North Sea Energy II

Screening impacts of offshore infrastructures on marine species groups: a North Sea case study for system integration

Deliverable D.1.

As part of Topsector Energy:
TKI Offshore Wind & TKI New Gas

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1 Abstract

Energy production at the North Sea is undergoing a transition from gas and oil production to the generation of renewable energy sources, such as wind energy. The abandonment of the existing infrastructure for gas and oil production provides opportunities for its re-use in new applications. In this study we developed a screening methodology to assess the potential ecological impacts of a number of re-use options related to the energy transition. Re-use options considered relate to the electrification of platforms, making use of energy produced by wind farms. This energy source can be used to meet the energy requirements for the production of gas, and after stopping production, platforms can subsequently be converted for the use as carbon capture and storage and green hydrogen production. For these activities, environmental pressures are appointed to sub-activities involved in the production phases, transition phases and the final decommissioning. For these pressures, the ecological impacts on marine benthos, fish, birds and marine mammals are semi-quantitatively scored. Many (855) effect-chains were considered. Cumulative effect scores show that temporary effects during the transitions are relatively high, but short-lived. As a result of electrification, the cumulative effects of the production of gas are comparable with those for conventional gas production, mainly due to the discharge of produced water and transport activities. The re-use as carbon capture and storage facility and as hydrogen production facility was predicted to have relatively low potential impacts on the marine biota considered in this study.

2 Introduction

The North Sea is an important area where the energy system is in transition, where gas and oil reserves are becoming exhausted and revenues are declining. The Netherlands is currently experiencing a strong ramp-up of offshore wind energy construction activities in the North Sea (Ministry of Economic Affairs and Climate Policy, 2018). The energy transition can be accelerated by making use of synergies between different functions, here referred to as 'system integration'. Synergies may especially apply in the energy domain, for instance if different sectors like the offshore wind energy sector and offshore gas sector combine their infrastructure(s), services, human capital, products and knowledge. Now there is a need to work in high pace towards concrete business cases and demonstrations/pilots for system integration.

With this development, it is important to start the environmental assessment on a high strategic level insight into which topics are of high interest in strategic environmental impact assessments for system integration and to better understand the ecological impacts on marine life of re-using or adding hard substrates.

This study aims to better understand the consequences of different system integration options for marine life. Since part of these activities are currently not taking place at the North Sea empirical information on their ecological impacts is largely unknown. Therefore we developed an assessment methodology to make semi-quantitative risk predictions in a structured way in order to identify the most likely causing risk factors. We assess the potential environmental impacts of offshore system integration options in the North Sea, using concept developments for selected sites on the Dutch Exclusive Economic Zone (EEZ). The scenarios involve a basic scenario of 'normal' offshore oil and gas platform operation and three integration concepts representing future scenarios: platform electrification, power to hydrogen (H_2) and Carbon Capture & Storage (CCS). The assessment output is expressed in semi-quantitative impact scores, which provide information on the relative impact. This enables ranking and comparing impacts of pressures resulting from different activities required for the scenarios on selected ecosystem components.

3 Method

To assess the environmental impacts of offshore system integration concepts we follow the generic framework for environmental assessment (Tamis et al., 2016):

- *Decision-making level*. Plan or program level: Informing government and developers of the (potential) environmental impact of offshore energy infrastructural developments
- *Spatial scale*. Three system integration demonstration locations on the Dutch EEZ are used to represent different system integration concepts. The assessment will not involve spatial distribution of impact, i.e. the predicted impact will not be spatially explicit.
- *Temporal scale.* Present situation and future activities and pressures. The assessment will not involve a defined temporal distribution of impact i.e. the predicted impact will not be temporally explicit.
- *Level of detail* (information availability and requirement): This broad scoped assessment does not require a high level of detail. Information needs to be sufficient for distinguishing between the level of risk of impacts from the different options. This enables prioritising of risks of system integration options for marine life. The required information is derived from literature reviews and available environmental assessments of offshore energy developments: Knights et al. 2013;2015; Bergstrom et al., 2014, and additional literature as referred in the text. In other cases, assessments are based on expert opinion.
- *Selection of elements*: The activities included in the assessment cover the basic scenario of platform operation and the system integration options: Platform electrification, power to H_2 and CCS in future scenarios (Table 1). Species groups of different environmental compartments (air, water column, seabed) are included to cover a broad selection of environmental components. Pressures are conform the European Union Marine Strategy Framework (Directive 2008/56/EC, MSFD) and selected from Knight et al. (2013; 2015) and Tamis et al., (2016) (Table 2). Ecosystem components were arbitrarily chosen.
- *Establishing linkages*: A wide range of human activities in the marine environment already linked to potential pressures and ecosystem components (Knights et al. 2013), was used to identify the linkages, additional linkages were based on expert knowledge (Figure 1). Indirect effects and interactions between elements (e.g., species interactions) are not included.
- *A semi-quantitative scoring* of intensities of pressures and sensitivities of ecosystem components is used to assess the relationships between activities, pressures and ecosystem components. This is most suitable for a broad scale, low-detailed assessment on a high process (strategic) level (Tamis et al., 2016). The assessment criteria (Table 5) are based on Knights et al. (2015) and Bergstrom et al. (2014) and adapted to the scope of this study.
- The semi-quantified relationships are *integrated* by summation of the individual chains (i.e. activity-pressure-ecosystem component relationships), thus assuming additive effects.

3.1 Definition of activities

Scenarios for system integration deployments are considered that transfer conventional gas producing platforms into platforms using power produced from wind farms (electrification via connection to the e-grid), for CCS, and for the production and transport of H_2 as an energy source (green hydrogen assets).
In the transition process, a number of common activities can be distinguished, each consisting of sub-activities that have emissions and pressures to consider for the assessment of potential environmental impacts (Table 3). Our scope is

limited to the impacts on local marine ecosystem components, and includes soft sediment benthos, fish, birds and sea mammals. We do not take into account emissions to air of NO_x, CH_4 and CO_2, which have a more global scale of impact. We consider the following (sub-)activities in the transition process (overlap in time is possible, and cumulative assessments can be considered).

3.2 Gas production

Conventional platform operation – This activity concerns the baseline operation of gas production at the platforms, as is currently taking place. It includes all operations involved in the exploitation of gas at the platform, including the supply of materials by shipping, helicopter transport of people and goods, transport of gas to land, diesel or gas fuelled generators etcetera's. Excluded are initial phases preceding the production phase, such as seismic surveys and drilling operations. Pressures and assessments are taken from Tamis et al. (2011).

Connection to e-grid and platform electrification – In this phase, the platform is connected to the electrical grid that is present at a certain distance from the platform. Subactivities include additional shipping to the platform (for supply and export of equipment and personnel), cable lying activities to provide a connection to the existing grid, and construction activities at the platform (including e.g. removal of the gas turbine). Note: The construction of a new platform may be needed, with smaller jacket.

Natural gas production (electrified) – Natural gas is produced without the use of conventional energy supply, i.e. from generators using diesel or gas. This mainly reduces emissions to air, but also noise levels as produced by generators may be lower than during conventional platform operations.

Removal of natural gas production equipment – The production of gas will be stopped, the well will be plugged (except when transformed for CCS), and equipment will be removed. Additional shipping activities will take place.

3.3 Carbon Capture and storage

Conversion/addition of CO_2 transport and storage assets – CO_2 as produced elsewhere (on land) will be transported to the offshore platform and deposited in the geological formation of the original (produced) gas field. For this purpose, conversions to the platform need to be made, involving placement of CO2 compressor. Also additional shipping and laying/conversion of pipelines is needed. Adjustments to the well may be needed (workover).

Operation of CO_2 transport and storage assets – During the transport and storage process CO_2 needs to be compressed and heated. The potential venting of CO_2 will be considered here as well.

Removal of CO_2 transport and storage assets – Before the end of the lifetime of the platform, any equipment involved in the CCS process needs to be removed from the platform. The activities involved include demolition at the platform, removal of pipeline(s), well plugging and abandonment and shipping activities.

3.4 Green hydrogen production

Conversion/addition of green hydrogen assets – To prepare the platform for green hydrogen production, construction activities on the platform are needed (or a new platform may be needed, see above)), cables and pipelines need to be laid, and additional shipping will take place.

Operation of green hydrogen assets – In the power-to-gas process, energy from the e-grid, derived from wind farms in the neighbourhood, is converted into H_2 gas as energy storage. The activities include asset replacements (desalination, electrolysers, etc). During production, concentrated salt water (brine) produced in the desalination process will be discharged.
Removal of green hydrogen assets – After ending operations, equipment needs to be removed from the platform, involving demolition and transport (shipping). Also pipelines and cables need to be removed.

3.5 Decommissioning of platform

Decommissioning of platform & infrastructure – After the lifetime of the platform it needs to be removed from the site. The well needs to be abandoned, and equipment needs to be removed from the platform. Also the remaining pipelines and cables should be removed, although in the drafted scenarios they will be left in situ. The platform will be deconstructed. All material needs to be transported onshore and disposed and the former production site should be cleared, according to the best available method at that time.

3.6 Pressures

As a step in the assessment of ecological effects arising from the sub-activities we first define the relevant pressures on the basis of our expert knowledge and inputs from the operators that have defined the scenarios. We made use of a gross list of pressures derived from the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC, MSFD) and the European ODEMM project (Knights et al., 2013, 2015). Table 2 lists the pressures that were considered relevant to the defined sub-activities. The pressures were assigned to the relevant sub-activities on the basis of expert knowledge as presented in Table 3.

In the next step we selected the ecosystem components that we considered sensitive to the identified pressures (Table 4). This study focuses on benthos, fish, birds, and sea mammals, without further specification of sub-groups. The linkages between sub-activities and pressures and pressures with ecosystem components resulted in 855 effect-chains being considered relevant, as illustrated in Figure 1.

3.7 Scoring

Both the intensity of the pressure and the sensitivity of the ecosystem components were scored in a (semi-)quantitative way in order to assess a cumulative effect score (Figure 2). To characterize the intensity of the pressure, scorings were designed that reflect its temporal (frequency, duration) and spatial (area) extent (Table 5a) based on Knights et al (2013, 2015), Bergstrom et al (2014) and Tamis et al (2011). For the intensity of effects, the resilience, effect type and recovery potential were scored according to Table 5b.

The criteria are defined as follows (note that the categories used here are often adapted from the original source because of the different scope of this study):

- Exposure:

- Spatial extent: the expected dispersal of the pressure from its source (Bergstrom et al (2014): 1) < 100 m^2; 2) 100- 1000 m^2; 3) 1000 – 10000 m^2 4) > 10000 m^2;
- Persistence: The period over which the pressure continues to cause impact following cessation of the activity introducing that pressure (Knights et al., 2015): 1) hours (<1 day); 2) days (< 1 month); 3) months (< 1 year); 4) one year or longer;
- Frequency: How often a pressure type and ecological characteristic interaction occurs (Knights et al., 2015): 1) rare (once per year or less); 2) occasional (multiple times per year); 3) common (weekly or daily); 4) continuous (several times per day or continuously);
- Magnitude: A relative measure for the level (intensity or size) of the pressure, such as a concentration or amount: 1) low level, 2) moderate level, 3) high level, 4) very high level;
- The scorings for spatial extent, persistence, frequency and magnitude are multiplied and dived by four to calculate the scoring for the level of exposure.

- Sensitivity:
  - Resistance: The tolerance of the ecological characteristic, indicating whether the characteristic can absorb disturbance or stress without changing character (Tyler-Walters et al., 2018): 1) high (effect unlikely) 2) moderate (effect possible); 3) low (effect likely); 4) no resistance (effect definite);
  - Effect type: The direct effect caused by the pressure, distinguishing in a direct effect on: 1) behaviour (behavioural changes of an individual when exposed to a pressure); 2) individual health (all aspects of the internal state of an individual that might affect its fitness); 3) vital rates (survival and reproduction) and; 4) population decrease (a significant reduction in biomass or number of individuals). These categories are loosely based on the framework for modelling the population consequences of disturbance (PCoD) (Harwood et al. 2013 & 2016; King et al. 2015). Note that the behavioural changes could subsequently cause population level effects, as assessed by the PCoD framework;
  - Recovery: The resilience (recovery time) of the ecological characteristic to return to pre-impact conditions (adjusted from Knights et al., 2015): 1) instant (< 1 day); 2) days (< 1 month); 3) months (< 1 year); 4) one year or longer;
  - The scorings for resistance, effect type , and recovery are multiplied and dived by three to calculate the scoring for the level of intensity.

The evaluation was made separately for each pressure, where the intensity was assessed in relation to the activity and sensitivity was assessed in relation to each ecosystem component (marine mammals, fish, birds, and benthic species). The level of certainty was assessed based on the level of documentation in peer-reviewed literature (cf Bergstrom et al 2014). A score for certainty is 1 in case limited or no empirical data is available to assess the score of a pressure-ecosystem component combination, 2 in case of available documentation, where results of different studies may be contradictory, and 3 in case of available documentation is available with relatively high agreement among studies.

Results are presented on the cumulative impacts of activities, considering a one year time period. The cumulative impacts of scenarios can be assessed by combining the impacts of different activities in a certain time frame.

4 Results

The cumulative effect score (CES) for each activity is based on a different number of impact chains. It appears that the number of impact chains has no systematic effect on the outcome of the cumulative effect score (Figure 3).

The cumulative effects as assessed for the various activities show that the activities with highest scores result from the exploitation of natural gas (Figure 4). The main pressures are related to the discharge of produced water, leading to the introduction of synthetic , non-synthetic compounds and radionuclides that negatively affect the considered ecosystem components of benthos, fish, birds and sea mammals. Figure 5 shows that all ecosystem components are affected by each activity, although the impact of individual pressures differ (not shown). The contribution of each ecosystem component to the sum of CES ranges from 23 % for fish to 27 % for benthos.

In addition to the discharge of produced water, responsible for 33 % off the sum of the CES for all activities, also transport activities have a high contribution (34 %) to the sum of CES. The results of the assessment shows that the CES for the production phase of green hydrogen production is slightly higher than for the production phase of CCS.

Since all activities run for different periods of time, we show the dynamics of a hypothetical scenario for a platform, including all stages of activities (Figure 6). We assumed that each production phase lasts 5 years, and that transitions take place during one year.

5 Discussion

In this study the consequences of different system integration options for marine life were assessed by making use of a structured approach that enables a semi-quantitative assessment. In general, the scoping phase is an important step in defining the relevant activities and sub-activities to consider, to select the relevant pressures related to these sub-activities, and to select relevant linkages between the pressures and selected ecosystem components.
The selection of activities were provided by stakeholders, i.e. the owners of offshore gas platforms planning re-use of infrastructure. The main activities were defined as follows: a transition to energy supply from wind farms, i.e. electrification of the platform replacing energy supply from diesel generators; transformation into a Carbon Capture and Storage facility; transformation for green hydrogen production. Based on descriptions of the (sub)activities by the stakeholders, potential pressures were identified making use of a gross list based on the Marine Strategy Framework Directive and studies dedicated to the assessment of ecological impacts caused by maritime activities (Knights et al., 2013, 2015; Tamis et al., 2011). Pressures were not selected when they were not caused by the defined sub-activities, do not to have an impact on the selected ecosystem components (benthos, fish, birds, sea mammals), or were not considered to be discriminative between the different sub-activities.
We focused on impacts of a limited number of ecosystem components; benthos, fish, birds, sea mammals, thereby excluding other biota in the pelagic zone (phytoplankton, zooplankton). Furthermore, emissions to air were not taken into account, since they do not cause direct effects on marine biota. Therefore, a reduction of air emissions for example as a result of the transformation from diesel generators to wind power and having relevance on a global level, are not revealed by our study. We also did not evaluate the ecological impacts arising from wind turbines that supply the energy to the electrified platforms. We also did not consider ecological benefits of leaving offshore structures in place. The subsea parts of offshore platforms form a type of reef system that contributes to the overall biodiversity (Coolen, 2017), and removing these structures also takes away its biota.

The scoring of criteria to establish cumulative effect scores (see Figure 2) were based on preliminary scenarios for the re-use and transition of platforms. Furthermore, expert opinion and knowledge on the effect assessments from preceding studies was applied to assess the sensitivity of ecosystem components. Because of the limited level of precision of input data, a semi-quantitative assessment seems currently the most feasible way for predicting impacts from energy transitions to the environment. A quantitative risk assessment requires a substantial increase in input information, both in establishing intensity levels of pressures, and in knowledge on dose-related ecological effects to these pressures.

The results show that negative impacts of gas production after electrification is about equal as compared to conventional gas production, since reductions in air emissions are not considered relevant to the ecosystem components considered. The CCS and green hydrogen production clearly have lower impacts as compared to gas production. Only during transition phases, an overlap of activities may result in a temporary higher impact level.

We conclude that the applied screening methodology enables a structured assessment of cumulative effects in relation to several activities. The outcome provides offshore stakeholders valuable insight into the potential impacts for marine life. This can be used to ease demonstration and implementation of system integration options within the near future and contributes to the effort for minimising environmental impact within the energy transition process.

6 References

Bergström L., .Kautsky L., Malm T., Rosenberg R., Wahlberg M., Åstrand Capetillo N., Wilhelmsson D. 2014. Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environ. Res. Lett. 9: 034012. doi:10.1088/1748-9326/9/3/034012

Coolen J.W.P. (2017). North Sea Reefs Benthic biodiversity of artificial and rocky reefs in the southern North Sea. Wageningen University.

Harwood J. et al. (2016) Understanding the Population Consequences of Acoustic Disturbance for Marine Mammals. In: Popper A., Hawkins A. (eds) The Effects of Noise on Aquatic Life II. Advances in Experimental Medicine and Biology, vol 875. Springer, New York, NY

King S., R. Schick, C. Donovan & C. Booth (2013) "A protocol for implementing the interim population consequences of disturbance (PCOD) approach: quantifying and assessing the effects of UK offshore renewable energy developments on marine mammal populations," report SMRUL-TCE-2013-014. Scottish Marine and Freshwater Science 5(2). Accessed on May 19 2017 at: http://www.gov.scot/Resource/0044/00443360.pdf

King, S.L., Schick, R.S., Donovan, C., Booth, C.G., Burgman, M., Thomas, L., Harwood, J. (2015) An interim framework for assessing the population consequences of disturbance. Methods in Ecology and Evolution, 6 (10), pp. 1150-1158. DOI: 10.1111/2041-210X.12411

Knights AM, Koss RS, Robinson LA. 2013. Identifying common pressure pathways from a complex network of human activities to support ecosystem-based management. Ecol Appl 23:755–765.

Knights AM, Piet GJ, Jongbloed RH, Tamis JE, White L, Akoglu E, Boicenco L, Churilova T, Kryvenko O, Fleming-Lehtinen V, et al. 2015. An exposure-effect approach for evaluating ecosystem-wide risks from human activities. ICES J Mar Sci Available from: DOI: 10.1093/icesjms/fsu245

Ministry of Economic Affairs and Climate Policy (2018). Offshore Wind Energy Roadmap 2030. Accessed on November 30 2018 at: https://english.rvo.nl/sites/default/files/2018/03/Brief%20routekaart%20windenergie%20op%20zee%202024-2030%20-%20EN.pdf

Tamis, J.E. ; Karman, C.C. ; Vries, P. de; Jak, R.G. ; Klok, T.C. (2011). Offshore olie- en gasactiviteiten en Natura 2000: inventarisatie van mogelijke gevolgen voor de instandhoudingsdoelen van de Noordzee. (Offshore oil and gasactivities and Natura 2000: inventory of potential consequences for the conservation objectives for the North Sea). Den Helder : IMARES, (Rapport / Imares Wageningen UR C144/10).

Tamis, J.E., de Vries, P., Jongbloed, R.H., Lagerveld, S., Jak, R.G., Karman, C.C., Van der Wal, J.T., Slijkerman, D.M., Klok, C. 2016. Toward a harmonized approach for environmental assessment of human activities in the marine environment. Integrated environmental assessment and management 12 (4): 632-642. DOI: 10.1002/ieam.1736

Tyler-Walters, H., Tillin, H.M., d'Avack, E.A.S., Perry, F., Stamp, T., 2018. Marine Evidence-based Sensitivity Assessment (MarESA) – A Guide. Marine Life Information Network (MarLIN). Marine Biological Association of the UK, Plymouth, pp. 91. Available from https://www.marlin.ac.uk/publications

Appendix 1 List of Tables and Figures

Table 1 Overview of activities and related sub-activities

Activity	Sub-activity: Discharge produced water	Shipping and helicopter transport	Construction of / at platform	Cable laying	Pipeline laying	Well plugging	Well workover	CO2 compression/heating	Demolition at platform	Pipeline/cable removal	Platform removal & disposal	Site clearance
Conventional platform operation	X	X										
Connection to e-grid and platform electrification		X	X	X								
Natural gas production (electrified)	X	X										
Removal of natural gas production equipment		X				X			X			
Conversion/addition of CO2 transport and storage assets		X	X		X		X					
Operation of CO2 transport and storage assets		X						X				
Removal of CO2 transport and storage assets		X				X			X	X		
Conversion/addition of green hydrogen assets		X	X	X	X							
Operation of green hydrogen assets		X										
Removal of green hydrogen assets		X							X	X		
Decommissioning of platform & infrastructure		X				X				X	X	X

Table 2 List of relevant pressures

Pressure	Description
Death or injury by collision	Death or injury of marine fauna due to impact with moving parts of a human activity, e.g. marine mammals with ships/ jet skis, seabirds with wind turbines etc. *At platforms, potential collisions of birds (attracted to light).*
Introduction of Non-synthetic compounds	Introduction of non-synthetic substances and compounds (e.g. heavy metals, hydro-carbons, resulting, for example, from pollution by ships and oil, gas and mineral exploration and exploitation, atmospheric deposition, riverine inputs). *At platforms, discharge of produced water (hydrocarbons, heavy metals), platform corrosion protection (use of aluminium-zinc anodes), antifouling (metal based), sanitary waste, etc.*
Introduction of Synthetic compounds	Introduction of synthetic compounds (e.g. priority substances under Directive 2000/60/EC which are relevant for the marine environment such as pesticides, anti-foulants, pharmaceuticals, resulting, for example, from losses from diffuse sources, pollution by ships, atmospheric deposition and biologically active substances. *Discharge of production chemicals in produced water, antifouling (synthetic), sanitary waste, etc.*
Introduction of Radionuclides	Introduction of radio-nuclides. *At platforms, discharges of natural radionuclides in produced water.*
Electromagnetic changes	Change in the amount and/or distribution and/or periodicity of electromagnetic energy emitted in a marine area (e.g. from *electrical sources such as underwater cables*).
Salinity regime changes	Significant changes in salinity regime (e.g. by constructions impeding water movements water abstraction). Discharge of brine water.
Marine litter	Marine litter. *Loss of materials by several operations.*
Underwater noise	Underwater noise (e.g. from shipping, underwater acoustic equipment). *Relevant for normal operation on board of the platform and all transport activities: ships, helicopters for transport of personnel, goods, material and equipment.*
Abrasion	Abrasion (e.g. impact on the seabed of commercial fishing, boating, anchoring). *Considered relevant to installation and decommissioning of platform, cables, pipelines.*
Changes in siltation	Changes in siltation (e.g. by outfalls, increased run-off, dredging/disposal of dredge spoil). *Considered relevant to installation and decommissioning of platform, cables, pipelines.*
Selective extraction non-living resources	Selective extraction (e.g. exploration and exploitation of living and non-living resources on seabed and subsoil). *Considered relevant to installation and decommissioning of platform, cables, pipelines.*
Smothering	Smothering (e.g. by man-made structures, disposal of dredge spoil). *Considered relevant to installation and decommissioning of platform, cables, pipelines.*

Lighting	The lighting of platforms (for visibility to helicopters and illuminate workspace). *Birds may get disorientated by light sources.*

Table 3 Pressures arising from the different sub-activities

	Pressures										
Sub-activity	Death or injury by collision platform	Introduction of Synthetic compounds	Introduction Non-synthetic compounds	Introduction of Radionuclides	Electromagnetic changes	Marine litter	Underwater noise	Abrasion and smothering	Changes in siltation	Selective extraction non-living resources	Emission of light
Gas production (operational)	X					X	X				X
Discharges produced water		X	X	X							
Shipping & helicopter transport	X	X	X			X	X				X
Constructions works at / of platform	X	X	X			X	X	X	X		X
Cable laying						X	X	X	X	X	
Electricity cable (operational)					X						
Well plugging						X	X				
Demolition at platform	X	X	X			X	X	X	X		X
Pipeline laying						X	X	X	X	X	
Well workover						X	X				
CO2 transport and storage (operational)	X					X					X
CO2 compression & heating							X				
Cable & Pipeline removal						X	X	X	X	X	

H_2 production (operational)	X					X					
Platform removal & disposal	X	X	X			X	X	X	X	X	
Site clearance	X	X	X			X	X	X	X	X	

Table 4 Combinations between pressures and biological components considered relevant

	Ecosystem components			
Pressures	Benthos	Fish	Birds	Mammals
Death or injury by collision			X	X
Introduction of Synthetic compounds	X	X	X	X
Introduction Non-synthetic compounds	X	X	X	X
Introduction of Radionuclides	X	X	X	X
Salinity changes	X	X		
Electromagnetic changes	X	X		X
Marine litter	X	X	X	X
Underwater noise		X	X	X
Abrasion and smothering	X			
Changes in siltation	X	X	X	X
Selective extraction non-living resources	X			
Lighting			X	

Table 5 Scoring of the exposure intensity of pressures (a, above) and the sensitivity of ecosystem components (b, below)

Category	Score	Spatial extent	Persistence	Frequency	Magnitude level
Low	1	< 100 m^2	Hour(s) (< 1 day)	Rare (once per year or less)	Low
Moderate	2	100 - 1000 m^2	Day(s) (< 1 month)	Occasional (multiple times per year)	Moderate
High	3	1000 - 10000 m^2	Month(s) (<year)	Common (weekly or daily)	High
Very high	4	> 10000 m^2	Years	Continuous (several times per day or continuously)	Very high

Category	Score	Resistance	Effect type	Recovery
Small	1	High tolerance, effect unlikely	Behaviour	Instant (< 1 day)
Moderate	2	Moderate tolerance, effect possible	Individual health	Days (< 1 month)
Large	3	Low tolerance, effect likely	Vital rates population	Month(s) (< 1 year)
Very large	4	No tolerance, effect occurs	Population decrease	Year(s)

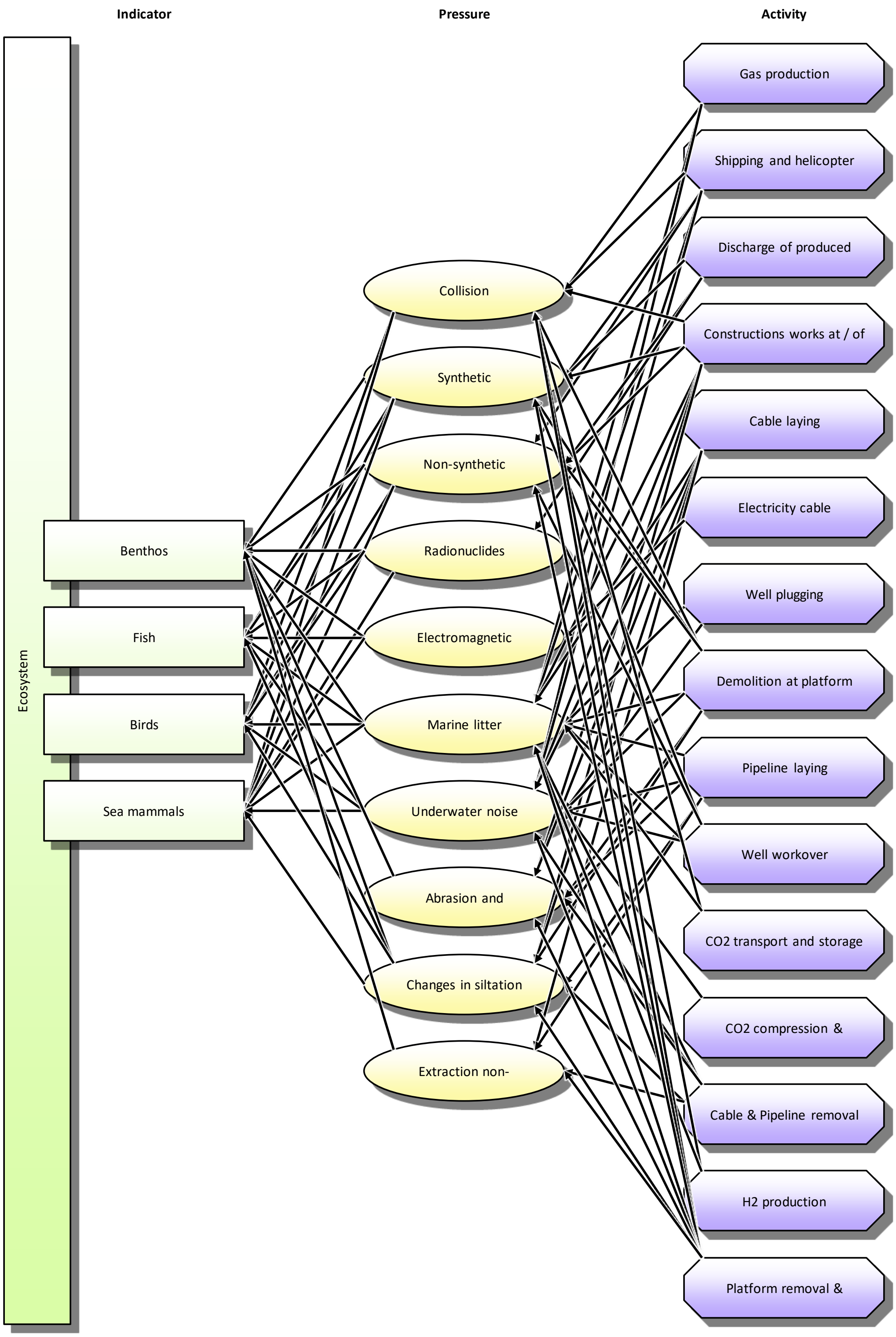

Figure 1 Effect chains linking (sub)activities to relevant pressures and ecosystem components.

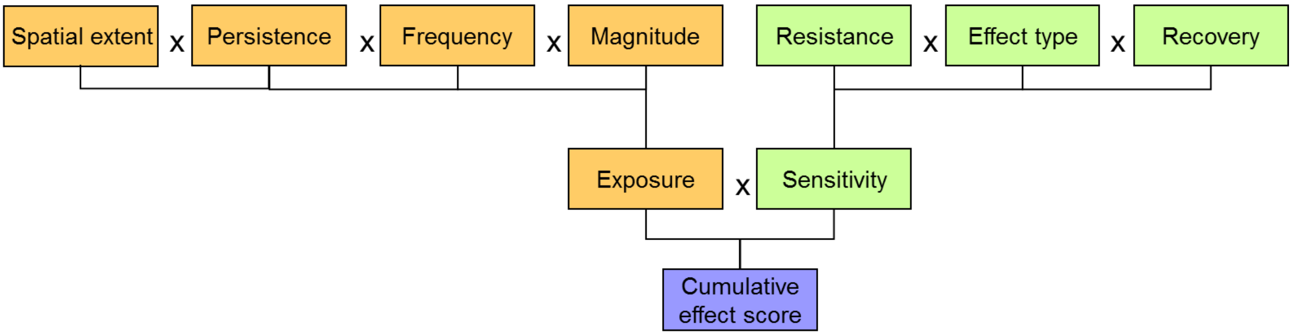

Figure 2 Assessment scheme to calculate the cumulative effect score.

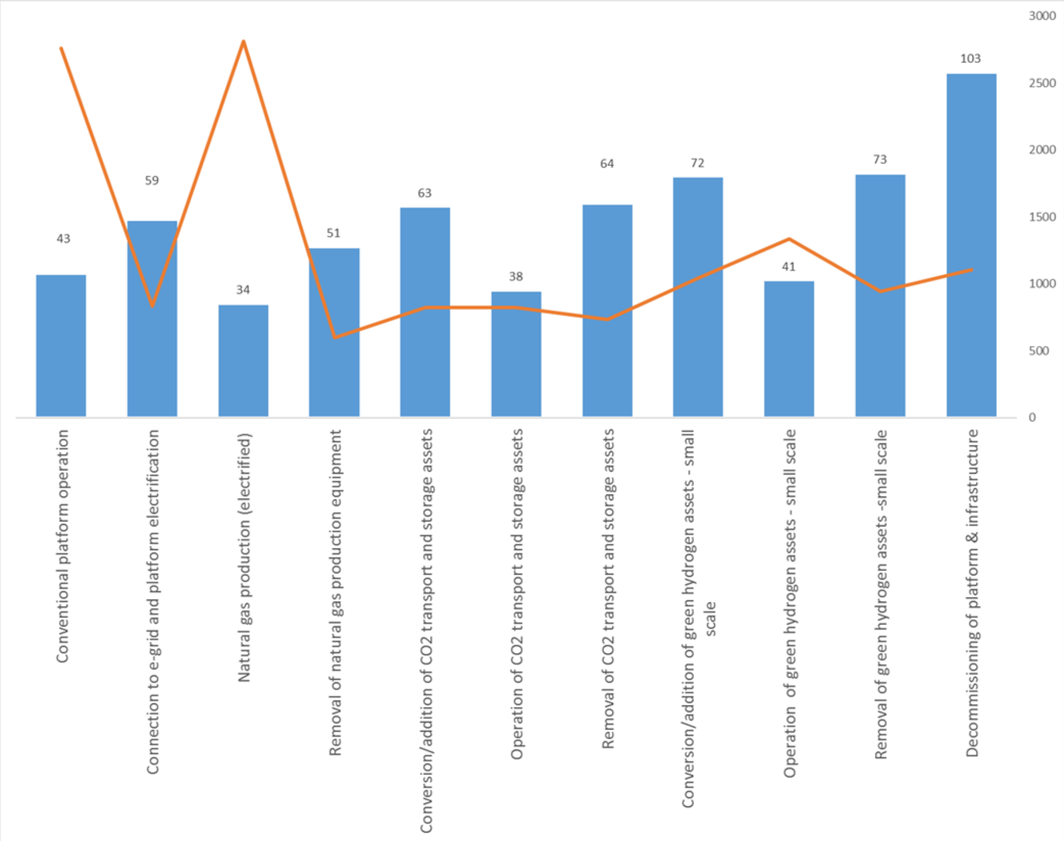

Figure 3 Number of impact chains (bars, showing the number of chains on top) and cumulative effect score (line) per activity.

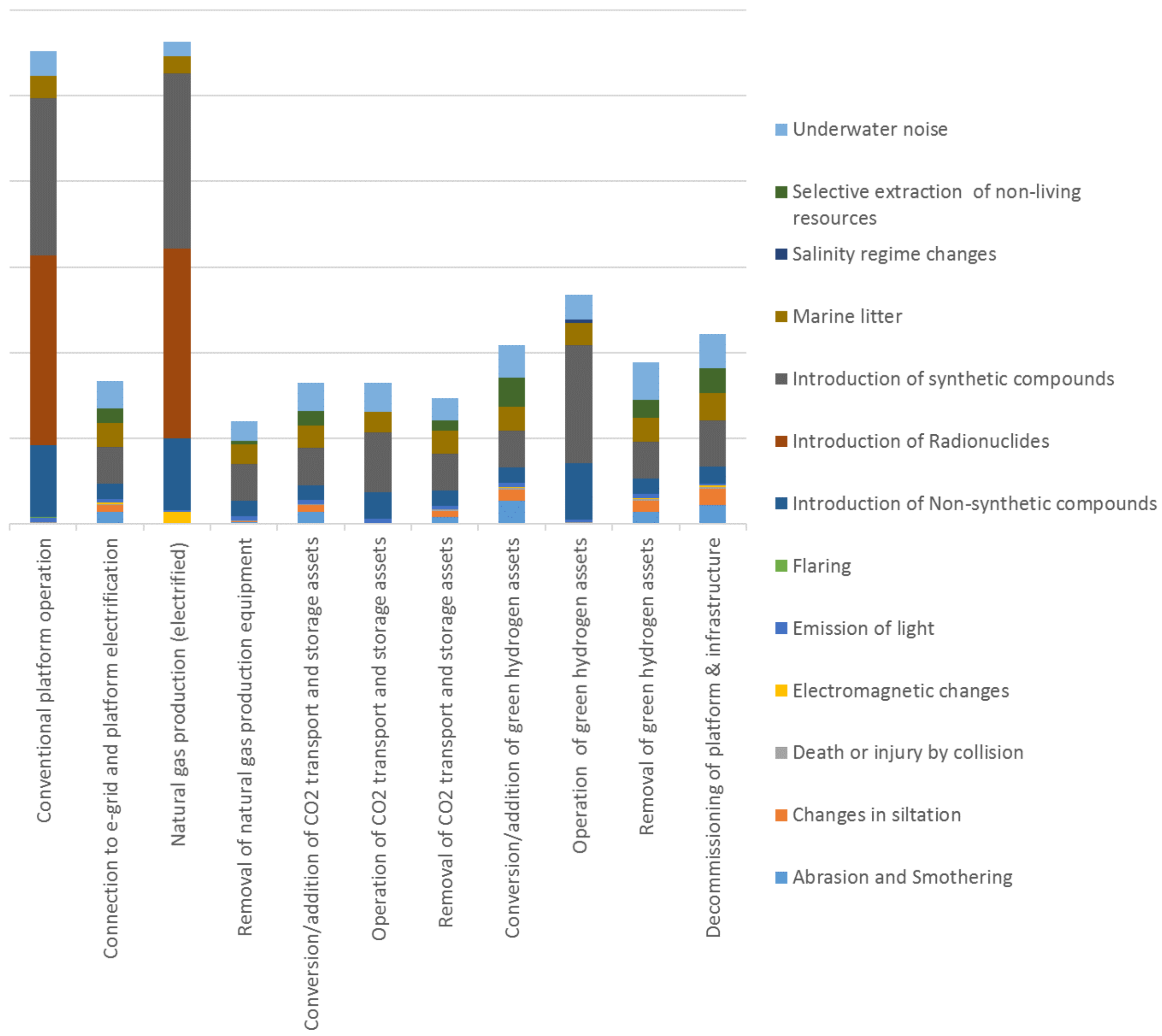

Figure 4 The relative cumulative effects for the individual activities showing contributions from the distinguished pressures.

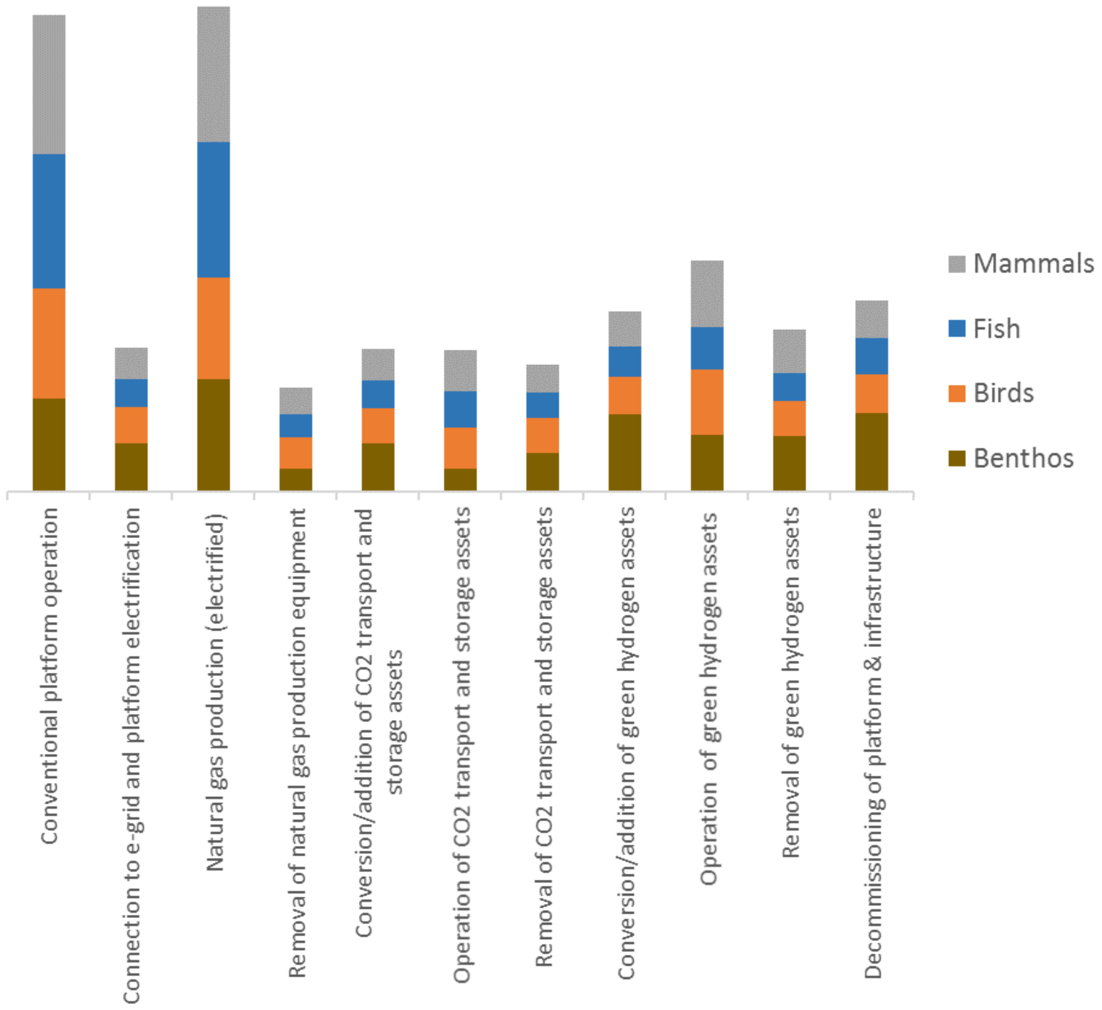

Figure 5 Contribution of species groups to the overall cumulative effects for each sub activity.

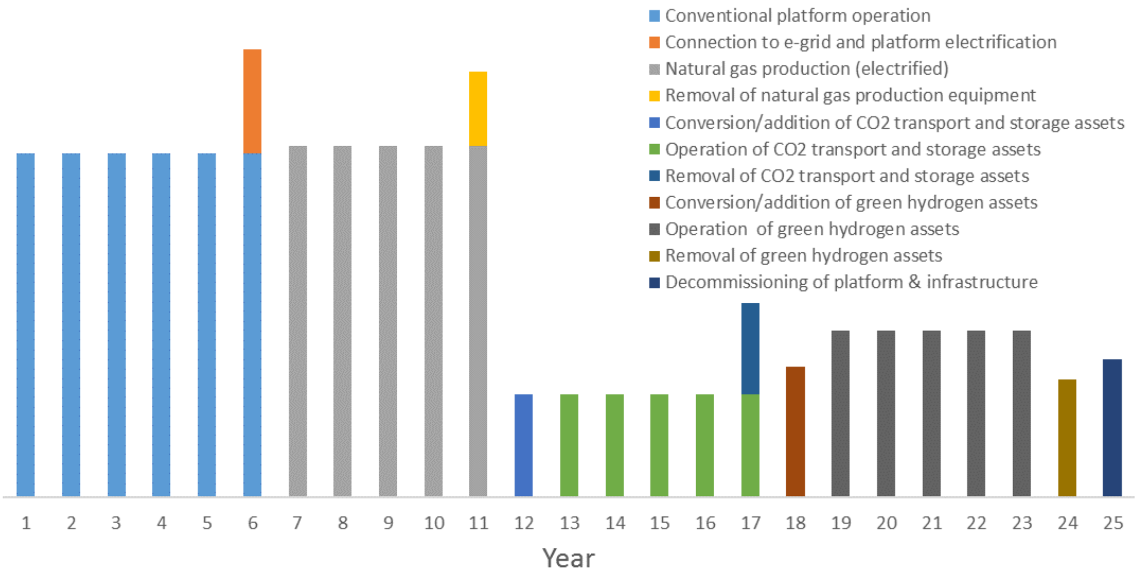

Figure 6 Dynamics of Cumulative Effect Scores over a 25 year period of a hypothetical scenario where a conventional gas production platform is subsequently electrified, transformed into a CCS facility, and thereafter applied for green hydrogen production.