocene and effects of large scale introduction of man-made structures (**D5**). The cluster D projects build on SDG14, North Sea Strategy 2030, PBL-study 'The Future of the North Sea' (https://www.pbl.nl/en/publications/the-future-of-the-north-sea), the North Sea Energy Programme, literature, and on inter/transdisciplinary discussions among cluster A, B, C and D research. The most important outcomes will be a clear understanding of:

- Social, economic and legal obstacles for the transitions and pro-active approaches to address these obstacles (e.g., problems deriving from nature conservation regimes, sectoral legislation regarding the establishment/use/after-use-phase of installations, social and economic concerns, loss of ecosystem-services);
- Tools and strategies, such as Integrated Ecosystem Assessments (IEA), ecosystem services and innovative legal strategies, to promote that the three North Sea transitions go hand-in-hand and will result in 'value creation' for energy, food and nature;
- Societal benefits of this inter/transdisciplinary research will support: North Sea Strategy 2030 policymakers, industry sectors using North Sea resources, and North Sea focussed NGOs and other stakeholders. The outcomes may prevent unnecessary social protest and legal disputes.

Importance of the proposal
The proposed research programme is of utmost importance for the future development of the North Sea. The Netherlands' government is developing a North Sea Strategy 2030 to address the challenges of the energy and food transitions within a sound ecological system. This strategy will be sent to Parliament in the course of 2019. It will include a North Sea Research Agenda set up in cooperation with industry sectors, NGO's and research institutes. Both applied and fundamental research questions of this agenda have been used in drafting this NiT proposal. Given the importance of the proposed NiT research programme for the implementation of the North Sea Strategy 2030 in the years to come, the ministries involved, industry and NGO's will participate in this programme.

Strategic Research Agenda North Sea 2030
North Sea research topics are an important element of the North Sea Strategy 2030 of the Netherlands' government. This agenda will be submitted to Parliament in 2019. This agenda will address societal challenges in the field of the energy transition, sustainable food production, robust nature and blue economy, with North Sea policy, societal challenges and research being clearly interlinked. Therefore special attention will be given to the topics in the Research Agenda of the North Sea Strategy 2030 of the Netherlands' government, pointing at a clear reason for the government to co-finance this research proposal and to participate in the Governance Board.
Given the importance of the proposed research programme for the implementation of the North Sea Strategy in the years to come, the ministries involved, will participate in this programme.

In drawing up the North Sea Strategy 2030 the involved parties posed many questions in terms of policy dilemmas. Answering these questions requires research: both applied and more fundamental. Part of the Strategy 2030 therefore will be a Research Agenda, focusing on the central themes:

towards a Robust Nature;

towards a Sustainable Food Supply;

towards an Energy Transition;

towards a Blue Economy.

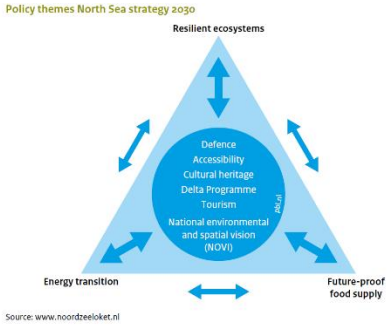

Figure 3: Policy Themes North Sea Strategy 2030

This proposed NiT proposal addresses scientific research components of the whole triangle (Figure above) from the North Sea 2030 programme of the Netherlands' government.
The prioritized science needs of this Strategic Policy Agenda are formulated in 115 knowledge questions (on themes nature, food, energy, and blue economy), for 88 % of which (101 questions) one or more Work Packages in NiT will produce building blocks for sound answers. For 50 % of the knowledge questions the NiT project can contribute expertise delivered by 3 or more WPs, and for 16 % of the questions even more than 6 WPs may deliver multidisciplinary knowledge. More details on the questions and relevant Work Packages can be found on the website.

Integrated Knowledge and Innovation Agenda (IKIA)
Furthermore, this NiT research proposal contributes to paving the way to achieving the climate protection goals of the Netherlands as set out in the National Climate Agreement (NCA) and the accompanying Integrated Knowledge and Innovation Agenda (IKIA, Sect. D3 of NCA). Based on Offshore Wind Parks (NCA C5.4) Cluster A proposes multiple use of ocean space for energy production aiming at hydrogen and sustainable fuels for heavy transport as well as hydrogen from renewable sources (NCA C2.3 & C5.7) and integration of the energy production with the main (inter-)national energy system (NCA C5.6 & D1).
The IKIA sets out Multi-year Mission-driven Innovation Programmes (MMIPs). This proposal supports the MMIPs 1, 6, 8, 9, 12, 13, in which energy system (Cluster A), ecology (Cluster B), marine food production (Cluster C), and the societal dimension (Cluster D) will all work together to achieve the climate protection goals.

Relation to other national and international North Sea research
The proposal builds on current North Sea research, notably WOZEP (Wind Op Zee Ecologisch Programma), strategic research programmes of the TO2-institutes and NIOZ and the international INSITE-UK programme. When this proposal is granted we will link up with other Dutch and international North Sea programmes that will be running during the time of this proposal. Together with the Ministries and research institutes, we intend to set up an overarching Programme Bureau for further exchange of information and tuning of research.
Furthermore, the international dimensions of the research projects are an important part of this proposed approach. We will cooperate with lead North Sea scientists from Germany, UK and Belgium in setting up overviewing scientific articles on the cumulative effects of the huge offshore wind development, carrying capacity for multi-functional use and nature protection.

This proposal fits in and will contribute to the following NWA Routes
This proposal primarily addresses the ***Blue Route*** in which water is a pathway to innovation and sustainable growth. The methodology followed by us fits exactly to the Blue Route approach where innovations are created in open networks, with all the stakeholders in science, society and enterprise engaged in co-creation. Our project contributes to the game changer *Water as a Source* by studying new food supply methods for both humans and animals – sustainable fisheries, aqua farming and seaweed cultivation –, and wave power, solar power and wind power for sustainable energy generation. It also contributes to the game changer *Living on Water* by testing floating structures and studying their ecological impact. Besides the Blue Route this proposal also addresses the route ***Energy transition*** filling in their game changer of an integrated approach to technical, social, economic, legal and spatial challenges by unlocking the potential for the compound use of the sea (combinations of wind, wave, sun, bio-energy, bio-materials and energy storage) and increasing the value of offshore wind energy. We fit to the route ***Circular economy and resource efficiency: sustainable circular impact*** by studying *closed-loop cycles* of circular food production systems at sea, and we fit to the route ***Sustainable production of safe and healthy food*** by contributing to the game changer *Blue*

biodiversity, which focuses on developing new, integrated concepts for the sustainable production of fish and shellfish, as well as algae and seaweeds in combination with offshore wind farms for sustainable energy production. Our proposal also fits into the route ***Quality of the living environment*** addressing the game changer *Nature-inclusive societies* by studying sustainable utilisation of natural capital, studying which forms of governance and guidance are effective and legitimate and how to adapt existing government policy to create more scope for synergy and societal innovation with the right amount of nature conservation. It also addresses the game changer *Resilience as a unifying concept for socio-ecological systems* by transdisciplinary studying the consequences of natural and socio-economic changes to the living environment. Last but not least we fit to the route ***Creating value through responsible access to and use of big data*** by adopting a common Data Archive System that will enhance multidisciplinary data sharing and research from technology and the natural sciences to legal and socio-economic research.

Disciplines involved and why they are vital for tackling the research problem.
The NiT proposal addresses major challenges arising from energy, food and nature transitions with a multi-disciplinary approach. A wide variation of disciplines, from engineering, field testing, ecological effects, food production, economic, social and legal sciences is included in the consortium team. NiT participants from applied as well as fundamental science will work together with engineers, industry, governmental and non-governmental organisations. By combining their disciplinary backgrounds and their open-mindedness to collaborate with many different parties, the partners of this consortium form a unique group to address the complex phenomena of the North Sea in transition.

2.2 Approach/methodology

We will apply a multidisciplinary approach to key developments determining the future use of the North Sea. Therefore, we will perform mathematical modelling and numerical simulation of innovative energy technologies at sea and develop new engineering tools. Large-scale prototypes will be tested under realistic conditions with multi-directional waves, wind, and currents. Dedicated modelling techniques will be combined with lab experiments for fundamental energy process investigations. We will investigate material-liquified hydrogen interaction with material tests under cryogenic conditions. We will use a variety of existing man-made structures (MMS) as vehicles for monitoring (as sensing systems and to follow changes in biodiversity). We will data-mine (so far unpublished) data available at industrial stakeholders such as offshore operators. Field studies and ecosystem modelling will elucidate the carrying capacity for marine food production. We will integrate legal, governmental and social-ecological aspects of the energy, food and nature transitions. There will be close cooperation between several scenario studies in clusters A, B and C, to assess changes in the energy system, biodiversity and ecosystem functioning. Cluster D will be instrumental in defining the scenarios to link them as close as possible to actual policy objectives. Conversely, these model results will help to evaluate these objectives within a legal and social context. The project as a whole is very multidisciplinary and requires extensive sharing of many different types of data and metadata. This is facilitated by the adoption of the central data management system DAS by all participants, ensuring easy and uniform data transfer from engineers, natural scientists and policy scientists alike. We will organise joint multidisciplinary cruises as well as shared model tests, combining work of various clusters and work packages. This is both cost-efficient and fosters cross-fertilisation of knowledge and ideas across disciplines.

2.3 Knowledge utilisation and entrepreneurship

The knowledge utilisation, entrepreneurship and outreach is organized along various lines:

1. **Own content on own platforms**. NiT content such as factsheets, videos, blogs and presentations are produced for the dedicated NiT website, social media, quarterly newsletter, workshops and other events, to communicate research questions and plans, work in progress, results, to show the faces and voices of the NiT research community, to engage all NiT partner institutes in sharing content and to grow the NiT outreach network at large. We will organize 10 workshops (2/year) with all partners and 3 large symposia for all those interested.

2. **Paid media-partnerships** with relevant, well-used media platforms. Payment is not for advertorials but for editorial capacity based on journalistic freedom to ensure continuous professional journalistic content for an already existing readership and an expanding, high quality of online NiT-dossiers.

3**. Free publicity**. From the start, on each NiT expedition at least one berth is reserved for independent journalists and artists 'in residence', familiarizing themselves with sea-going research and scientists, generating professional multi-media output (articles, pictures, videos and radio broadcasts / podcasts) on a wide variety of (inter)national platforms. This serves as an outreach multiplier and expands the NiT-network of science journalists, following-up on the research(ers) they have covered.

Background stories and news on hot NiT topics are actively brought to the attention of Dutch national media and policy-makers via press releases and events. NiT-speakers are pitched as speakers at relevant stakeholder events and public events. Co-ownership of communication by different NiT partners is essential, so their communication officers are involved in drafting NiT communication plans and attending workshops.

4. **Societal use and dissemination of results**

The North Sea Foundation (NSF) will use its central role in the North Sea playing field to function as the interface between science and society. The results, developments and consequences of the project will be disseminated to relevant scientists, policymakers, users, industry, NGOs and the general public. Moreover NSF will press for incorporation of the results in relevant policies, and will try to connect the project with other relevant (research) projects. This will be executed by means of:

- Information and policy implication: New knowledge will be distributed fast and in a coordinated manner to both governments and industry. We will advocate consideration of the results in relevant policies.
- Links with other research and projects: Connect with other relevant (international) projects or research programmes, such as WOZEP or active nature restoration projects.
- Stay involved with and connected to stakeholder and societal developments and needs, and when necessary provide feedback to influence programme direction.
- Inform the wider public and relevant stakeholders through various (social media) channels, to enhance societal understanding and support, together with researchers and partner organisations.

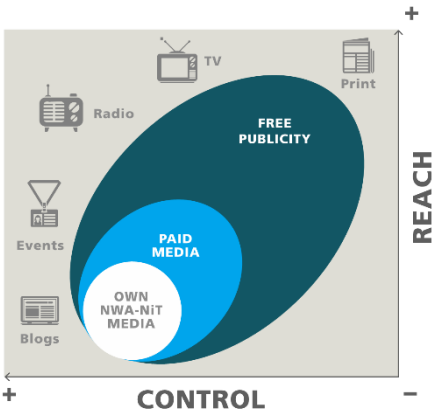

Figure 4: Maximizing outreach.

5. **New technological developments and tools for policy, society and industry**

The results of the four Clusters will each deliver techniques, and concrete materials and tools that can be used by third parties and may deliver services and benefits for stakeholders and society.

- New theoretical models for Wave Energy Converters (WECs), Floating Solar Platforms (FSPs), and Artificial Hybrid Islands (AHIs) as well as materials and processes for Direct Air Capture of CO2 (DAC) and Liquefied Hydrogen (LH2) storage will be used by the industry to develop their products and expand their business. Herein the co-financing partners will have a leading.
- Research institutes and universities can use new knowledge and technologies to further develop and extend the mathematical models into more widely applicable engineering tools for industrial use.
- Based on new and significantly improved modelling and testing techniques new research and development projects can be started to investigate the fields of Cluster A even further.
- The system model for integrated Offshore Energy Parks (OEPs) together with the developed scenarios is crucial to determine the technical and economic feasibility of OEPs and can be used by policymakers and project developers to determine the contribution of OEPs to the energy system.
- New technical developments within cluster B can be employed in operational monitoring, such as: (1) new optically based techniques to assess changes in primary production, as well as changes in functional algal groups; (2) an automated technique to measure shellfish behaviour (3) an automated methodology to detect changes in microbial and microalgal composition indicating potential fundamental changes in the ecosystem. Specific applications of this methodology are: an early warning detection system for harmful algal bloom and potential pathogen detection (specifically also valuable for aquaculture (Cluster C)).
- Significantly improved and thoroughly validated numerical tools that can be used for future environmental impact assessments and appropriate assessments.
- Stimulation of sustainable economic activities, such as seaweed cultivation, as well as shellfish hatcheries (for commercial farming purposes, as well as for restoration efforts).
- Improved insight, based on knowledge developed in Cluster C, that will aid in solving global food production problems while taking into account sustainability and circularity. It provides options for multi-use and addresses the Blue Growth Strategy on Aquaculture of the EU (https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en).
- In cluster D: Scenarios and multiple management objectives, ecosystem service indicators and weights derived by a new App for stakeholder involvement to effectively include stakeholder preferences (quantitatively), will be used to upgrade existing assessment frameworks.
- Improved predictions of epifauna biomass on man-made structures (MMS) to be used in industry guidelines for design of safer and cheaper MMS, and for maintenance and lifting activities for decommissioning.

- Fundamental insight into the carrying capacity for the different biodiversity groups and the effects of climate change and MMS on this, providing a solid base for management guidelines.

Section 3 - The consortium

3.1. Description of the consortium

For the execution of this project we have collated a very strong consortium with Research Institutes, Universities and Colleges, Ministries and Stakeholders (Industry and NGO's) that play a major role in technical, ecological and social research and management of the North Sea:

The partners are (in alphabetic order): AWI, Boskalis, Bureau Waardenburg, CEFAS, Deltares, Differ, Ecorys, ENGIE, GTT, Krone-Projekte, MARIN, Maritiem Kennis Centrum, Ministry of Agriculture, Nature and Food Quality, Ministry of I&W, Nederlandse Vissersbond, NIOZ,NOGEPA, Noordzeeboerderij, Ocean Grazer, Oceans of Energy, OSF, Rijksuniversiteit Groningen, Rijkswaterstaat, Royal Belgian Institute of Natural Sciences, Shell, Stichting de Noordzee, Tilburg University, TNO, TU Delft, Van Hall Larenstein, VisNed, Vogelbescherming Nederland, WECR, WMR, WUR.

Boskalis is a leading global services provider operating in the dredging, maritime infrastructure and maritime services sectors. The company provides creative and innovative all-round solutions to infrastructural challenges in the maritime, coastal and delta regions of the world.

Bureau Waardenburg is the Netherlands' leading consultancy in the field of North Sea ecology, with a strong record in impact assessments, policy advice, field monitoring, experimental research and nature restoration.

Deltares is a research institute in the field of water and subsurface, working on smart solutions, innovations and applications for people, environment, society. Disciplines: hydrodynamics, hydraulic engineering, sediment dynamics, ecological processes, governance and socio-economic sciences.

Differ (Dutch Institute for Fundamental Energy Research) is an NWO institute with over 200 staff carrying out basic research on materials, processes and systems for a global sustainable energy infrastructure in close partnership with Academia and Industry.

ECORYS is an international consulting company aimed at improving public policy across the world and to deliver real benefits to society. Employees have varied backgrounds in economic, environmental and life sciences, and provide consulting services in e.g. social policy, energy, environmental issues.

ENGIE provides highly efficient, innovative energy and services solutions to residential, commercial, and industrial customers and is highly involved in sustainable energies including hydrogen. ENGIE Lab CRIGEN is the corporate R&D center of ENGIE Group and dedicated to gas and new energies.

GTT is the market-leading engineering company and expert in membrane-type containment systems for cryogenic liquefied gases, in particular LNG. With 50 years reliable relationship to all stakeholders of the gas industry, GTT develops solutions for efficient and safe storage and transport of LNG.

Maritiem Kennis Centrum (MKC) is a foundation of four Dutch Maritime Knowledge institutes (MARIN, NLDA, TNO and TU Delft) and six leading maritime and offshore companies to provide an adequate (fundamental) knowledge base for the Dutch maritime industry to secure her world-leading role.

Given the importance of the NWA-NiT research programme for the implementation of the North Sea strategy a good co-operation with ministries is foreseen: the ministries of Infrastructure and Water Management and of Agriculture, Nature and Food Quality will also co-finance the project.

The (CPO) NEDERLANDSE VISSERSBOND is an interest organization for Dutch professional fishermen, owners and crew members in the marine, coastal and inland fishery. Our services are focused on the sustainable development of member companies (members).

The Royal Netherlands Institute for Sea Research (NIOZ) is the national oceanographic institute and principally performs academically excellent multidisciplinary fundamental and frontier applied marine research addressing scientific and societal questions pertinent to the functioning of oceans and seas.

NOGEPA is the Netherlands Oil and Gas Exploration and Production Association. NOGEPA wants to contribute to the transition to a fully sustainable energy supply in 2050 in open and transparent manner. An energy supply that is safe, reliable, affordable and accepted.

The North Sea Farm Foundation is a non-profit organisation aimed at realising a sustainable seaweed industry. Our mission is to develop a strong and healthy seaweed supply chain, in and from The Netherlands via our Seaweed Platform (network) and North Sea Innovation Lab (offshore test facility).

"Ocean Grazer B.V. develops hybrid solutions for the offshore renewable energy sector, focusing on integrating multiple renewable sources together with on-site storage technology. They will contribute in-kind in the form of engineering support to develop and build a WEC prototype."

Oceans of Energy will contribute in-kind in the form of field data and knowledge on interaction of floating structures and the (offshore) ecosystem (environmental impact, bio-fouling).

Offshore Service Facilities (OSF) is preparing the construction of an artificial, multifunctional island.

The University of Groningen has chosen 'energy' as one of the key areas for its research. UG scientists work on (1) the design of new products and production concepts, renewable energy harvesting and storage technologies, and (2) covers legislation and regulation applying to the entire energy chain.

Shell is an international energy company with expertise in the exploration, production, refining and marketing of oil and natural gas, renewable energy resources, and the manufacturing and marketing of chemicals. Shell co-finances and participates in Work Packages.

The North Sea Foundation (NSF) functions as the interface between science and society. Results, developments and consequences of NiT will be disseminated to scientists, policymakers, users, industry, NGO's and general public to stimulate incorporation in policies and link with other projects.

Tilburg University is a public research university specializing in the social and behavioral sciences, economics, law, business sciences, theology and humanities, located in Tilburg in the southern part of the Netherlands.

TU Delft, MARIN and TNO are institutions in ship and offshore engineering, coastal protection, and material sciences, continuously working together in various projects involving a broad range of partners, forming the backbone of innovation in technical marine disciplines in NL.

Van Hall Larenstein (VHL), University of Applied Sciences. VHL offers curricula and carries out applied research in the domains: Delta Areas and Resources, Food and Dairy and Animals and Business.

VisNed is an umbrella-organization representing the interests of a group of Producer Organizations active in Dutch trawl fisheries. It represents >65% of the trawlers. It does so in national and international fora on subjects such as policy, management, research & innovation, safety, etcetera.

Vogelbescherming Nederland is a Dutch Nature Protection Organization which is committed to the protection of wild birds and their habitats. It is a foundation with approx. 150,000 members, a professional staff and more than 350 active volunteers.

Wageningen Marine Research, Wageningen Economic Research and WU are part of Wageningen University and Research Centre (WUR), a globally renowned knowledge institute in the fields of nutrition health, sustainable agricultural and marine systems and environmental quality.

Other organisations, e.g. Tennet, Vattenfall/NUON, NWEA, ministry of Economic Affairs and Climate Policy (EZK), have indicated that they might like to join, but the relatively short preparation time and the Christmas holidays made it unfeasible to get final commitment.
When preparing the pre-proposal, sand extraction research was excluded because another pre-proposal was prepared for that topic but did not make the second round. Prof S. Aarninkhof (TUD) is already partner in our consortium and when granted we will further discuss possibilities to include effects of sand extraction in our programme.

NWO/NIOZ will supply scientific ship time. RV Pelagia will be available 2-6 weeks per year for the duration of this project (not included in the requested budget). Other partners from industry and fisheries will supply ship time on ships of opportunity.

International co-operation.
Because of the international character of the North Sea and to get full co-operation with research in the neighbouring countries, colleagues from RBINS Belgium, CEFAS UK and AWI Germany who are leading major projects in their country, especially on windfarms, will participate in the project. In addition, Krone-Projekte will provide marine growth samples from offshore structures in Germany, not accessible to Dutch scientists.

3.2 Complementarity and diversity of the consortium

The organisations within this consortium select their employees based on competences and expertise, and not on gender, age or ethnicity. As a result, the consortium consists of various ages (28-70, but expected to decline since PhD students are generally young people), genders (currently roughly 80% male and 20% female; 50% of the cluster leaders is female) and ethnicities (a.o. Dutch, Indonesian, German, French, Cyprian, Hungarian, Vietnamese, Australian). However, since most organisations are Dutch and the project is Netherlands-oriented, by default the majority of partners will be Dutch. Due to the high level of multi-disciplinarity and the wide array of organisations involved, there is a high diversity in competences and expertise. We have a.o. technicians, engineers, ecologists, microbiologists, economists, modellers, jurists, nature-conservers, and fishermen.

Please see section 3.3.1. for more information on expertise. In addition, more employees, e.g. PhD's, will be hired for this project, which will change the gender, age and ethnicity ratios and add expertise and competences.

3.3.1 Main applicants, co-applicants and co-financiers

Main applicant			
Name, title(s)	*Organisation*	*Position*	*Expertise*
1.Prof dr H Brinkhuis	NIOZ	*director*	*Marine geology, Paleoceanography*

	Co-applicant(s)*			
	Name, title(s)	*Organisation*	*Position*	*Expertise*
2	*Ir. A. Capel*	Deltares	*Senior advisor*	*Coastal struct. engineering*
3	*Prof.dr.ir M.L. Kaminski*	TU Delft/3mE	*Professor*	*Ship and Offshore Structures*
4	*Dr.-Ing. S. Schreier*	TUDelft/3mE/SHS	*Ass. Professor*	*Ship Hydromechanics*
5	*Dr. A.J. Böttger*	TUDelft/3mE/MSE	*Ass. Professor*	*Material Sciences*
6 *7*	*Prof.Dr.Ir R v d Sanden* *Dr. A.P.H. Goede*	Differ	*Director* *Adviser*	*Plasma chemistry, Solar Fuels*
8 *9*	*Maurits Huisman,* *Pieter Boersma*	TNO, Maritime & Offshore	*Business develop.* *Business director*	*Sustainability maritime offshore sector*
10	*Dr.Ir.Bas Hofland*	TU Delft/CITG	*Ass. Professor*	*Hydrolics / Structures*
11	*Dr. M.Eleveld*	Deltares	*Senior Advisor*	*Remote sensing, modelling*
12	*Dr. S. Salama*	ITC / TU Twente	*Senior scientist*	*Remote sensing, hydrology*
13	*Dr. Jacco Kromkamp*	NIOZ	*Senior scientist*	*Primary production*
14	*Prof.Dr. K. Timmermans*	NIOZ	*Head department*	*Ecol. aquaculture seaweed*
15	*Dr A. vd Werf*	WMR / WUR	*Senior scientist*	*Plant Physiology*
16	*Rene Peters*	TNO	*scientist*	*Progr Manager Energy*
17	*Dr. Pauline Kamermans*	WMR/WUR	*Senior scientist*	*Aquaculture, oyster rest.*
18	*Dr Henrice Jansen*	WMR/WUR	*Senior Scientist*	*Sustainable Aquaculture*
19	*Marnix Poelman*	WMR/WUR	*Scientist*	*Blue Growth*
20	*Dr.Ir. N. van Dooren*	VHL	*Senior Lecturer*	*Spatial planning / food syst.*
21	*Prof.dr.ir. S.Aarninkhof*	TU Delft / CITG	*Professor*	*Coastal Engineering, BwN*
22	*Prof. dr. D van der Wal*	NIOZ/Uni Twente	*Professor*	*Remote sensing*
23	*Dr Martin Baptist,*	*WMR/WUR*	*Scientist*	*Marine ecology, bird telem.*
24	*Dr BJP Berges*	*WMR/WUR*	*Scientist*	*Hydro acoustics*
25	*As Couperus*	*WMR/WUR*	*Researcher*	*Pelagic fisheries, acoustics*
26	*Dr Mardik Leopold*	*WMR/WUR*	*Scientist*	*Sea bird telemetry, diet*
27	*Dr. Joop W.P. Coolen*	WMR/WUR	*Researcher*	*Benthic ecology NS reefs*
28	*Dr. CJ Camphuysen*	NIOZ	*Senior scientist*	*Marine ecology, seabirds*
29	*Prof. dr. G-J Reichart*	NIOZ/U-Utrecht	*Head department*	*Marine geology*
30	*Dr. ir. J. van der Molen*	NIOZ	*Senior Scientist*	*Physics, biogeochemistry*
31	*Dr Henko de Stigter*	NIOZ	*Senior Scientist*	*Physics, biogeochemistry*
32	*Dr. Rob Witbaard*	NIOZ	*Senior Scientist*	*Benthic biology and bivalves*

33	*Prof. Dr. Amaral-Zettler*	NIOZ / UVA	*Senior Scientist*	*Microbial Ecology*
34	*Prof dr Han Lindeboom*	HAME/NIOZ/WUR	*Em prof, Sen.Adv.*	*Mar.Ecol. project coordinator*
35	*Prof Dr Tinka Murk*	WUR	*Professor*	*Adaptation marine animals*
36	*Dr. Jan Jaap Poos*	AFG WU	*Ass. Professor*	*Fisheries, Marine Ecology*
37	*Niels Hintzen*	WUR	*Scientist*	*Fisheries*
38	*Katell Hamon*	WMR	*Scientist*	*Fisheries*
39	*Prof. Dr. C Bastmeijer*	Tilburg University	*Professor*	*Environmental law*
40	*Prof. M.M. Roggenkamp*	RUG/GCEL	*Professor, Director*	*Energy law, Law of the Sea*
41	*Prof.Dr. H. Hummel*	NIOZ	*North Sea Coord.*	*Mar.Ecol, proj. management*
42	*Prof dr Karline Soetaart*	NIOZ	*Senior Scientist*	*Marine biologist*
43	*Prof. Dr. T. J. Bouma*	NIOZ	*Senior scientist*	*Restoration ecology*
44	*Dr. Luca van Duren*	Deltares	*Senior scientist*	*Marine ecology*
45 46	*Prof. B. Jayawardhana* *Prof. dr. ir. A. Vakis*	Rijksuniversiteit Groningen	*Professor* *Ass. Professor*	*Mechatronics and control of nonlinear systems*
47	*David Goldsborough*	VHL	Lecturer Mar. Pol.	Multi-level governance
48	*Dr Marloes Kraan*	WU ENP/WMR	*Researcher*	*Governance, fisheries*
49	*Prof Dr.H.Van Meijl*	WECR/WUR/WU	*Research Director*	*Technology, Ec. analyses*
50	*Dr Heleen Bartelings*	WECR/WUR	*Senior scientist*	*Env Econ Modelling*
51	*Dr Katrina Soma*	WECR/WUR	*Senior scientist*	*Ecos. Services, Mar govern*
52	*Dr Stijn Reinhard*	WECR/WUR	*Senior Scientist*	*Ecos Services, Nature 2000*

	Co-financiers partner(s)*			
	Name, title(s)	*Organisation*	*Sector***	*Expertise*
53	*Henk Merkus*	Ministry of I&W	*Government and education*	*Economy and energy*
54 55	*Jeroen Vis* *Ton IJlstra*	Ministry LNV	*Government and education*	*Ecology related issues*
56 57	*Drs C.H. Oostinga* *Dr I. van Sprundel*	Rijkswaterstaat	*Government and education*	*Acting director* *Progr man. Offshore Wind*
58	*Aart Tacoma*	NOGEPA	*Oil and gas*	*Oil & Gas and environment*
59	*Dr. Wouter Lengkeek*	BUWA	*Service industry*	*Marine environment*
60	*Johan Nooitgedagt*	NL Vissersbond	*Agriculture*	*Fisheries*
61	*Mr Pim Visser*	VisNed	*Agriculture*	*Fisheries*
62	*Eef Brouwers*	Noordzeeboerderij	*Agriculture*	*Sea farming*
63 64	*JSM van Thiel de Vries* *Paul Peters*	Boskalis	*Industry*	*Construction* *Marine Biologst*
65	*Bert Fokkema*	Shell	*Industry*	*HSE and social performance*
66	*Drs. RTB Visser*	MKC	*Science*	*Maritime developments*
67	*Floris van Hest*	SDN	*Sustainability*	*Manag. marine Env*
68 69	*Dr. Brigitte Vlaswinkel* *Robert van der Wiel*	Oceans of Energy	*Industry*	*Floating energy platforms*
70	*Frits Bliek*	Ocean Grazer	*Industry*	*Hybrid solut. offs ren energy*
71	*Dr. Ir. H. de Neve*	TNO/Solliance	*Materials*	*Senior Scientist*
72	*Mr Nicolas Thenard*	GTT	*Industry*	*Materials Dep Manager*
73	*Ir. W. Otto*	MARIN	*Construction*	*Hydrodynamic expert*
74 75	*Dr E.J. van Zuijlen* *Chris Westra*	OSF	*Construction*	*Wind and islands @ sea*
76	*Dr Mures Zarea*	ENGIE	*Industry*	*Senior Scientist*

3.3.2 Cooperation partners

	National cooperation partner(s)*			
	Name, title(s)	*Organisation*	*Type***	*Sector***
77	*Mr H. Dotinga*	Vogelbesch. NL	*NGO*	*Sustainability*
78	*Dr Nga Nguyen*	Ecorys	*Business medium*	*Sustainability*
79	*Mr Iris Kieft*	ENVIR advocaten	*Business small*	*Sustainability*

	International cooperation partner(s)*			
	Name, title(s)	*Organisation*	*Type***	*Sector***
80	*Dr Silvana Birchenough*	CEFAS	*Public knowledge institute*	*Science*
81	*Prof. Dr. Steven Degraer*	RBINS / UGent	*Public knowledge institute*	*Science*

82	*Dr Jennifer Dannheim*	AWI	*Public knowledge institute*	*Science*
83	*Dr Roland Krone*	Krone-Projekte	*Business micro*	*Science*

Country table international partners*
Belgium
United Kingdom
Germany

In total we have 83 partners from 42 organizations

Section 4 - The work plan

4.1 Overall work plan

The NiT research project has distinguished research into four (4) main clusters. Each cluster deals with major issues that the North Sea system is subject to, and which will go through strong transitions the coming decades. The clusters are referred to as: New Energy (cluster A), Carrying Capacity (cluster B), Marine Food (cluster C) and Enabling Changes (cluster D). Within each cluster, priority topics have been identified, which each will be explored in specific Work packages (WPs) and underlying Tasks. Thereby, within each cluster, five (5) to six (6) prime WPs have been recognised (see picturised scheme below; for an overview of the Tasks see the Gantt chart in chapter 4.3). Notably, during the course of the project time, some additional topics may evolve and embedded in the project structure once recognised by stakeholders and society. For further specifications of the WPs and Tasks, see website http…
The responsibilities for the WPs and the Tasks have in consultation with stakeholders and ministries been assigned to Dutch institutes and scientists with excellent expertise of the particular research issues. A strong management team with outstanding experience in coordination of (even larger) (inter)national project has been appointed (NIOZ) (see Ch. 4.5)

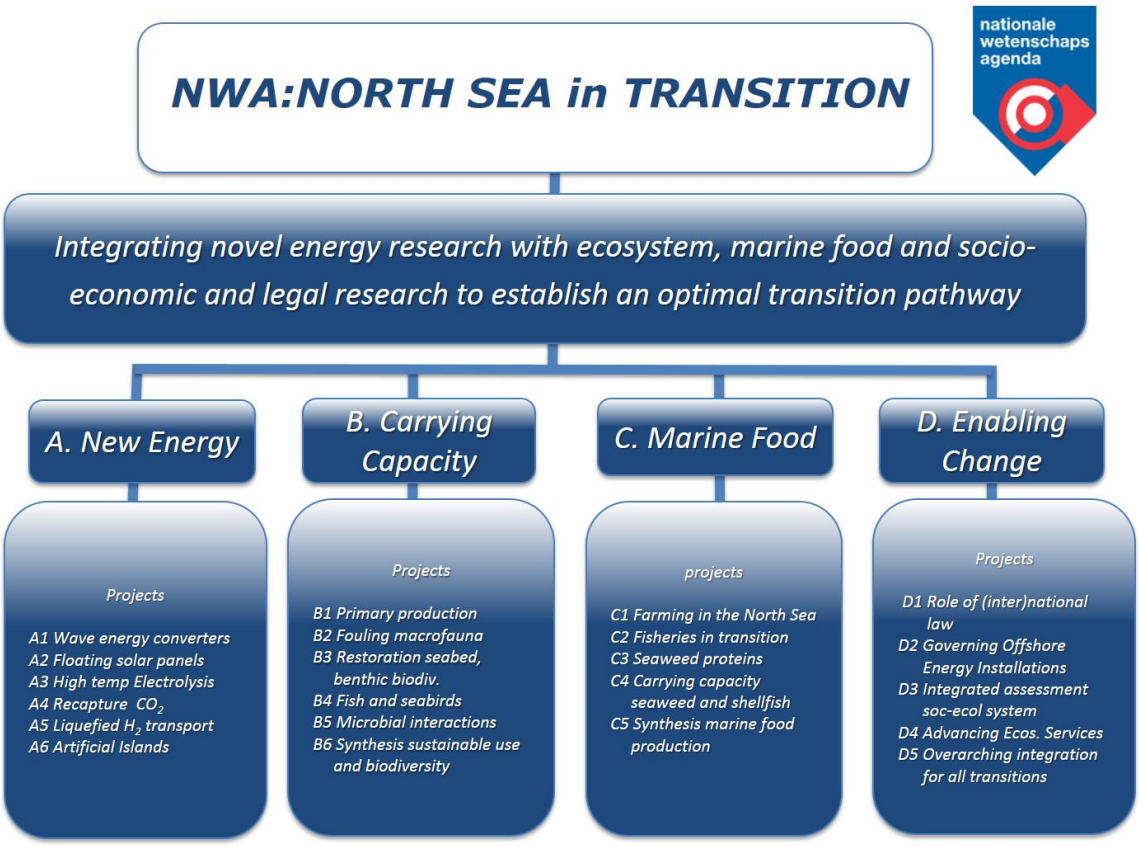

Figure 5. The overarching goal, division in 4 clusters and 22 Work Packages (or projects)

Each cluster is coordinated by a Cluster Leader and each Work Package by a Work Package leader.

The research within and between (the Tasks in) the 4 clusters will be fully interweaved and integrated (see scheme below on interrelations between Work Packages) and will result in strong interdisciplinary scientific publications, as well as profound recommendations for policy and management, and general information on the transitions in the North Sea system for the public at large.

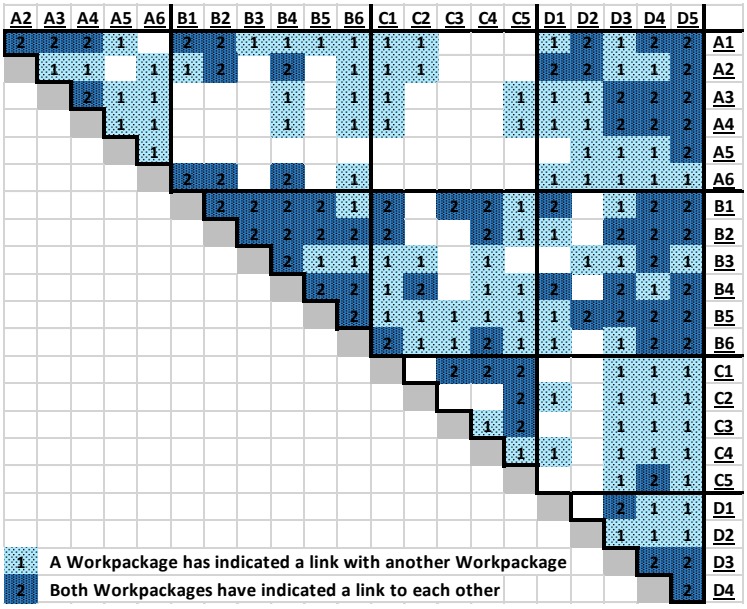

Figure 6. Relationships and cooperation between the 22 Work Packages

4.2 Work packages

Cluster A

Work package number / title	**A1 – Hybrid Wave-Storage Device and Integration**
Work package leader	Prof. dr. A.I. Vakis (RUG)
Involved partners	M. van Rooij (Ocean Grazer B.V.) + Partners A2-A6
Start date / end date	1-1-2020 / 31-12-2023

Objectives. This work package comprises two distinct modules running in parallel. Module 1 investigates Ocean Grazer Wave Energy Converters (OG-WECs) (Barradas-Berglind et al., 2018) on Gravity Based Structure (GBS) foundations that feed into a Pumped-Hydro Storage (PHS) system (Wei et al., 2019), which provides short-term energy storage and regulating power to the OEP. The OG-WECs form arrays on the OEP's windward side to reduce wave height within the OEP and provide sheltered conditions for Floating Solar Platforms (FSP) and Artificial Hybrid Island (AHI). In order to achieve this, the WECs need to be effective over a large range of wave frequencies and heights. This requires adaptable power take-off (PTO) technology and non-linear control strategies. Module 1 aims to (i) develop predictive models and control algorithms for the adaptable OG-WEC and offshore pumped-hydro storage technologies (both at the device and device array level); and, (ii) apply these models and control algorithms within an integrated scale prototype for lab testing for validation.
Module 2 investigates the whole Offshore Energy Park as one large, complex system, which is the integration of subsystems of Cluster A together with the existing technologies of among others offshore wind turbines, solar panels, water purification, electrolysis, and hydrogen liquefaction. The feasibility of this overall concept needs to be evaluated based on different scenarios for national and international development. This requires a system model including all interconnections between the subsystems and their links to the system environment, i.e. nature, (inter-)national energy system, society, as well as close cooperation with the synthesis work packages of Clusters B, C, and D.
Module 2 aims to synthesize the work of Cluster A with input from Clusters B, C, and D to identify the possibility of future application of OEPs in the North Sea.

Description of activities to be carried out, led by the RUG. (1-6: Module 1, 7-11: Module 2)

1. Create the mechanical design of the integrated scale prototype (Ocean Grazer B.V., TUD)
2. Design and implement the mechatronics and control systems
3. Develop predictive models for the performance of the hybrid OG-WEC device and optimize the design for the intended scale and operating conditions
4. Build the scale prototype (Ocean Grazer B.V.)

5. Design, execute and assess wave tank experiments (Ocean Grazer B.V., MARIN) 6. Compare experimental outcomes and model simulation results for purposes of validation 7. Define and assess scenarios for energy transition at the North Sea 8. Determine critical components and subsystems required per scenario including interfaces, timelines, growth scenarios and synergy potential of subsystems as well as existing assets 9. Develop integrated OEP model as combined electric and molecule based energy system 10. Carry out case study of OEP performance based on several scenarios 11. Reach out to related innovation programs with focus on systems integration in offshore energy
Expected output - Reports, conference papers and presentations on the predictive models and control algorithms - Integrated scale prototype ready in year 2 - Journal and conference papers summarizing the results of the wave tank experiments - Energy transition scenarios for the North Sea as a power source for Europe (t1, 6/2021) - Integrated system model and configurations connected to envisaged scenarios (t2, 12/2022) - Case study report over scenarios for OEP with subsystems and interrelations (t3, 9/2023) - Recommendations for feasible setups of OEPs based on scenarios (R, 12/2023)

Work package number / title	**A2 - Floating Solar Platforms (FSP)**
Work package leader	Dr.-Ing. Sebastian Schreier (TUD/3mE/SHS)
Involved partners	B. Blez (ENGIE)), W.Otto (MARIN), M. Huisman (TNO) , B. Vlaswinkel (OoE)
Start date / end date	1-4-2020 / 31-3-2024
Objectives The Floating Solar Platforms (FSPs) with horizontal dimensions of 1 km x 1 km are placed between the offshore wind turbines and cover tens of square kilometers. Affordable floating structures are required for very low payload of PV panels. Envisaging floating mattresses with high flexibility for this purpose, failure modes include fabric-like wrinkling and buckling. This cannot be predicted by existing engineering tools, as recent experience from The Ocean Clean-up demonstrate. Therefore, such engineering tool needs to be developed for the design of durable support structures of FSPs. This work package aims to (i) develop and validate a mathematical model based on Isogeometric Analysis (IGA) for simulation of lightweight flexible FSP in waves including all relevant physics and (ii) to apply of this model to a scale demonstrator of an FSP on lab scale.	
Description of activities Following activities are envisaged, led by TUD 1. Definition of initial concept design of FSP (Engie: evaluation of concept design) 2. Concept development of mooring system (OoE) 3. Development and verification of mathematical model for simulation of highly flexible FSP 4. Identification and investigation of loading phenomena and failure mechanisms of FSP (TUD, TNO) 5. Design, execution and assessment of 2D model tests (TUD) and 3D demonstrator test (MARIN) 6. Comparison of experimental and model results for validation purposes 7. Design case study for FSP using model (Engie: evaluation and feedback on design)	
Expected output - Concept design of ULFS for FSP (t1, 9/2020) - Preliminary (T1, 9/2021), verified (T2, 9/2022), and validated (T3, 9/2023) model for simulation of lightweight flexible ULFS - Mooring system (t2, 6/2021), relevant loading phenomena and failure mechanisms (t3, 12/2021) - Model test data of 2D experiments (TUD) and 3D lab scale demonstrator (MARIN) (Pr, t4, 3/2023) - Concept design of FSP for use in OEP (T4, 3/2024)	

Work package number / Title	**A3 - Power to Molecules**
Work package leader	Dr Michalis Tsampas (DIFFER)
Involved partners	Partners from cluster A and cluster D
Start date / End date	1-01-2020 / 31-12-2022
Objective There are several processes for the production of hydrocarbon-based high energy density fuels based on feedstock CO2 and H2O available on lab scale. The most critical step of these processes is the disassociation of CO2 and H2O into syngas (CO and H2). Solid-state electrochemical cells (ECs) are a promising starting point. To become an integral part of an OEP, hydrocarbon fuel production needs to be scaled up to industrial-size level. This requires the development of compact, reliable and durable process equipment with high performance, process stability and long lifetime under offshore operating conditions and high power levels. This work package aims to (i) develop a 3D electro-catalysts able to efficiently convert CO_2 into targeted products, as well as to overcome imitations of product selectivity and improve reaction kinetics by (ii) creating a 3D electrode structure with a photo-responsive substrate, using light as external stimulus	

and (iii) exploiting the vibrational excitation of CO_2 by plasma activation, a largely unexplored area, expected to enhance the transition of CO_2 in CO.
Description of activities Following activities are envisaged, led by DIFFER 1. Development, fabrication and characterization of selected electrode/electrolyte combinations using novel 3D electrode engineering (M1-18) 2. Investigation of process efficiency and selectivity dependence on operational parameters of EC (i.e. temperature, gas flow rate, applied bias) (M3-24) 3. Integration of ECs with light and plasma stimulus (M18-36)
Expected output - Modified ECs with new operation modes, employing the most promising materials from task A 3.2 - Evaluation of EC under light and/or plasma activation w.r.t. target energy efficiency >55%, conversion rate, selectivity >80% and stable performance (<10% deactivation after 100h) - Solid state EC to convert feedstock CO2 and H2O into syngas or methane powered by renewable electricity with productivity 0.2 L/h syngas per kW electricity input

Work package number / title	**A4 - Direct Air Capture of CO_2 (DAC)**
Work package leader	Dr Michael Gleeson (DIFFER)
Involved partners	Partners from cluster A and cluster D
Start date / End date	1-01-2021 / 1-12-2024
Objective Production of hydrocarbon fuel at an OEP requires a source of carbon. Without CO2 from fossil fuel in the future, DAC of CO2 is the most promising solution. Due to low 0.04% CO2 concentration in ambient air, strongly binding sorbents are employed and energy required for CO2-release by thermal regeneration (bulk heating of sorbents to high temperature, 900 degC in case of KOH sorbent) dominates the energy budget in state-of-the-art DAC processes. To increase the economic viability of DAC in an OEP, the energy demand for the CO2- release needs to be reduced and more efficient DAC processes with short response time need to be developed. This WP aims to develop localized and rapid heating of the CO2–loaded sorbent by tailored Microwave Swing Regeneration (MSR) process to significantly reduce the required energy input, to ensures rapid response time as well as accelerated the CO2 release and material regeneration process.	
Description of activities Following activities are envisaged, led by DIFFER 1. Test bench development to evaluate microwave absorption by candidate materials on material- and class-specific basis including determining optimum frequency depending on electrical power efficiency of microwave source, depth and uniformity of microwave heating zone (M1-18) 2. Measurement and evaluation of frequency-dependent response of candidate material in frequency range 200 MHz to 20 GHz (M12-24). 3. Materials development for MSR starting with sorbent-stabilized amines and exploring other candidate materials (M6-36) 4. Performance evaluation of DAC materials with most efficient microwave absorption at lab scale up to 1 kW for cyclical capture and release of CO2 from dilute gas streams against conventional thermal regeneration (M24-48)	
Expected output - Test bench for evaluation of microwave absorption - Evaluation of frequency-dependent response of candidate material - Demonstration of a tailored MSR process including optimized combination of microwave frequency and sorbent material requiring significantly less energy for CO2-release than thermal regeneration	

Work package number	**A5 - Liquefied Hydrogen**
Work package leader	Dr. Amarante Böttger (TUD/3mE/MSE)
Involved partners	N. Thenard (GTT), B. Blez (ENGIE), M. Huisman (TNO)
Start date / end date	1-4-2020 / 31-03-2024
Objectives Liquefaction and storage of liquefied hydrogen (LH2) at -250 degC and ambient pressure shall facilitate seasonal energy storage. This requires suitable thermal insulation and materials containing the LH2 at cryogenic temperatures. LNG membrane tank technology is a starting point for this. LH2 has much lower temperature than LNG (-160 degC) and much smaller molecule size. This requires a step change in insulation material properties to minimize evaporation loss (boil-off) and identification of suitable materials to contain LH2 in the tank. This work package aims to develop materials for (i) thermal insulation and (ii) LH2 containment enabling the membrane technology for LH2 use, and (iii) to develop procedures for testing material-(L)H2 interaction.	
Description of activities Following activities are envisaged, led by TUD 1. Literature study & property screening of (non-)metallic materials (GTT, Engie) 2. Selection of (non-)metallic materials based on their properties for testing with H2 (GTT, Engie) 3. Design, conduction and assessment of material-H2 interaction tests at ambient conditions (TNO)	

4. Design, conduction and assessment of material-(L)H2 interaction at cryogenic conditions (TNO) 5. Advanced materials characterization 6. Prediction of material behavior, optimization and selection of (non-)metallic material for an LH2 cargo containment system (GTT, Engie, TNO)
Expected output - Material database for (non-)metallic materials (t1, 9/2020) - Shortlist of suitable (non-)metallic materials for testing with hydrogen (t2, 6/2021) - Test report and publication on material-H2 interaction at ambient conditions (T1, 12/2021) - Test report and publication on material-(L)H2 interaction at cryogenic conditions (T2,C, 12/2022) - Update to material database from advanced material characterization (t3, 3/2023) - Selection of (non-)metallic materials with predicted (L)H2 interaction properties (T3, 3/2024)

Work package number / title	**A6 - Artificial Islands**
Work package leader	dr. ir. Bas Hofland (TUD)
Involved partners	W.Otto (MARIN), A. Capel (Deltares)
Start date / end date	1-1-2020 / 31-12-2023
Objectives Installation and production of renewable energy as well as sustainable food on the North Sea requires durable and flexible building space at sea. Artificial islands as considered for offshore wind parks *IJmuiden Ver* (Routekaart 2030) and Doggersbank are an option. More flexibility is added by combining reclaimed and floating parts into an Artificial Hybrid Island (AHI). At the envisaged size of several hectare, there will be strong interaction between floating and reclaimed part. Such AHIs necessitate new engineering tools based on novel interdisciplinary knowledge to predict the loads due to near field wave and current conditions. The objective of this work package is the development of engineering tools for the prediction of the interactions between the floating parts of AHIs including wave transmission, reflection, diffraction, slow-drift effects due to infragravity waves (Hofland et al. 2017) and mooring loads (Waals et al. 2018).	
Description of activities The following activities are envisaged, led by TUD. 1. Identification and description of reef/floater/mooring configurations and processes 2. Evaluation and selection of suitable tools for numerical simulation 3. Development of dedicated instrumentation and models including 2D trial test at TUD 4. Execution of AHI demonstrator tests in the unique Deltares wave basin 5. Validation of the numerical and empirical models 6. Case study for hydraulic optimization of an Artificial Hybrid Island 7. Provision of specialist knowledge and data by Marin, TNO and Deltares in especially Items 1-4.	
Expected output After the project the TRL of the AHIs will have increased, by the following results: - Potential AHI configurations (t1) - Physical relations for hydraulic response of AHI's from 2D Model test, including test data (T1) - Publication on performance of AHI in a realistic setup (basin test), including test data (T2) - Validated 2D and 3D simulation results from the developed numerical tool (T3) - Verified numerical tool for artificial hybrid islands (with T3) - Conceptual Hybrid Island design optimized for hydraulic response (T3)	

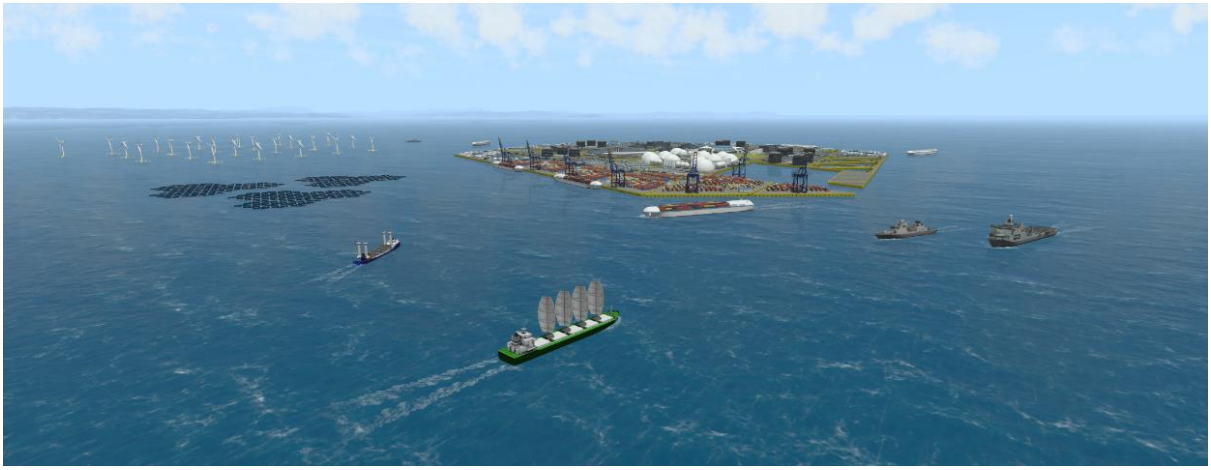

Figure 7 : Technically and ecologically sound solutions for the North Sea in 2030 (source MARIN)

Cluster B

Work package number /title	**B1 / Primary production as basis for the Carrying Capacity and multi-functional use of the North Sea**
Work package leader	Dr. Jacco Kromkamp, NIOZ[1]
Involved partners	prof vd Wal[2], S. Salama[3] (UT/ITC), Prof K. Soetaart[4], J vd Molen[5] (NIOZ), M. Eleveld[6] (RWS)
Start date / End date	01-01-2020 / 31-12-2024

Objectives: to obtain synoptic, high spatial and temporal resolution estimates of primary production (**PP**), phytoplankton functional types (**PFT**) and potential carrying capacity at the scale of a wind turbine farm and of the entire North Sea.

Activity 1. **Automated High resolution method to measure PP[1,2,4,5] .** The lack of PP data for the North Sea prevents validating ecosystems models. We will use automated Fast-Repetition Rate Fluorometry (FRRF) to measure PP, and will also collect (bio)optical data, nutrients etc. A model will be developed to predict the conversion factor necessary to convert FRRF obtained rates into PP.

Activity 2. Automated high resolution measurements of phytoplankton abundance and PFT[1]. Carrying capacity is not only set by PP, but also by the food quality (=PFT=size & biochemical composition) of the algae. In-line flow cytometry (FCM) will give this info. With this information we will determine how environmental controls act on phytoplankton PFT and abundance.

Activity 3. The effect of water column disturbance by wind turbines on primary production[1,2,3,4,5]. Wind turbines can mix stratified water columns and create large sediment plumes. By detailed sampling inside and outside wind turbine farms and by using Sentinel-2 satellite data we will investigate in detail the effect of wind turbines on PP.

Activity 4. **Developing remote sensing based PP models[2,1,3,6].** Data from activities 1,2 & 3 and bio-optical modelling & improved atmospheric correction will be used to calibrate and validate a newly developed coastal PP algorithm, currently being tested in the Eems-Dollard.

Activity 5. **Spatio-temporal dynamics of potential carrying capacity[1,2,6].** Data from Activity1-4 will be analysed in relation to hydrographic regions to assess changes in the spatial patterns of PP, phenology and potential carrying capacity. All data will be used for modelling (B5) and will give input for B2, B3 and B4. It is essential for evaluating the blue growth agenda (WP-C1, and especially C3-C5) and to assess effects effects of activities in A.

Expected output PhD-thesis, 5-6 peer reviewed papers. This work will deliver two new automated novel monitoring methods, which can be incorporated in the MWTL monitoring program: one for PP, and one for phytoplankton abundance and composition. Tested remote sensing algorithms for the different biochemical provinces of the North Sea will produce maps for PP and carrying capacity.

Work package number/title	**B2: Opportunities from epifauna biomass on artificial structures**
Work package leader	Dr. Joop W.P. Coolen (WUR & Wageningen Marine Research)
Involved partners	Dr. R.Witbaard (NIOZ), prof.H.Lindeboom (HAME), prof T. Murk (WU) B. Vlaswinkel(OoE), P. Peters MSc. (Boskalis), B. Fokkema (Shell)
Start date / end date	1-1-2020 / 31-12-2024

Objectives Predict the biomass productivity and metabolic activity of epifauna communities on offshore man-made structures (MMS; gas/wind/solar/tidal/wrecks) under different environmental conditions. Evaluate how different MMS influence benthic biodiversity and biomass by adding rare hard substrates to the background of soft sediment fauna on a local and North Sea scale. Using existing and new data, evaluate and validate current standard estimates for epifouling biomass productivity used by industry in guidelines for design, maintenance and decommissioning of MMS.

Activities Data will be mined from industry generated thickness and weight measurement data. These data will be complemented with own existing data and newly collected samples from various MMS and environmental datasets. Data will be used to create marine growth distribution models for weight and thickness predictions. The work is divided in the following questions with sub-questions:

1. What is the variation in biomass on MMS in the North Sea under different environmental conditions? Variation can be extremely large (0 to 90 kg wet weight per m^2); which environmental drivers can be identified? Activities include data-mining, sampling and modelling. (lead: WMR-WUR, support: Boskalis, Shell, OOE).
2. Which species form the main components of biomass on different locations? How do these species vary in fresh wet weight, volume, compressibility and weight after conservation? Activities: analyse species visually, generate conversion factors for biomass vs volume in water, data analysis, link to B1 to assess consumption of phytoplankton and B6 with biomass dataset. (lead: WMR-WUR).
3. Can we estimate the contribution of the filter feeding epifauna community in nutrient cycling within the North Sea? Activities: *in situ* measurements of metabolic activity and nutrient cycling on structures using measurement chambers. (lead: NIOZ, support: WMR-WUR & OOE).

4. What absolute and relative biomass and biodiversity changes may be expected in 2030 and 2050 when the predicted large numbers of offshore renewables (wind/wave/solar/tidal) have been installed? Activities: modelling impact of different development scenario's. Comparison of local environmental changes between different types of installations (e.g. floating/fixed) and model changes to total North Sea benthic biomass. Assess the contribution of additional biomass to the health of the North Sea ecosystem. (lead: WMR-WUR).
Expected output: The output is delivered in a PhD thesis, and 3 scientific papers, published open access including datasets, in 2021, 2022, 2023, 2024.

Work package number/title	**B3/ Seafloor recovery and restoration**
Work package leader	Prof Dr Tjeerd J. Bouma (NIOZ)
Involved partners	Henko de Stigter, R. Witbaard, Prof G-J Reichart (NIOZ); Pauline Kamermans (WMR); Paul Peters (Boskalis); Bert Fokkema (Shell)
Start date / End date	1-1-2020 / 1-12-2024
Objectives The majority of the North-Sea-floor is covered by soft sediments, subjected to decades of intensive bottom trawling. In the near future, up to 25% of the Dutch sector will be exempted from trawling. This is expected to significantly change the (eco)system, offering opportunities for both natural recovery and targeted biodiversity restoration. Our project will provide mechanistic insight into: **1) Seafloor recovery** following the creation of off-shore wind parks and the exclusion of fisheries, by analyzing **(1a)** *benthic faunal recovery* and **(1b)** *sediment development*. **2) Critical success factors for the restoration of North Sea reefs** by **(2a)** defining *suitable water quality for shellfish reefs* and **(2b)** quantifying *seafloor stability for shellfish reef establishment*.	
Description of activities Task 1a) Sampling campaigns in 2020 & 2022 will be used to assess the recovery of benthic macrofauna in wind farms already excluded from fisheries (Egmond, built 2006, sampled 2007; Prinses Amalia, built 2007, sampled 2008; Luchterduinen, built & sampled 2015) as well as in newly excluded areas (Frisian Front), using nearby areas with continued fisheries as control (cf Cozzoli et al. 2013). The (re-)sampling will cover different spatial scales using side-scan sonar, video surveys, boxcorer, Triple-D dredge, SPI camera. We will supplement measurements with data mining long-term observations around offshore platforms. **Task 1b)** Analysis of sediment cores and seabed video imagery collected from locations indicated at 1a, will be used to quantify how changes in abundance, composition and activity of benthic fauna (i.e., capturing of suspended organic matter and mud, bioturbation and bioirrigation) are reflected in the (sub)surface sedimentary structure, redox gradient and mud and organic matter content (cf Witbaard et al. 2017). **Task 2a)** Identification of suitable water quality conditions for shellfish reef restoration, through deployment of moorings (above ship wrecks) across the North Sea equipped with: *i)* Sensors for water quality parameters (temperature, turbidity, oxygen, chlorophyll, etc.) *ii)* Cages with reef-forming shellfish, for monitoring growth and feeding behavior (valve-gape sensors), and *iii)* eco-engineered artificial settlement structures (e.g., 3D-printed). **Task 2b)** Quantification of natural seafloor stability (i.e., a requirement for reef establishment) within wind parks and fishery exclusion zones (see 1a) by placing small frames with SED-sensors on the seafloor and quantifying the critical erosion threshold for reef establishment using (field-)flumes. SED-sensors allow for continuous measurement of seafloor elevation changes with a 2 mm resolution. **People:** HC de Stigter and R Witbaard will act as daily PhD-supervisors. P. Kamermans, P Peters and B Fokkema will provide critical feedback from the perspective of TO2 and industrial partners. The promotors TJ Bouma and GJ Reichart will supervise the overall project progress. Fieldwork of the PhD will be supported by the diving team of Bureau Waardenburg (subcontracting), whom will also translate knowledge into a policy report, guidelines and outreach (subcontracting W. Lengkeek).	
Expected output 4 scientific papers to be written by the PhD and **3 societal outputs** to be written by Bureau Waardenburg (subcontracting) with NIOZ support: ***i)*** a **policy report** on how building wind farms and fisheries exclusion affect the North Sea; ***ii)*** **guidelines on the best areas to restore** North Sea shellfish reefs and ***iii)*** an **outreach paper** on both aspects, for the general public.	

Work package	**B4. Offshore structures as biotope for seabirds and fish**
Work package leader	dr. ir. M.J. Baptist (WMR)
Involved partners	Wageningen Marine Research, Royal NIOZ
Start date / End date	1-1-2020 to 1-1-2024
Objectives To unravel temporal patterns in seabird–fish food web interactions related to tides and the enhancement of foraging in the wake of offshore structures.	
Description of activities Instrument-based approaches such as cameras and telemetry hold promise for continuous and more comprehensive understanding of the interactions between offshore structures and seabirds (Ronconi et al. 2015). Moreover, integration with fish monitoring to unravel food web interactions is a new endeavor (Baptist et al. 2019). We will establish an integrated observer- and instrument-based avian and fish monitoring program. Instruments will be placed near various offshore structures (wind turbine, production	

platform and/or floating PV) both under water and above water. Techniques include an upward looking echosounder for detection and quantification of pelagic fish (ASL Acoustic Zooplankton Fish Profiler), dedicated pelagic fish trawls with a Surface Trawl net, installation of visual, IR and thermal cameras on offshore structures, ship-based bird observations, birds' fecal analyses for prey typing, and bird telemetry with UvA-BiTS GPS-loggers. **Task 1**: Analysing European Seabirds At Sea (ESAS) database on the spatial distribution and behaviour of seabirds in relation to offshore structures, in combination with dedicated seabird observations. **Task 2**: Measuring and analysing the density and schooling of pelagic fish with underwater hydro-acoustic, flow and turbulence instruments. **Task 3**: Measuring and analysing temporal seabird foraging dynamics facilitated by the availability of pelagic fish due to tidal turbulence near offshore structures with seabird observations and fish surveys. **Task 4**: Upscaling of local food web effects to large-scale effects through spatial modelling. **Team:** PhD-candidate: analysis of ESAS database, analysis of field data on flows, fish and seabirds. MJ Baptist: daily supervision, camera systems, telemetry. MF Leopold: seabird observations, seabird telemetry, prey remains & fish otoliths. CJ Camphuysen: seabird observations, seabird telemetry, prey remains & fish otoliths. BJP Bergès: hydro-acoustics. AS Couperus: pelagic fishing, hydro-acoustics.

Expected output The proposed research will provide new scientific insights in food web interactions between pelagic fish and seabirds near offshore structures that will be used to upscale effects of offshore wind farms on seabirds and fish distribution, aiding in sustainable marine spatial planning and juridical implications. Tangible outputs are a prototype of an observer- and instrument-based avian and fish monitoring program, a PhD thesis and four scientific articles.

Work package number/Title	**B5: Microbial Interactions with the Marine Built Environment**
Work package leader	Prof. Dr. Linda Amaral-Zettler
Involved partners	Dr. Jacco Kromkamp (NIOZ), Dr. Joop Coolen (WMR,WUR), Dr. Machteld Rijkeboer (RWS), Oceans of Energy, Sea Rangers
Start date /End date	1-1-2020 / 31-12-2024

Objectives This WP focuses on multi-use offshore open ocean installations and challenges stemming from microbial colonization/enrichment or degradation associated with these activities.
1) Colonization/Enrichment: **1a.** Increased nutrient availability associated with man-made hard structures in combination with anticipated climate-induced temperature increases are predicted to increase the occurrence of harmful algal blooming (HAB) species and shifts in the zooplankton dominance. *How will these be detected to inform "healthy harvests" of future possible aquaculture activities?* **1b.** Timing of turbine deployment or "cleaning" may enrich for potential pathogens (e.g. vibrio bacteria). *What is the potential for enrichment of possible shellfish pathogens or those species that are harmful for human health?*
2) Degradation: 2a. Increased aquaculture activities in combination with existing plastic marine debris (PMD: nano to macro-sized) from coastal inputs will introduce increased levels of litter into the multi-use offshore installations. *What are the impacts of increased aquaculture on the production of PMD? What are the threats of pathogen or HAB introduction via hitchhiking on PMD inputs?* **2b.** *What are the impacts of disturbance, both natural (sand storms at sea, predator activity) versus anthropogenic (periodic cleaning) on the underlying microbial communities?*

Description of activities: Task 1a) We will acquire a CytoBuoy flow cytometer as part of this project that will be deployed attached to a mooring at Scheveningen during the end of the first year of the project after testing off the NIOZ jetty to assure proper functioning. Part of the preparation will entail training the software to recognize potential HABs and zooplankton species that are known to occur in the North Sea. We will coordinate deployment activities with B1 Cluster members. **Task 1b)** We will coordinate with deployment operations to collect samples during maintenance of the turbines to determine the composition of the biofilm communities and their relationship with potentially pathogenic species. In the case of vibrios, we will monitor vibrio enrichment potential using vibrio-specific media followed by DNA sequencing of relevant genetic markers to differentiate species. **Task 2a)** We will monitor the distributions of PMD using a combination of manta trawls and in situ automated detection instrumentation and compare these levels with those from offshore sites. We are working with the Sea Ranger Service to train their interns on the protocols required to make these measurements and obtain samples of microplastics for microbial community profiling using Next-Generation DNA Sequencing methods. The data from examining individual fragments of PMD will be interrogated for HABs and potential pathogens to determine whether PMD acts to enrich for them. **Task 2b)** We will conduct a series of laboratory disturbance experiments wherein we compare microbial community structure during different times of year including after large storms or cleaning activities to determine whether pioneer communities that form are enriched for the same or different communities. Ultimately we are interested in understanding the impact of natural or anthropogenic activities on the biodiversity of the biofilm communities and their associated megafauna.
People: Linda Amaral-Zettler will serve as the promoter for the PhD student who will work fulltime on the project. A part-time technical person will help with instrument maintenance and deployments.

Expected output We expect to produce **4 peer-reviewed publications** in this WP related to the PhD thesis of the participating student. We also plan to develop and a **HAB early warning system** based on the CytoBuoy data that can be streamed live to NIOZ.

Work package number / Title	**B6 / Synthesis for sustainable use and optimal biodiversity**
Work package leader	Luca van Duren
Involved partners	L.A. van Duren, P.M.J. Herman, T. Troost (Deltares); J. van der Molen, H. Hummel, K. Soetaert (NIOZ)
Start date / end date	1-1-2020 / 31-12-2023
Objectives The North Sea system is governed by physical processes, such as transport of nutrients, stratification, SPM dynamics and light extinction. These processes will be influenced by the envisaged upscaling of offshore wind farms, changes in nutrient run-off and changes in offshore food production. Numerical ecosystem models are essential to gain insight into such processes. However, no model is capable of incorporating all relevant processes and all relevant temporal and spatial scales. Applying different models (the Deltares 3D DCSM North Sea model, coupled to the General Ecosystem Model with Dynamic Energy Budget models and the NIOZ 3D GETM-ERSEM model including a three-layer benthic model, a wave- and current-driven SPM model), will yield important insights in the behaviour of complex systems. Results of the models are compared for similar scenarios to gain insight in which fundamental ecological processes are likely to be significantly affected by single human activities as well as cumulative effects of multiple activities.	
Description of activities: **Task B6.1** Formulation of up to three large-scale offshore wind farm scenarios, based on input from A1, A2, A6 and D1-D4. Deltares and NIOZ. **Task B6.2** Model runs on hydrodynamic effects of large scale offshore wind farms in the North Sea (Deltares). Assess the effects on mixing and stratification. **Task B6.3** Model scenario studies on effects of large scale offshore wind on primary productivity. Assess effects on productivity as well as on timing of spring bloom, using B1 and B5 for calibration and validation (Deltares). **Task B6.4** Model scenario studies on shellfish grazing in wind farms, using input data for scenario choice from D1-D4 and B3 and other subprojects from cluster B. Delivering input to D5. Deltares and NIOZ. **Task B6.5** Model assessments regarding the effects of offshore aquaculture (seaweed and mussels). Together with C4, using input from C1 and C2 for model validation and calibration. Deltares and NIOZ.	
Expected output Manuscripts on 1) changes in physical boundary conditions for productivity in the North Sea; including technical model assessment (m. 12 yr 3), 2) ecological effects of projected up-scaling of offshore wind farms (m.12 yr 4), 3) interactive effects between colonised 'new' habitat and the carrying capacity for other ecosystem parameters (m. 12, yr 5), 4) the potential carrying capacity for flat oyster restoration with and without competition of mussels and aquaculture taken into account (month 12, yr 5). Assessments on interactive effects between food cultivation and ecosystem components (in combination with task C4) (month 12, yr 4). Presentations and reports regarding the outcome of different scenarios for different stakeholders, accessible for non-specialists.	

Work package number / Title	**C1 / Farming in the North Sea**
Work package leader	Pauline Kamermans (WMR/MAE)
Involved partners	H. Jansen (WMR), A. vd Werf (WPR), NIOZ (prof K Timmermans, NZB (E. Brouwers), WU (prof. T Murk)
Start date / End date	1-1-2020/ 31-12-2024
Objectives To determine optimal management strategies and evaluate the ecological implications for off-shore seaweed and mussel cultivation in order to stimulate the development of a sustainable and economic viable aquaculture sector in the North Sea. The productivity of the North Sea is promising for commercial production of high quality seaweeds and mussels. Yet, large scale cultivation is not taking place. A solid ecological and species basis knowledge is essential for economically feasible and sustainable seaweed and mussel production. To optimize management and governance strategies profitable end-products derived from seaweed biomass (see work package C3) must be identified as well as potential environmental impact and positive or negative consequences for other ecosystem services of large-scale aquaculture production to define policy strategies for sustainable use of the North Sea.	
Description of activities **Task C1.1. Optimizing management strategies in seaweed and mussel culture (WMR, WPR, NZB).** Field studies on how seasonal performance of mussel and seaweed (settlement, growth, content and attachment to the substrate up to harvest) is affected by timing of actions such as deployment of seeding lines and harvesting. Biological drivers will be monitored at the offshore innovation lab location (Stichting NZB) where seaweed and mussels are cultivated to optimize timing of seeding/harvesting. Growth and protein/amino acid concentrations in seaweeds will be compared to results of C3 to validate the effect of ecological drivers on protein/amino acid concentrations under field conditions. Shellfish	

settlement, growth and food safety aspects will be monitored. Effects of deployment/harvesting time and environmental factors will be analysed statistically.

Task C1.2. Environmental sustainability (WMR, WPR, NIOZ).

Seaweed and phytoplankton both take up nutrients for their growth. Will seaweed farming affect nutrient availability (absolute, stoichiometric) for phytoplankton or do the two groups differ in preference of certain nutrient types? In addition, mussels release nutrients and graze on phytoplankton of which the seaweed may profit (reduced competition for nutrients and more light due to a more transparent water column). On the other hand, it is known that seaweed exudates can cause reduction of byssus production in mussels. How do different seaweeds species (e.g. *Ulva spp* versus *Saccharina latissima*) influence the mussel cultivation cycle and growth? These questions will be targeted in controlled laboratory experiments and used in C5.

Task C1.3. Carrying capacity for culturing seaweed and mussels (WMR, NIOZ, NZB).

Field and laboratory observations on nutrient uptake and release of cultured algae and mussels and grazing rates of mussels will be carried out. Results will also link to B1, B2 and B6 and feed into Task C4.2 (Model Simulations).

Expected output Recommendations for optimal species choice and culture management strategies and a better understanding of environmental interactions in off-shore seaweed and mussel culture farms will help to define policy strategies. And 4-6 scientific papers in peer reviewed journals, sufficient for a PhD thesis. The results will also be communicated with the general public via social media and video.

Work package number / title	**C2 Fisheries in transition**
Work package leader	Jan Jaap Poos (Wageningen University)
Involved partners	Niels Hintzen (Wageningen Marine Research); Katell Hamon (Wageningen Economic Research)
Start date / end date	1-1-2020 / 31-12-2023

Objectives This project will study the effects of closed areas (i.e. windfarms, nature conservation areas) on fisheries and their bottom impacts. Closed areas are expected to affect fisheries because of i) changing fish habitat use and migration, ii) changing fishing opportunities. Affected fisheries will redistribute their activities, leading to changes in the impact of fishing on benthic communities.

Description of activities Task 1) develops a model for fish habitat use and migration of the major flatfish stocks that are important for this fishery. The model is based on life-history characteristics of fish stocks, following Dynamic Energy Budget theory (Teal et al. 2012). Ontogenetic shifts in habitat requirements during the life of the fish result in migration patterns for each stock. Results of task 1 will be verified by means of tagging fish with electronic archival tags that reveal fish migration in the field. Lead WU, supervising partner WMR.

Task 2) builds on the results from task 1 uses these in a fleet dynamic state variable model (Poos et al. 2010). In the model, the heterogeneous economic environment of individual fishers is used to estimate spatial distributions in fishing activities, catch opportunities, and revenues. These can be evaluated for different fisheries under different scenarios of area closures. Lead WU, supervising partners WMR and WEcR.

Task 3) takes the spatial distributions of fishing activities and combines them with the physical characteristics of fishing gears to evaluate impact on benthic communities. This task will also evaluate potential feedback loops on the effects of fishing on the benthic communities on migration patterns of commercially important benthic fish resulting from task 1. Lead WMR, supervising partner WU.

Expected output

T1.1 Conference paper on habitat use of flatfish (01-08-2021).
T1.2 Article in refereed journals on migration dynamics of North Sea fish (1-1-2022).
T2.1 Stakeholder outreach event with the aim to collect and share information relevant to task 2 (01-03-2022).
T2.2 Article in refereed journals on transitioning fisheries in the light of area closures (1-1-2023).
T3.1 Article in refereed journals on benthic impacts of North Sea fisheries (31-12-2023).

Work package number/title	**C3 Seaweed Proteins**
Work package leader	Prof. Klaas Timmermans (EDS, NIOZ-Yerseke)
Involved partners	Dr Henrice Jansen (WMR), Dr Fred vd Velde (HAS Hogeschool), Dr Dorien Derksen (HZ), E. Brouwers (NZB)
Start date / End date	1-1-2020 / 31-12-2024

Objectives Generate insight in seaweed proteins as a sustainable alternative for animal and/or terrestrial plant proteins, promising in the food/protein transition. Large scale off-shore seaweed cultivation in the North Sea is not taking place because of biological and technical challenges (see WP C1) and because it is unclear what the most suitable/profitable end-product derived of seaweed biomass is. In this WP we investigate proteins, peptides and amino acids as end-products. With these end-

products, their distinctive properties and value, cultivation may become more attractive for producers. This in turn will result in larger seaweed demand, which results in increased nutrient uptake (less eutrophic conditions), more multi-use, more cultivation and therewith increased economic activities in the North Sea.
The WP will focus on 1) most suitable native North Sea seaweed species for protein production, 2) the abiotic conditions (positively) affecting protein concentrations and specific amino acid composition and 3) specific functionalities of proteins and peptides, in relation to 2).

Description of activities

Task C3.1. Selection of most suitable native North Sea seaweed species for protein production. Likely candidates are *Ulva lactuca*, *Saccharina latissima* and *Chondrus crispus*. In laboratories of NIOZ and WMR, experiments will be performed with respect to protein/peptide concentration/amino acid composition. Protocols for extraction and analytical tools (HZ, HAS) for subsequent analyses of these compounds are available. These experiments will be run parallel to field trials performed in work package C1 at the site of 48, to compare the effects of field conditions on ultimate protein concentrations/amino acid composition.

Task C3.2. Variations in abiotic conditions (nutrient availability, turbulence, light conditions) affecting protein concentration and specific amino acid composition, will be investigated under laboratory conditions (NIOZ, WMR), including most efficient extraction and subsequent analyses of proteins, peptides and amino acids (HZ, HAS). Previous work has shown that total protein concentrations in *U. lactuca* and *S. latissima* can be enhanced. In the this task, we aim at a similar response, but now for proteins and peptides for human consumption. Insight in drivers for protein and amino acid composition will help to define the optimal management strategies for offshore cultivation (see WP C1).

Task C3.3. Protein-rich products can be distinguished in raw and processed. Seaweed proteins are promising and suitable for raw and processed products as alternative in the protein transition from animal to plants. To make this transition a success, both technological improvements as well as motivation of the consumer are crucial. For seaweeds, the aim will be to understand the functionality (e.g. solubility, gelling, foaming, emulsifying, etc.) of ingredients based on their molecular properties.

Expected output We expect the work to result in **4-5 scientific papers** in peer reviewed journals, sufficient for a PhD thesis.

Work package number /title	**C4/ Carrying Capacity for seaweed and shellfish farming in relation to the nutrient budget**
Work package leader	J. van der Molen, (NIOZ)
Involved partners	L v Duren (Deltares), prof H Hummel, prof K. Soetaert (NIOZ)
Start date / end date	1-1-2020 / 31-12-2024

Objectives The carrying-capacity of the North Sea will be estimated for natural and cultivated primary and secondary producers for large-scale seaweed and shellfish farming scenarios. These will remove substantial amounts of nutrients, while anthropogenic nutrient loads are reducing since 1985. Seaweed farming will also affect the light climate. Together, these may limit growth conditions in the North Sea. We will investigate the environmental sustainability and interactions with cultivated ecosystem components using model simulations, field and laboratory observations.

Description of activities

Task C4.1 : Field and laboratory observations

In cooperation with B1, B2, B3 and C1, field observations will be obtained on nutrient concentrations and metabolism levels of biota in natural and cultivated populations in the North Sea (NIOZ). Laboratory observations under controlled conditions will flank these to unravel the effects of multiple stressors (NIOZ). The data will be used to advance the modelling (C4.2).

Task C4.2: Model simulations

Pelagic filter-feeders will be added to ERSEM (coll. B6) to simulate shellfish cultivation and turbine biofouling, allowing for simultaneous macroalgae farming (existing seaweed module; NIOZ). Offshore shellfish farming, wild shellfish, mussels on wind turbines, and potential flat oyster beds in wind farms will be included in Delft3D (DEB modelling, DELTARES) and will be run with the macroalgae module in the GEM model. At least one model scenario of B6 will be run with shellfish and macroalgae farming to assess farm yields and effects on nutrient concentrations, light regime, primary production, and secondary pelagic and benthic production. (NIOZ/Deltares).

Task C.4.3: Limiting conditions and advice for sustainable farming

Using the observations and model simulations we will advise on a cost-effective and sustainable aquaculture of seaweeds and shellfish within pre-defined environmental limits in the North Sea

Expected output Metabolic variation in seaweed and shellfish under relevant nutrient conditions (12/Y2). Spatial maps of farming potential for seaweed and shellfish (12/Y4). Limiting conditions for natural and farmed production in the North Sea (12/Y4). Yields for farming scenarios, with impacts on the natural system (12/Y4). Interactions between seaweed and shellfish farms (12/Y4). Advice on sustainable farming of seaweed and shellfish in the North Sea (12/Y4). A suitable set of manuscripts reporting the above.

Work package number / title	**C5 / Synthesis marine food production**
Work package leader	Pauline Kamermans (WMR)
Involved partners	M. Poelman (WMR), H. Jansen (WMR), JvdMolen (NIOZ), prof T. Murk (WU/MAE), NvDooren (VHL)
Start date / end date	1-1-2020 /31-12-2024
Objectives This work package aims to determine the potential and limits of the North Sea for sustainable large scale offshore food production and its spatial implications. This animal and seaweed production should be economically feasible and have positive or neutral impact on the North Sea ecosystem.	
Description of activities This work package will reveal the factors determiningmarine food productivity, methods for habitat-safe harvesting and sustainability limits of the North Sea system. Results obtained in C1-4 and B6 will be synthesized and expanded with literature surveys and modelling exercises. **Task C5.1: Ecological feasibility (WMR, NIOZ).** This task will collate and interpret data on large-scale off-shore plant and animal marine food production (obtained in C1-4 and from literature). It will look at the relation between farming management and seasonality in ecological functioning (biodiversity –eDNA-, nursery, carrying capacity, effects on bottom, fish and birds). In addition, relations between nutrient or food uptake and quality of the product over a season will be studied. Furthermore, the seasonal effect of harvest (removal of nutrients and habitat) on the ecosystem will be estimated. **Task C5.2. Scenario's for future marine production (WMR, NIOZ).** Potential areas where marine food production can take place in the North Sea will be identified in cooperation with C4 and D4. Scenario's with different species produced will be defined in cooperation with B6. Seaweed cultivation, shellfish cultivation and fisheries will be studied for different scales and locations and for mono or combined productions. In a cost-benefit analysis ecological impacts and ecosystem goods and services of large-scale sustainable marine food production and harvesting methods at the North Sea will be identified and when possible quantified for the different scenario's. A Life Cycle Analysis (LCA) is part of that analysis. In addition, use of space by future marine production, smart function combinations, visual aspects above and beneath sea level as well as the effect of marine food production on the main land will be studied.	
Expected output The outcome is a better understanding of potentials, limits and implications of the North Sea for marine food production and balanced and habitat-safe harvesting. Furthermore, we will present the results in 3-4 scientific papers in peer reviewed journals. The results will also be communicated with the general public via social media and video.	

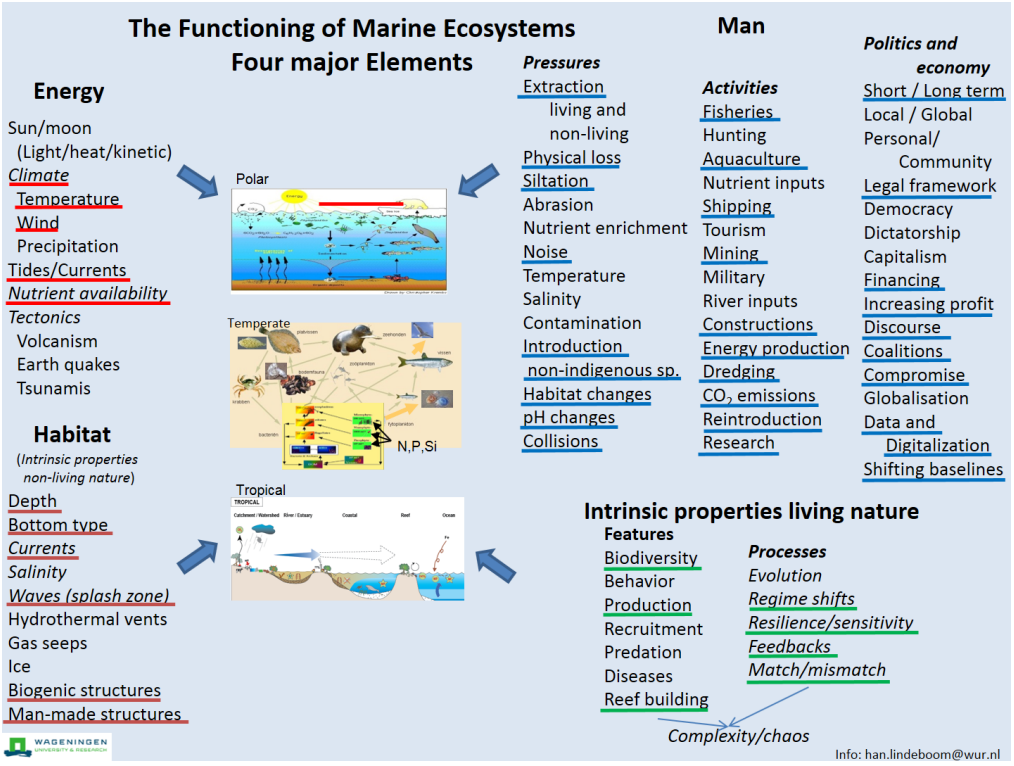

Figure 8: The complex functioning of marine ecosystems, underlined are the influences and processes that play a role in the North Sea transitions.

Cluster D

Work package numb/title	**D1 / North Sea Energy Transition and the Role of International and EU Nature Conservation Law**
Work package leader	Prof. C.J. (Kees) Bastmeijer
Involved partners	Min. LNV, Min.I&W, RWS, vHL, Stichting Noordzee, Vogelbescherming NL, industry sectors, clusters A, B and C-partners for ecological knowledge
Start date / end date	01-01-2020 / 31-12-2024

Objectives International and EU nature conservation law defines strict boundaries for acceptable negative impacts by human activities. Therefore, activities relating to the food and energy transitions in the North Sea run the risk of becoming the subject of intensive legal debates ('juridification'). However, experiences on land show that active eco-restoration may limit the tensions with the legal regimes. Therefore, the central aim of this project is to investigate strategic approaches that may ensure that the transitions: (a) take place within the existing legal frameworks, (b) actively contribute to the objectives of the nature conservation regimes and (c) experience less juridification.

Description of activities

The PhD-candidate and main applicant will work together with partners to conduct the following tasks:

1. Identify the main transition activities regarding food and energy, based on existing scenario's (e.g. the PBL-scenario of "Samen Duurzaam"), a workshop in the first year and taking into account projects D3 and D4 (PhD, project leader, all partners).
2. Describe, analyse and clarify – in light of the transition activities (task 1) – the meaning of the central objectives and legal requirements of existing legal regimes for the North Sea (Bern Convention, Bonn Convention, OSPAR Convention, EU Birds Directive, EU Habitats Directive and the EU Marine Strategy Directive) (PhD/main applicant).
3. Identify the main risks of juridification as well as opportunities for eco-restoration by comparing the outcomes of tasks 1 and 2 and additional consultation with partners (PhD, project leader, all partners).
4. Identify strategic approaches that may ensure that the transition activities (task 1) take place within the existing legal frameworks (task 2), actively contribute to the objectives of the nature conservation regimes (task 3) and experience less juridification (task 3). For instance, what strategic choices can be made to this end in relation to cumulative impacts, spatial planning of human activities, connectivity of protected areas, strengthening attention for potential future nature values within the framework of the Natura 2000-regime, etc. (PhD, project leader, all partners).

Activities to this end include the organization of a workshop in the first year to discuss future scenario's and sharpen the research questions, on-going bilateral contact and cooperation between the PhD-student, main applicant, other projects that form part of this NWA-application and experts of the partners, the organization of a symposium with stakeholders in the third year to discuss preliminary outcomes of the PhD-research, as well as outreach activities for policy makers, stakeholders and the general public in the final year of the project.

Expected output: PhD (2023), scientific publications, various outreach activities (popular publications, presentations, etc.), depending on potential knowledge users: impact on policy making.

Work package number	**D2 / Governing Offshore Energy Installations**
Work package leader	Prof. mr. dr. M. M. Roggenkamp
Involved partners	Nogepa, RWS
Start date / End date	1-1-2020 / 31-12-2024

Objectives The process of energy transition (reaching the 2050 energy and climate goals) will have an impact on the North Sea as a source for energy and food supply. Apart from existing installations like petroleum installations, wind turbines and converter stations, this process will require the use of new installations such as floating solar panels and 'energy islands' (see A1, A2 and A6). Moreover, these offshore installations may also serve as a source for food supply. This research project aims at identifying legal obstacles and providing legal solutions for facilitating the development of new energy structures, varying from multi-use structures (energy islands) to floating structures, including the possibility to re-use installations for other uses such as food supply.

Description of activities This work package will consist of several tasks, including:

Task D2.1: A general introduction to the research, This consists of three parts. First, an assessment of the different uses of the North Sea and the types of installations, which are/can be involved. Secondly, an overview of the Law of the Sea Conventions regarding the offshore competences of coastal states and the rules applicable to offshore installations, structures and devices. Thirdly, an assessment of the legal regimes that currently apply in (some) North Sea States governing the use of energy structures.

Do these regimes distinguish between installations, structures and devices? Which laws govern the establishment, operation and removal of these installations, structures and devices? **Part D2.2**: This part will examine the development of new uses of the North Sea. It will discuss the extent to which the installations that need to be involved are/may governed by existing legislation or require a new legal framework. Here we will in particular assess the development of 'energy islands'. It will also assess the rules governing decommissioning. The current rules are specifically drafted for unused petroleum installations and may need to be changed for other installations. Moreover, given future food supply requirements, it may be necessary to take the re-use of installations as a 'food installation into account. **Part D2.3**: Here we will assess, on the basis of the above analysis, the need for new legislation in order to meet the requirements of the 2050 goals. Should the applicable legislation be 'resource' driven or rather 'infrastructure' driven? What are pros and cons of each approach? The aim is to provide some solutions that could facilitate an integrated and long-term approach for the North Sea as regards the use of installations, structures and devices for energy and food supply.
Expected output The expected outcome is a PhD (book). In addition, the researcher will present some academic papers presenting parts of the research and, which will be discussed during workshops organized by cluster D and/or the consortium

WP number/title	**D3 / Integrated assessment of the North Sea social-economic-ecological system**
WP leader	Prof. Hans van Meijl (& Dr. Heleen Bartelings)
Involved partners	WEcR, vHL, WU-ENP, ICES, Min I&W, Min LNV
Start date /End date	1-1-2020 /31-12-2023
Objectives This project aims to achieve a transdisciplinary, fully integrated approach to balancing the social, economic, and ecological objectives for strategic and policy decisions of the North Sea by providing context-specific scenario analyses, using an integrated assessment model, and engaging stakeholders to identify conflicting objectives, uncertainties and trade-offs.	
Description of activities **Task 1**: Following a thorough literature review in collaboration with D1, sustainability goals and management objectives outlined in national and international policy documents for the North Sea will be analyzed to identify synergistic and antagonistic/contradicting objectives and guide the development of operational objective in the Dutch North Sea Strategy (NZS) process. **Task 2**: The conceptual integrated assessment framework MAGNET (Modular Applied GeNeral, Equilibrium Model) will be enhanced by incorporating North Sea specific features, such that it can quantify the relevant North Sea management objectives, policies, and strategies. **Task 3:** Current maritime sectors and competing claims for space (wind energy, aquaculture, fisheries, shipping, nature conservation and tourism and oil and gas industry) within the North Sea will be incorporated into MAGNET to model the strategic and policy decisions of the North Sea. A limiting resource "space" (similar to land in agriculture) will be introduced. **Task 4**: In collaboration with D4, interactive scenarios and policy options will be developed with stakeholders within the NZS process to assess saliency, legitimacy, and credibility to inform the future process, **Task 5**: Scenarios will be quantified (baseline, technology/policy options, trade-off and synergy effects on social, economic, and ecological objectives and the contribution to Sustainable Development Indicators identified and visualized.	
Expected output A1: Integrated assessment framework of policy objectives and competing claims in the North Sea (2021) A2: Enhancing the integrated assessment model MAGNET, with North Sea interactions (2022) A3: Quantification of trade-offs of scenarios (strategic, policy options) between the social, economic, and ecological objectives. (2023) A4: Comparative analysis of Dutch vs. international North Sea management scenarios (2023)	

Work package numb/title	**D4 / Ecosystem Services, ecological and human systems & natural capital**
Work package leader	Dr. Katrine Soma,
Involved partners	WEcR, WMR, Ecorys, vHL, Min I&W, OSPAR, Min LNV, CBS, North Sea 2030 stakeholders, partners from clusters A, B and C
Start date / End date	1-1-2020 /31-12-2024
Objectives: The overall aim of this project is to estimate social-ecological benefits of different multi-use solutions in the North Sea combining energy and food transitions. The project aims to (**1**) Design policy-relevant spatial multiuse scenarios, (**2**) Explore knowledge gaps related with ecosystem services (ES) and the	

link between ecological and human systems, (**3**) Evaluate ES as a support to natural capital accounting, (**4**) Assess possible effects of mitigation and adaptation strategies/ policies.
Description of activities: This research will contribute to estimating societal benefits of combining activities at sea, namely, nature conservation, as well as energy and food production. **Task 1**: Based on transition theory analyses focusing on the food-energy-biodiversity nexus, a series of multi-use scenarios for the North Sea[1] will be identified in collaboration with the North Sea 2030 (NZS 2030) stakeholder process and visualized on maps using advanced GIS methods. Scenarios will serve as benchmarks to identify societal benefits of different transition pathways. **Task2**: Taking an ecosystem services (ES) approach, knowledge gaps and links between the ecological and human systems will be explored, and indicators relevant to the multi-use scenarios identified. Multi-objective simulations (social, economic and environmental) will be carried out to estimate the benefits of nature conservation to human beings. The ES indicators will be evaluated and discussed with Min I&M, the OSPAR socio-economic group and representative groups of North Sea users/industries. Net Present Values (NPV) of the indicators, and relative importance will be evaluated across contexts. **Task 3**: Based on the ES indicators, assessments will be carried out (Multi-criteria analyses/Net Environmental Benefit Analysis) against different scenarios, and in support of natural capital accounting and the UN SEEA approach[2]. Building on the MSFD related work carried out by Min I&W, ecological and human systems will be conceptualized and made applicable for natural capital accounts. **Task 4**: A bow-tie approach[3] will be carried out to evaluate different mitigation (e.g. reducing CO2 emission or protecting biodiversity) or adaptation measures (e.g. dealing with floods or creating nature). For each scenario and management measure the benefits of ES will be estimated. Advice on use of the social value based ES approach for implementation of the MSFD will be provided.
Expected output: Article 1: North Sea multi-use scenarios and transition analyses (2020) Article 2: Ecosystem service values in ecological and human systems (2021) Article 3: Multi-use valuation in ecological and human systems (2022) Article 4: Policy analyses with bow-tie and advice on ES applications for MSFD implementation (2023)

WP number / title	**D5 / An integrated approach towards sustainable transitions**
Work package leader	Prof Dr Han Lindeboom
Involved partners	Dr Luca van Duren, Prof Dr Herman Hummel, Mr I. Kieft and all other project partners
Start date / End date	1-11-2019 / 31-12-2024

Objectives The future of the North Sea needs an integrated approach towards the synthesis of information on a complex system. A post doc together with the directors and cluster coordinators will collate the information of all projects, prepare integrated analyses and write publications. It will serve as a linking pin between this research programme, the scientific and socio-economic stakeholders, and policy objectives as laid down in the North Sea Strategy 2030.

Description of activities

Collating data and information from all other WPs (**task 1**), make sure that they are included in an open data system (the DAS system at NIOZ). Prepare integrated analyses to answer questions concerning the carrying capacity, biodiversity and food webs, and changes therein, in the North Sea.

Writing of overview publications (task 2), an overview article on the complex functioning of the North Sea ecosystem (see also figure 8) will be written with the emphasis on natural variability and the large-scale impact of human activities. We will also write an article on the value and acceptance of man-made nature in the North Sea in the Anthropocene. We will combine the knowledge obtained in the WPs with that available at the different research institutes on the hydrology (Deltares), geology (NIOZ), biodiversity and food webs (WMR, NIOZ, ...) to get more insight into the possibilities and effects of the integration of the three transitions: energy, food and nature.

Together with our foreign partners we will write state of the art publications on the effects of large-scale introductions of hard substratum, changing food webs, ... etc.

Determination of missing links in the research (task 3). In the course of the project we will discover what data are still missing to answer the questions on a sustainable spatial development of the North Sea and to redirect the studies if feasible and felt needed on basis of the available information.

Expected output Annual publications, inclusion of the data and outcomes in public datasets through DAS to repositories like EMoDNet and Seadatanet, advise to support spatial planning of the North Sea, and recommendations for government agencies on sustainable transitions and the (risk) management of the North Sea.

Work package numb / title	**Additional 1 / Management of the project**
Work package leader	Prof Dr Han Lindeboom
Involved partners	Prof Dr Henk Brinkhuis, Prof Dr Herman Hummel and all project partners
Start date / End date	1-11-2019 / 1-11-2025

Description of activities
The management of the project is organized as described in section 4.5. (see page 30)

Task 1. Management of the whole project. NIOZ is main applicant and responsible for execution of the programme as a whole. A governing board is established with the NIOZ director as chairman. Members are representatives of the different partner groups.
Task 2. The daily coordination and execution of the project will be handled by a management team. Prof Han Lindeboom and prof Herman Hummel will be made available by NIOZ for this project as Programme director and Executive director, respectively. Furthermore we will set up administrative and financial support. Frequently coordination meetings will be organized with the cluster leaders: A) S. Schreier (TUD), B) L.van Duren (Deltares), C) P. Kamermans (WMR), D) C. Bastmeijer (TU).
Task 3. An International Advisory Committee will be established. During the project internal workshops will be organized twice a year. Three large international symposia will be organized.
Task 4. When funded we will take the initiative to organize together with the participating ministries and larger research institutes an overarching North Sea Programme Bureau.

Expected output Annual publications, inclusion of the data and outcomes in public datasets in DAS, recommendations for government agencies on sustainable transitions, organization of many workshops and 3 symposia for optimal cooperation among all partners and outreach and

Work package numb/title	**Additional 2 / Knowledge utilization and entrepreneurship**
Work package leader	Kim Sauter (NIOZ)
Involved partners	All project partners / North Sea Foundation
Start date / End date	1-11-2019 / 1-11-2025

Description of activities.
Knowledge utilization and entrepreneurship is organized as described in section 2.3. (see page 7)

We plan to disseminate the results in various formats, through the years, through all of the participating consortium members, and including e.g., presence in existing series of North Sea conferences and workshops related to NiT topics, to developing new, dedicated outreach platforms, workshops, web-presence and otherwise, for the broad stakeholder group(s). We will do so from dedicated means (5%), and in concert with the program bureau, where representatives of ministries and research institutions reside.
The task are:
Task 1. Own content on own platforms (NIOZ and all partners)
Task 2. Paid media-partnerships (NIOZ)
Task 3. Free publicity (NIOZ and all partners)
Task 4. Societal use and dissemination of results (North Sea Foundation and all partners)
Task 5. New technological developments and tools for policy, society and industry (all partners)

Expected output
Annual publications, a quarterly newsletter, inclusion of the published outcomes in public datasets like DAS, recommendations for government agencies on sustainable transitions, 10 workshops, 3 international symposia, television outreach, newspaper interviews, ...

Netherlands Organisation for Scientific Research

4.3. Timeline, Milestones and Output

WP	WP / Task Titles	Partners involved (leaders in bold)	2020 - Year 1				2021 - Year 2				2022 - Year 3				2023 - Year 4				2024 - Year 5			
			1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A	**Technical transitions and Energy innovations**	**DIFFER**																				
A.1	Hybrid Wave-Storage Device and Integration	**RUG**, Ocean Grazer BV	P	P,Mo	Mo,P	t,Mo	D,Mo	tC,Mo,Pr,P	F,L,D,P,t,M	L,t,D,Mo	T,L,D,Mo	Sy,T,L,Mo	D,C,Mo,Sy	T,t,Sy,C	Sy,C	Sy,C	t,C	R				
A.2	Floating Solar Platforms	**TUD**, Engie, MARIN, OoE, TNO		P	t,P	Mo	Mo	t,Mo,P	T,Sy,P	L,Mo,t	D,Mo	Pr,Sy	T,D	Sy	t,Sy	Sy	T,Sy	Sy	T			
A.3	Power to Molecules (P2M)	**DIFFER**	P	P	L	L	L	L	L	T,t,L	L	L,Pr	T,t,L	T,t,L								
A.4	Recapture of CO2	**DIFFER**					P	P	L	L	L	L	L	L,P	L,P	L	Pr,L,T	Pr,T,L,t	L,Pr	T	T	T
A.5	Liquefied Hydrogen (LH2)	**TUD,** GTT, Engie, TNO		P	t,P	Sy,P	t,L	L	D	T,P	L	L	Sy,D	T,Sy,Mo,C	t,Mo	Mo	Sy	Sy,T	T			
A.6	Artificial Islands	**TUD**, MARIN, TNO, Deltares			P	P	P	t	L	L	D	T	P	*Pr*	D	T	Sy	Sy	Sy	T		
B	**Optimal biodiversity and carrying capacity**	**Deltares**																				
B.1	Primary production as basis for the Carrying Capacity	**NIOZ**, UT/ITC, RWS, Deltares	P,L	F,D	F,D	D,L	t,T,L	F,D	F,D,Mo	D	t,T,Mo,L	F,D	F,D	D,L	D,t,T,Mo	F,D	F,D	D,Mo	T	Pr	Sy	R
B.2	Fouling macrofauna biomass on artificial structures	**WMR**, NIOZ, WUR, Boskalis, Shell, OoE	L,P	F,L,P	F,L,P	L,D,P	L,D,Pr	F,L,Pr	F,L,T	L,D	L,D,Pr	F,L,Pr,t	F,L,T	L,D,P	L,D	F,L,D	F,L,D,T	L,D,Sy	L,D,Sy	D,t	T	
B.3	Restoration in and around windfarms	**NIOZ**, BuWa, WMR, Boskalis, Shell	P	P	F	L	F	L	F	L	D,P	T,P	F	L	D,L	T,L	D	T	R	R	C	
B.4	Offshore structures as biotope for seabirds and fish	**WMR**, NIOZ	P	F	D	D,P,t	P,D	F,D	D	T	D	F	Pr,P,D	t,T	D	T	Sy,D	T				
B.5	Microbial interactions with the marine built environme	**NIOZ**, WMR, OoE, SeaRangers	L,F	P,F,L	F,L,D	D,L,F	L,F	F,L	F,L	D,L,F,T	L,F	F,L	F,L,D	F,L,D,T	L,F,Sy	L,F,Sy,R	F,L,R,T	F,L,D,R,T	D	Pr,D	Sy	R
B.6	Synthesis for sustainable use and optimal biodiversity	**Deltares**, NIOZ	P	P	Mo, P	Mo	Mo	Mo	Mo	Mo	Mo	Mo	Mo	T,t,Mo	Mo	Mo	Mo	T,t,C,R		R,C,Sy		T
C	**Marine food production**	**WMR**																				
C.1	Farming in the North Sea	**WMR**, NIOZ, NZB, WPR, MAE	P	F,L	F,L	F,L	F,L	t	F,L	F,L	F,L	F,L	t	F,L	F,L	D	T,R	T				
C.2	Fisheries in transition	**WU,** WMR, WEcR	F	D	Mo	Mo	Mo	t,Mo	D	T,Mo	*S*	Mo	Mo	T	Mo	Mo	Mo	T				
C.3	Seaweed proteins	**NIOZ**, WMR, HZ, HAS	P	F, L	F, L	F, L	F, L	F, L	F, L	F, L	F, L	F, L	F, L	T	F, L	F, L	F, L	T	F, L	F, L	F, L	T
C.4	Carrying Capacity for seaweed and shellfish farming	**NIOZ**, Deltares	P	F,L	F,L	L,D,Mo	T,L,Mo	F,L,Mo	F,L,Mo	T,D,Mo	Mo	Mo	Mo	T,Mo	Mo	Mo	Mo	T,R				
C.5	Synthesis marine food production	**WMR**, NIOZ									P,D	D	Mo	t,W	D	D,Mo	T,W,D	Mo	D	W,Mo	Sy,T	R,Sy
D	**Enabling Change: Socio-Economic and Legal research**	**TiU**																				
D.1	Role of International Nature Conservation Law	**TiU**	P	P	W	F	F	F	F	D	D	D	D	D	t	W	C	Pr	Pr	Pr	T	R,Sy
D.2	Governing Offshore Energy Installations	**RUG**	P	P	W	F	F	F	F	D	D	D	D	D	t	W	C	Pr	Pr	Pr	T	R,Sy
D.3	Integrated assessment of social-ecological system	**WEcR**, vHL, I&W, LNV, WU-ENP	P	P	W,P	F,P	F,P	F	D,Pr,F,Mo	D,Pr,Mo	D,Pr,Mo	Mo,Pr,D,F	Mo,Pr	Mo,Pr	Mo,Pr	W,Pr,Mo	Pr,C	Pr,C	Pr,C	t,T	T	R,Sy
D.4	Advancing the Ecosystem Services (ES) application	**WEcR**, vHL, Ecorys, CBS, I&W, LNV	P	P	W,P	F,P	F,P	F	F,Pr	D,F,Pr	D,F,Pr	Mo,Pr,D,F	Mo,Pr,D	Mo,Pr,D	Pr,Mo	W,Pr,Mo	Pr,C	Pr,C	Pr,C	t,T	T	R,Sy
D.5	Integrated approach towards sustainable transitions	**HAME**, NIOZ, WU, Deltares	P	D	D,Sy,P	R,C,t,D,P	D,Sy	Sy,D	Sy,D	T,C,t,R	D,Sy	Sy,D	Sy,D	R,C,t,T	D,Sy	Sy,D	Sy,D	T,C,t,R	D,Sy	Sy,D	Sy,D	R,C,t,T
M	**Management, Stakeholder involvement & Outreach**	**NIOZ**																				
M.1	Management & Coordination	**NIOZ**	M	Mo	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
M.2	Stakeholder involvement; networking	**NIOZ,** all partners		*N*	*S*	*G,N*	*S*	*N*	*S*	*G,N*	*S*	*N*	*S*	*G,N*	*S*	*N*	*S*	*G,N*	*S*	*N*	*S*	*S,G,N*
M.3	Outreach	**NIOZ, SdN**, all partners	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

C	= Communication (dissemination)	M	= Management and Coordination
D	= Data handling, services	Mo	= Model development, validation, runs, scenarios
F	= Fieldwork, sampling and monitoring	N	= Networking
G	= General Assembly	O	= Operational
L	= Laboratory tests and analyses	P	= Plan development
I	= Proteactable Intellectual Property, Patent	Pr	= Prototype, demonstrator, concept

R	= Recommendations and Policy options
S	= Steering and Stakeholder committee meetings
Sy	= Synthesis
T	= Thesis, Publications (peer reviewed)(with number in case >1)
t	= Report, conference papers (with number in case >1)
W	= Workshop (and evaluations)

Figure 7. Gantt chart on the Work Packages of "North Sea in Transition". Each cell is a season of the year. In a cell several codes can be depicted, whereby the first code is the most important activity in that season and determines the colour of the cell. An extended version with all tasks is available on the website.

A summary of the expected output from the work packages is given in the Table below.

		Number	Expected year of publication
Academic output			
☒	Articles in refereed journals	70	2020-2024
☐	Articles in non-refereed journals	0	
☐	Books	0	
☐	Book chapters	0	
☒	Dissertations	17	2023-2025
☒	Conference papers	37	2020-2024
☒	Data (see also section 5)	36	2020-2024
☐	Other scientific output (specify):	0	
Output related to knowledge exchange, impact and utilization			
☒	Professional publications	31	2020-2024
☒	Publications aimed at general public	27	2020-2024
☒	Prototypes/demonstrators/concepts	12	2022-2024
☐	Protectable Intellectual Property	0	
☒	Open source technologies	1	2022
☒	Other output (specify): videos, website	3	2023-2024

4.4 Risk assessment

Risk	Mitigation measures
Scientific research questions do not match the questions or expectance of the stakeholders.	Close collaboration with stakeholders; involvement of civil servants, industry and other stakeholders in all clusters, including defining scenario choices and designing field campaigns is planned.
Differences in work practice, jargon and culture between engineering, natural sciences and policy and socio-economic sciences.	Joint meetings, joint data platform, joint cruises and involving experienced scientists that have a track-record in multi-disciplinary research are planned.
Permission to work in close proximity to operational Man-Made Structures.	Close collaboration with operators; do not plan anything within safety zones where possible. Data sharing will make research also relevant to operators.
Field work cancelled due to weather and research vessels being booked at other times.	Assess fall-back options at e.g. "Rijksrederij" commercial vessels or through other cooperation (e.g. Sea Rangers)
Due to unforeseen conditions field experiments with live organisms cannot be controlled as much as laboratory experiments. This can lead to failure.	Frequent evaluation of progress in experiments and potential shift of field work to laboratory experiments.
Data are held within industry, it may not be allowed to use or publish these.	Data-sharing partnerships are already being formed, which makes industry realize how they also benefit from sharing.
Getting the right candidates – there is certainly a major (international) shortage in lawyers and ecosystem modellers.	Start acquisition early and look far afield. If needed, have greater input of senior in-house expertise. And make sure that the candidates will stay for the whole project duration.
The budget for consumables and model testing appears to be insufficient for the initial objectives.	The experimental objectives can be trimmed down and less validation can be performed.
The design, building and deployment of the demonstrator takes longer than planned.	The current time planning can be extended by one year. Correspondingly, computational activities can take over the potential loss time.
The models and control systems become too complex to handle for model-based engineering.	Approximation models will be developed as a mid-step.

4.5 Management structure

Programme management

NIOZ is main applicant and responsible for the overall execution of the project. The NIOZ director is chair of the Governing board. Coordination takes place by a Management Support Team led by a part time (0.2fte) Programme Director (Prof. Dr. Han Lindeboom) for the scientific coordination and a part time (0.2fte) Executive Director for the logistic coordination (Prof. Dr. Herman Hummel).

Prof. Lindeboom and Prof.. Hummel both have a long-standing experience in leading and coordinating large-scale (inter)national scientific projects and networks. Prof Hummel was Executive Director of the Network of Excellence MARBEF "Marine Biodiversity and Ecosystem Functioning" with 95 participating European institutes and the Presidency of the European Marine Research Institutes and Stations (MARS) Network, a network uniting over 60 marine stations in Europe with the aim to promote marine research in Europe. For 6 years, prof Lindeboom was chair of the Scientific Steering Committee of the IGBP project LOICZ (Land Ocean Interactions in the Coastal Zone), he was coordinator of 2 large EU projects IMPACT (Effect of fisheries) and he coordinated the ecological research in Netherlands first Offshore Wind Farm Egmond at Zee (OWEZ).

Furthermore, a part time secretary and part time financial expert are member of the Team. Communication and utilisation is coordinated by the NIOZ Communication Department.

We will set up a Governing Board consisting of 1 or 2 representatives of all the partner-groups (Institutes, Universities, Government, Stakeholders from Industry and NGO's).
Depending upon the requirements of NWO extra members can be added. The Board will meet at least twice a year to review the programme and advice the Chair and Directors on progress and possible changes in the programme.

We will establish an International Advisory Committee (IAC) with renown scientists from different countries and from the different disciplines that are crucial for this programme. The IAC advices the Chair, Directors, and members of the board.

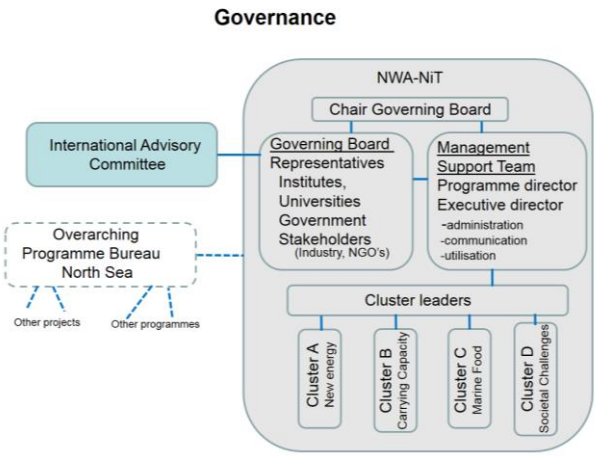

Figure 8. Management structure of the proposed research

In the discussion with the participating ministries it has been suggested to set up an overarching Programme Bureau. This does not only apply to this NWA proposal but should play a major role in knowledge exchange between all relevant North Sea projects and those involved in North Sea management and research. If this NWA-proposal is granted we intend to play a major role in the setting up of this Bureau.

4.6 Justification of project budget

Expenditure per Cluster	k€	Expenditure per Cost Category	k€
A. New Energy	2.320	PhD's	4.061
B. Carrying Capacity	2.950	PostDocs	1.396
C. Marine Food	1.823	(Senior) Staff	1.416
D. Enabling Change	1.804	Bench fee	120
Programme bureau	445	Materials / subcontracting	1.648
Communication & outreach	495	Investments	258
Internationalisation & MFC	100	Other	1.040
Total	**9.938**		**9.938**

The NiT-project has set highly ambitious scientific goals and this will be met with a total project budget of k€ 9,938 and a requested funding from NWO-NWA of k€ 8,888. Almost 55% of the budget has been dedicated for the appointment of excellent young scientists (17 PhD's and 5 Postdocs) divided over universities (13,3 fte), NWO institutes (8 fte), TO2 (1 fte) and supporting staff within TO2 institutes. Together with k€ 1,648 for material costs such as (lab / fieldwork) consumables, sensors, (LCA) software, rental of (small) boats, performing tests (Cluster A) and k€ 258 for investments in FCM, fish profiler, camera's and bird telemetry system the goals of this project should be met. To disseminate, promote and embed the research in both national and international communities an amount of k€ 595 (6,6% of the budget requested from NWO) is available for activities such as a dedicated NiT website, social media, quarterly newsletter, workshops and other events, to communicate research questions, plans, work in progress and results. To have a smooth and well equipped management of this project 5% (k€ 445) has been dedicated to implement the programme management office as described in section 4.5.
With a total of k€ 1,050 cash contribution from stakeholders (e.g. Governmental organizations, NGO, businesses) to this project the highly ambitious goals of the NiT-project are well acknowledged by the co-financiers. Besides this cash funding, an amount of k€ 708 in-kind co-funding has been committed by many stakeholders.

4.7. Literature references (2 per project / click for extended version)

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Section 5 –Data management and Ethical aspects

5.1 Data management

1. Will data be collected or generated that are suitable for reuse?

Answer: Data will be collected in several formats in all WPs. Most of these will have an open format and therefore easily allow reuse, other formats will be collected using lab instruments producing binary output only. These formats can only be read by the software used to acquire the data.

2. Where will the data be stored during the research?

Answer: All data collected during the project will be stored using the Data Archive System (DAS; more information on our website) as developed by NIOZ. This high flexibility system allows the long-term

storage of every thinkable file format for every thinkable discipline. The metadata describing the data archived is placed in a relational database easing the search for project data related to each other. The data itself is stored on a file system on the NIOZ network, secured against unallowed access. A copy of all data stored in DAS is placed on a mirror file server in the co-location of NIOZ in Yerseke.

3. After the project has been completed, how will the data be stored for the long-term and made available for the use by third parties? To whom will the data be accessible?

Answer: During the project a public accessible website will be created containing a data portal. Data published here will be copied from the long-term data storage in DAS. The website will remain at least 5 years after the project finishes. Details can be found in
Data that are relevant for international specialized data systems such as GBIF, SeaDataNet or EMODnet will also be made available in those data systems.

4. Which facilities (ICT, (secure) archive, refrigerators or legal expertise) do you expect will be needed for the storage of data during the research and after the research? Are these available?*

Answer: DAS, being NIOZ institutional data repository, is fully serviced by NIOZ employees using the NIOZ IT Infrastructure. The project site containing the data portal will be serviced by NIOZ IT.

5.2. Ethical aspects

	Not applicable	Not yet applied for	Applied for	Received
Approval from a recognised (medical) ethics review committee	☒	☐	☐	☐
Approval from an animal experiments committee	☐	☐	☒	☐
Permission for research with the population screening Act	☒	☐	☐	☐

Proof of approval will be sent to NWO before the start of the project.

Netherlands Organisation for Scientific Research

Section 6 – Other

6.1. Public summary

English public summary
The transitions of energy, food and nature will lead to huge changes the North Sea. This has large implications for the use and protection of the ecosystem with conflicting demands for space and resources. This proposal investigates the interrelationships and thereby enables sustainable future use of the North Sea.

Dutch public summary
De energie, voedsel en natuur transities zullen leiden tot enorme veranderingen van de Noordzee. Dit gaat grote effecten hebben op gebruik en bescherming van het ecosysteem, met conflicterende belangen voor ruimte en hulpbronnen. Dit voorstel onderzoekt de wederzijdse effecten en faciliteert daarmee een duurzaam toekomstig gebruik van de Noordzee.

6.2. Signature

☒ By submitting this form I declare that I satisfy the nationally and internationally accepted standards for scientific conduct as stated in the Netherlands Code of Conduct for Research Integrity (Association of Universities in the Netherlands).

Main applicant: Prof.dr. Henk Brinkhuis
Place: Texel
Date: 31/1/2019

Signature: