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SYSTEMATIC REVIEW PROTOCOL Open Access

What are the local impacts of energy systems on marine ecosystem services: a systematic map protocol

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Abstract

Background: Increasing concentrations of atmospheric greenhouse gases (GHG) and its impact on the climate has resulted in many international governments committing to reduce their GHG emissions. The UK, for example, has committed to reducing its carbon emissions by 80% by 2050. Suggested ways of reaching such a target are to increase dependency on offshore wind, offshore gas and nuclear. It is not clear, however, how the construction, operation and decommissioning of these energy systems will impact marine ecosystem services, i.e. the services obtained by people from the natural environment such as food provisioning, climate regulation and cultural inspiration. Research on ecosystem service impacts associated with offshore energy technologies is still in its infancy. The objective of this review is to bolster the evidence base by firstly, recording and describing the impacts of energy technologies at the marine ecosystems and human level in a consistent and transparent way; secondly, to translate these ecosystem and human impacts into ecosystem service impacts by using a framework to ensure consistency and comparability. The output of this process will be an objective synthesis of ecosystem service impacts comprehensive enough to cover different types of energy under the same analysis and to assist in informing how the provision of ecosystem services will change under different energy provisioning scenarios.

Methods: Relevant studies will be sourced using publication databases and selected using a set of selection criteria including the identification of: (i) relevant subject populations such as marine and coastal species, marine habitat types and the general public; (ii) relevant exposure types including offshore wind farms, offshore oil and gas platforms and offshore structures connected with nuclear; (iii) relevant outcomes including changes in species structure and diversity; changes in benthic, demersal and pelagic habitats; and changes in cultural services. The impacts will be synthesised and described using a systematic map. To translate these findings into ecosystem service impacts, the Common International Classification of Ecosystem Services (CICES) and Millennium Ecosystem Assessment (MEA) frameworks are used and a detailed description of the steps taken provided to ensure transparency and replicability.

Keywords: Energy systems, Ecosystem impacts, Ecosystem service impacts, Biodiversity, Habitats, Ecosystem functions, Ecosystem Processes, Human health and well-being, Ecosystem service classifications

Background

Increasing concentrations of greenhouse gases (GHG[a]) in the atmosphere and its impact on the climate has been a concern of governments around the world over the last few decades culminating in the signing of a UN treaty on climate change [1] and subsequent ratification of the Kyoto Protocol [2] in 1997 by a number of countries. Carbon dioxide (CO_2) released from the burning of fossil fuels for energy is one of the main contributors to the basket of GHG and the resulting greenhouse effect (i.e. the warming of the earth's temperatures). Replacement of this fuel with alternative low-carbon technologies (such as renewables) is considered one way to significantly reduce these emissions. Globally, the International Energy Agency (IEA) along with the International Renewable Energy Agency (IRENA) are leading the way in providing roadmaps for the uptake and development of a suite of low-carbon energy technologies.

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In addition to international GHG reduction targets, some governments have enforced further national commitments. For example, in the UK, a legally binding target of 80% GHG reduction by 2050 has now been set [3]. This move towards a low carbon future requires lower carbon energy commodities (such as natural gas and nuclear) and renewable energy commodities (such as wind) to play a more prominent role in the UK's energy mix. The UK government has already initiated action towards this change in fuel mix through a number of policies and actions. The UK Renewable Energy Road Map [4], for instance, notes that by 2020, 15% of all UK energy consumption is to be supplied through renewable energy with a significant proportion of electricity production coming from offshore wind energy (25% of total projected renewable demand). For offshore wind to make this contribution, there will need to be an increase from the current 1,100 (3.6GW) to 5,500 (18GW) operational offshore turbines in UK waters. Nuclear and natural gas are also seen as major contributors to an alternative energy mix. Scenarios in the UK Government's Carbon Plan [5] forecast nuclear to account for between 10-15GW of power by 2030 reducing the UK's "carbon emissions by between 7% and 14%" [6]. It is also projected that natural gas will account for at least half of energy used for heating in the UK "well into the 2020s" [5].

Based on the above projected energy supply trends, continued and increased use of the marine environment to satisfy energy demand appears certain, whether it be due to the construction, operation or decommissioning of offshore wind farms, offshore oil and gas platforms or offshore infrastructure associated with nuclear energy. To date a wealth of research on ecosystem (see for example [7-9]) and human impacts (see for example [10,11]) has shown that there are varied outcomes associated with installing energy provisioning systems into, and next to, the marine environment. However, little has been done in translating these impacts into ecosystem services and the effects on human well-being (but see UK NEA [12]).

Ecosystem services (ES) are the "benefits people obtain from ecosystems", i.e. the goods and services derived from ecosystems that contribute towards human well-being, such as food, equable climate and inspiration. Changes and impacts on ecosystems can be translated into these ES providing comparability of results across studies and standardisation of inputs into policy and management decisions [13]. This translation process is facilitated by the ES classification systems, such as those presented in the UK National Ecosystem Assessment [12], Millennium Ecosystem Assessment [14] and the Common International Classification of Ecosystem Services [15], which allocate ES to four main ES groups: provisioning, regulating, supporting and cultural. There is a real requirement in generating an evidence base which presents knowledge of the different impacts of energy systems on the environment and humans within this ES framework. Research on ecosystem service impacts associated with offshore energy technologies is still in its infancy and progress in establishing this evidence base is slow. Accordingly, there has also not been an objective synthesis comprehensive enough to cover different types of energy under the same type of analysis.

This review aims to bolster the ecosystem services impact database by (i) strictly abiding by the systematic review protocol to draw on the wealth of existing studies that have quantified impacts on marine ecosystems and humans attributable to the offshore energy industry and (ii) translating these into ecosystem service impacts through a framework which clarifies how the process of conversion between the two types of information has taken place. This review is therefore intended to assist in better informing how the provision of ecosystem services around the world will change under different energy provisioning scenarios.

Specific objective of the review

The main objectives of this review are firstly to record and synthesise results regarding the impacts of the marine energy provisioning technologies: offshore wind, offshore gas, offshore oil and offshore components of nuclear in a standardised manner, which to the best of our knowledge, is entirely novel. We focus on impacts at the ecosystem level and those more widely associated directly with human health and wellbeing.

Secondly, we translate these impacts into explicit ecosystem service impacts by using the Common International Classification of Ecosystem Services (CICES) [15] and the Millennium Ecosystem Assessment (MEA) [14] framework. For example, the results of ecosystem level impacts can be used to derive impacts on the ecosystem services: supporting, provisioning and regulating; while the direct human impacts can be used to derive effects on cultural services [13-15]. The proposed objective mapping methodology differs from the more frequently observed ES literature, which often relies on expert judgement for the translation of ecosystem impacts into ES, making the process opaque and the ability to compare the findings of different studies challenging. By using a systematic review approach to collate the literature, and an explicit and recognized ES classification (i.e. CICES and MEA) for ES attribution, this framework is expected to overcome these shortcomings, providing a consistent and transparent approach.

Primary question

What impacts do the construction, operation and decommissioning of offshore oil and gas, offshore wind and offshore structures of nuclear installations have on biodiversity, habitat, structure, and function of marine ecosystems, and their relation to human well-being?

Table 1 Definitions of components of the review question

Populations	Exposure	Outcomes	Comparators
Benthic, demersal, pelagic and marine mammal species, seabirds, habitat types, seabed, general public	Energy installations	Species distributions, biodiversity, species richness, community structure, abundance, abundance of non-indigenous species, ecosystem function, ecosystem process, recreational use, inspiration, spiritual influence, human health	Predevelopment baseline and/or reference sites

Table 1 lists the different components of the research question that will be used to drive the search for relevant studies.

Methods

Search strategy

The databases Sciencedirect and Web of Science will be used to source published peer reviewed research while the Aquatic Sciences and Fisheries Abstracts (ASFA) database is used to access grey literature. These published databases were chosen as they produced relevant, and some of the expected, articles in the test and scoping searches. No additional sources of grey literature were sought given resource constraints. The final search terms are listed in Table 2, along with the Boolean operators.

Study inclusion criteria

A number of selection criteria will be used to evaluate whether studies returned by the literature search will be included in the review. These criteria will be used in a sequence of stages. Initially, each reviewer will be assigned a specific technology. At a first level, the reviewers will evaluate the title of all returned references specific to their technology, and any spurious results excluded. All remaining articles will be assessed at a second level based on their abstract and whether they satisfy the inclusion criteria. All abstracts which are retained will progress to the third level where each will then be reviewed at full text. Articles that are chosen to be included for further review enter the fourth and final level where they will be re-evaluated and data extracted for analysis.

Before progression beyond level 2, a Fleiss' kappa test [16] will be conducted to measure the degree of agreement between reviewers based on a fixed sub-set of references. Each reviewer will be given the same list of randomly selected abstracts from the research database for review and asked to state whether they would include or exclude the article based on the inclusion criteria. A kappa result of over 0.5 will be considered acceptable for this review and indicates a moderate level of agreement between reviewers. If the kappa test result is lower than 0.5, inclusion criteria will be discussed to assess inconsistency in the interpretation of studies, and a second round of references assessed by all reviewers. The process will be repeated until a suitable kappa level is achieved.

The inclusion criteria to be used throughout each of the selection levels are defined to determine the subject,

Table 2 General search terms to be used in the review

Exposure	Populations	Outcome
Terms for offshore wind turbine (("offshore wind" OR "offshore wind turbine" OR "offshore wind farm*" OR "offshore wind park*" OR "offshore wind installation*") AND (construct* OR operat* OR decommiss*)) *Terms for offshore oil/gas platforms* (("offshore oil rig" OR "offshore gas rig" OR "offshore oil platform" OR "offshore gas platform" OR "offshore oil" OR "offshore gas" OR "offshore oil installation" OR "offshore gas installation") AND (construct* OR operat* OR decommiss*)) *Terms for nuclear* (("nuclear power station" OR "nuclear cooling system" OR "nuclear discharge') AND (construct* OR operat* OR decommiss*))	(marine OR sea* OR maritime OR benth* OR demersal OR pelagic OR ocean* OR mammal* OR bird* OR fish* OR "general public")	("species distribution" OR "species composition" OR "species richness" OR "community structure" OR evenness OR abundance OR biodiversity OR bio-diversity OR "biological diversity" OR population OR "ecosystem funct*" OR "ecosystem process" OR valu* OR recreation OR amenity OR leisure OR tourism OR inspiration OR religious OR spiritual OR cultur* OR heritage OR education* OR health OR wellbeing OR aesthetic* OR view OR seascape OR "artificial reef" OR perception OR information OR existence OR bequest)

An asterix (*) following a search term/word is used as a wildcard allowing the search engine to accept variations of the term/word in the search. Quotation marks around words or phrases signifies that only the exact word or phrase will be allowed in the search results.

exposure, comparators, outcomes and study types that best support the investigation of our primary question, and are described below.

Relevant subject

All marine and coastal species (including birds), marine habitat types and the general public are considered relevant subjects.

Relevant exposure

All installations and structures representative of offshore wind farms, offshore oil and gas platforms and offshore structures connected with nuclear power stations will be considered as relevant exposures. This will include monopole, multi-pile, gravity base/caisson, concrete and steel base structures, discharge pipes and electric cables.

Relevant comparators

Observational and experimental studies comparing marine biodiversity, habitat, structure, functioning and human impact of the installed energy provisioning structure in the following cases will be considered:

1. Before-After (BA), i.e. time comparison;
2. Before-After Control-Impact (BACI) i.e. spatial-temporal comparison; and
3. Control-Impact (CI), i.e. spatial comparison.

Relevant outcomes

A broad range of outcomes will be examined and recorded both quantitatively and qualitatively and will cover the following areas:

(1) Change in the species structure and diversity through (a) population size or distribution, breeding success, univariate diversity (richness) or evenness; (b) multivariate indices such as assemblage similarity patterns (c) changes in community components measured as abundance, biomass, density or cover or individual species or statistics describing abundance-biomass curves;
(2) Changes in benthic, demersal and pelagic habitats through changes in ecosystem functions and processes. Relevant processes considered included hydrographic changes, the stabilisation, transport and mixing of sediment, nutrient cycling and enrichment, carbon flux, contaminant inputs, and physical damage.
(3) Changes in cultural services, i.e. recreational use, derived inspiration, spiritual influence, cognitive development, enfranchisement, human health, and related values held for ecosystem components through changes in biodiversity, habitat, structure and function.

Relevant types of study design

Empirical studies conducted in the field or in the laboratory will be accepted for this review. This includes both experimental and observational studies. Studies that are theoretical in nature and those which include only modelling work will be excluded.

Study quality assessment

In undertaking a review, it is important to ascertain whether the results being presented in studies are reliable. The specific data quality scoring criteria to be used in this review are noted below (Table 3). This approach has been modified from Ashley et al. [17] so that the scoring totals provide an even weighting across the attribute categories (which contribute equal importance to the quality assessment) combining categorical and additive scoring types. The quality assessment is scored across a range of attributes including site comparisons which rely on either primary data collection, secondary data (especially long time series not collected by current researchers), regional knowledge (interviews with locals) and time series or single

Table 3 Attributes to be used for quality assessment of all studies

Attribute	Description	Score
Study design (categorical)	Site comparison: primary data collection	25
	Site comparison: historical or secondary data	20
	Site comparison: regional knowledge	15
	Time series comparison: post structure only	10
	Single sampling occasion in impacted area only	5
Comparator (categorical)	Before and after construction data collection both at structure site and outside structure reference site (BACI)	25
	Before and after construction study site (BA)	17
	Inside structure site and outside reference site (CI)	8
	No comparator	0
Between site variability (additive)	Region and depth comparable	6
	Sediment prior to construction comparable	6
	Size of sample area comparable	6
	Survey design comparable	6
Replication (categorical)	Temporal and spatial replication	25
	Temporal or spatial replication	12
	No replication	0

Table 4 Degree of impact

Quantitative	Qualitative
Decrease in species/functional process/ecosystem service	Negative impact
0% change (or +% and -% but cancel each other out)	No impact
Increase in species/functional process/ecosystem service	Positive impact
Inconclusive results	Unclear conclusion

sampling; the type of comparator included within the research studies (i.e. before-after control-impact, before-after, control-impact and no comparator). Variability between site areas is also included to highlight elements which might reduce comparability of results between the different sites. Replication of samples is recorded to provide an indication of the reliance of the results being reviewed. Details of each of these criteria will be extracted from studies read at full text and summed to give a final quality score. This study quality scoring framework is used across all articles reviewed.

In order to standardise the results recorded by the reviewers, all quality assessment criteria will be restricted to a set of prescribed answers per field which will have been agreed upon in advance by all reviewers.

Data extraction strategy

In addition to the information extracted for the quality assessments, the reviewers will also extract a variety of information from the reviewed studies including:

- Exposure and details
- Subject and details
- Geographic location
- Start and end dates of study
- Spatial and temporal scale
- Outcome variable
- Study measure and percentage change

The changes in the variables identified in the Outcomes column of Tables 1 and 2 (changes in species numbers, diversity, impacts on habitat and effect on the general public) will be recorded by the reviewers to create a database of results. Quantitative changes will be calculated by the reviewer, if not noted in the study, and recorded in the appropriate column of the record sheet. When data are available in a suitable format for calculation (i.e. tabular data) this will be used directly. If data are available in plot format (e.g. scatterplot) then data extraction will proceed by use of imaging software such as the freeware Image J 1.45 s (National Institutes of Health, USA). Qualitative scores will also be derived directly from each study and key words such as "negative", "positive" or "no impact" will be used to signify outcome of the study (Table 4).

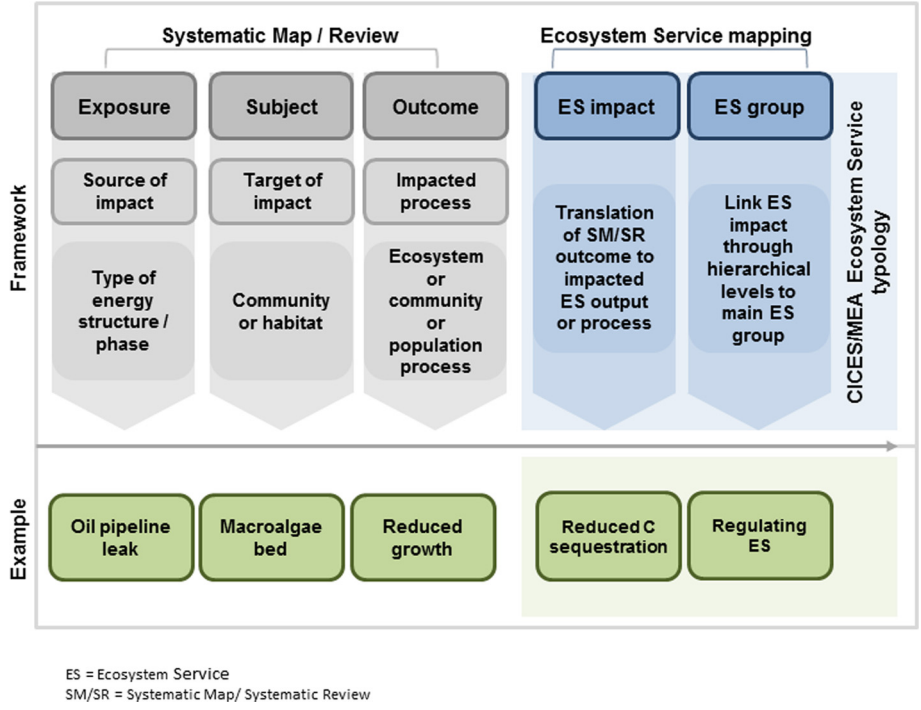

Figure 1 Translating ecosystem impacts to ecosystem service impacts.

Data synthesis and presentation

The findings of the review will be synthesised using a narrative approach [18] and summary tables for each technology (offshore wind, offshore oil and gas and offshore components of nuclear) created. The details of the studies will be recorded in a table under the following headings: article reference, subject population, intervention/exposure, setting/context, outcome measures, methodologies design, quality assessments, results of ecosystem/human impact. The information to fill these synthesis tables will be extracted from the review which can be seen as a stepwise progression (first three columns in Figure 1), beginning with identifying the source of impact (or exposure), followed by the target of impact (or subject), and the impacted process (or outcome).

To ensure that the findings of the review have meaning within an ecosystem service context, two columns are added to the synthesis tables: ecosystem services impacted and classification framework used. To fill these last two columns for each of the reviewed studies, the Common International Classification for Ecosystem Services (CICES), version 4.3 [15] and the Millennium Ecosystem Assessment (MEA) [14] are used. The CICES classification system describes in detail the types of ecosystem and cultural functions and processes attributed to the ecosystem service groups: provisioning, regulating and cultural services, while MEA gives a broad overview and definitions of all of the ecosystem services (provisioning, regulating, cultural and supporting). It is necessary to employ both classification frameworks as the supporting ecosystem services considered by the Millennium Ecosystem Assessment [14] fall outside of the CICES classification which focuses on the three so called "final ecosystem services" (provisioning, regulating and cultural). The supporting services are predominately considered as "intermediate ecosystem services", integral to the provision of the final ecosystem services, and will be used to represent outcomes from reviewed studies which cannot be linked directly to a final ecosystem service.

The outcome results from the review are therefore translated into ES impacts by identifying relevant examples of the biological or material outputs and bio-physical and cultural processes outlined within the CICES classifications. Outcomes which fall outside of the CICES classification are by default attributed to the supporting services from the MEA. Once the ES output or process has been identified in CICES, it is traced to the ecosystem service group, i.e. provisioning, regulating or cultural through the hierarchical levels of the classification system (see last two columns in Figure 1).

In Figure 1, we exemplify how a hypothetically reviewed study produces information about how exposure of an oil pipeline leak on macroalgae leads to reduced macroalgae growth. This outcome is then used to identify a relevant ES process or function within the CICES framework by scanning the examples provided in the framework (see [15] for detailed description). If a relevant process is not found within CICES, then the process is considered a supporting service under the MEA definition and examples. In this example, the reduction in macroalgae growth would be translated into reduced carbon fixation and thus reduced CO_2 sequestration from the water column, which is considered as a regulating service within the CICES framework [15]. This ES group heading result is thus recorded within the synthesis table along with the fact that the CICES classification was used.

The collation of the results in this form will allow for a synthesis of the reviewed results to be made explicit, and of their translation into ecosystem services to be as transparent and repeatable as possible. The tables will also be compared and discussed to highlight the types of impacts associated with each energy system, the gaps in knowledge and what this could mean for future energy mixes.

Endnote

[a]Greenhouse gases include carbon dioxide, methane and nitrous oxide.

Competing interests

The authors declare that they have no competing interests.

Author's contributions

EP contributed to the design of the protocol, discussion of its components and drafted the manuscript. NB developed the scoring system, discussed the protocol components and contributed to writing the manuscript. TH assisted in the identification of the protocol components, preformed preliminary tests on the protocol's search methods and contributed to the writing of the manuscript. JN assisted in identifying the protocol components, contributed to the design of the protocol and the writing of the manuscript. AMQ suggested the systematic review approach, contributed to the development of the scoring system and other aspects of the rationale, suggested the translation framework, produced Figure 1, and contributed to writing of the manuscript. All authors read and approved the final manuscript.

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References

1. UNFCCC: *United Nations Framework Convention on Climate Change background information*. 1992. Available from http://unfccc.int/essential_background/items/6031.php.
2. UNFCC: *Kyoto Protocol*; 1997. Available from: http://unfccc.int/essential_background/items/6031.php.
3. HM Government: *Climate Change Act 2008*. London; 2008. http://www.legislation.gov.uk/ukpga/2008/27/pdfs/ukpga_20080027_en.pdf.
4. DECC: *UK Renewable Energy Road Map*. London; 2011. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48128/2167-uk-renewable-energy-roadmap.pdf.

5. DECC: *The Carbon Plan – Reducing Greenhouse gas Emissions.* London; 2011. https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions–2.
6. DECC: *Nuclear.* London; 2012. http://www.decc.gov.uk/en/content/cms/meeting_energy/nuclear/nuclear.aspx.
7. Skeate ER, Perrow MR, Gilroy JJ: **Likely effects of construction of Scroby Sands offshore wind farm on a mixed population of harbour Phoca vitulina and grey Halichoerus grypus seals.** *Mar Pollut Bull* 2012, **64:**872–881.
8. Warwick PE, Cundy AB, Croudace IW, Bains MED, Dale AA: **The uptake of iron-55 by marine sediment, macroalgae, and biota following discharge from a nuclear power station.** *Environ Sci Technol* 2001, **35**(11):2171–2177.
9. Fabi G, Grati F, Puletti M, Scarcella G: **Effects on fish community induced by installation of two gas platforms in the Adriatic Sea.** *Mar Ecol Prog Ser* 2004, **273:**187–197.
10. Hooper T, Austen M: **Tidal barrages in the UK: Ecological and social impacts, potential mitigation, and tools to support barrage planning.** *Renewable Sustainble Energy Rev* 2013, **23:**289–298.
11. Venables D, Pidgeon NF, Parkhill KA, Henwood KL, Simmons P: **Living ith nuclear power: Sense of place, proximity, and risk perceptions in local host communitiies.** *J Environ Psychol* 2012, **32:**371–383.
12. UK National Ecosystem Assessment: *The UK National Ecosystem Assessment Technical Report.* Cambridge: UNEP-WCMC; 2011.
13. DEFRA: *Ecosystem Services*; 2013. Available from https://www.gov.uk/ecosystems-services.
14. Millennium Ecosystem Assessment: *Ecosystems and Human Well-Being: Synthesis.* Washington: Island Press; 2005.
15. Haines-Young R, Potschin M: *CICES Version 4: Response to consultation.* London; 2012. http://cices.eu.
16. Fleiss JL: **Measuring nominal scale agreement among many raters.** *Psychol Bull* 1971, **76**(5):378–382.
17. Ashley MC, Mangi SC, Rodwell LM: **The potential of offshore windfarms to act as marine protected areas – a systematic review of current evidence.** *Mar Policy* 2014, **45:**301–309.
18. Doerr ED, Doerr VAJ, Davies MJ: **Does structural connectivity facilitate dispersal of native species in Australia's fragmented terrestrial landscapes? CEE protocol 08–007 (SR 44).** *Collaboration Environ Evid* 2008. www.environmentalevidence.org/SR44.html.

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