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A systematic multi-criteria decision-making framework for the re-use of old fixed offshore jackets for marine renewable energy

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Abstract– *Re-use of fixed offshore platforms used in oil and gas industry at end of its life is a topic discussed for long time. As the renewable energy extraction from offshore sector is also gaining momentum very fast. Development of offshore wind has shown significant progress with lot of new developments in execution stage or under planning. Especially there is rapid development happening in the floating offshore wind. Altogether the renewable energy sector industry will see accelerated development in utilizing the energy potential in offshore sector. There is requirement of support structures in offshore locations for these marine energy applications related to energy production, conversion, storage, and transmission. In this context, the re-use of old fixed offshore platforms as support structures for marine renewable energy (MRE) applications is studied. A systematic approach and methodology are proposed here for comparison and selection of different re-use cases considered. The concept of Structural Reusability Index is also introduced.*

Keywords– *Decommissioning, Expert System, Jacket Structures, Marine renewable energy, MCDM, Offshore structures, Re-use, Structural Reusability Index, Sustainability.*

INTRODUCTION

Numerous offshore platforms with fixed jacket substructures which are nearing its end of intended service life will need to undergo decommissioning. As per the decommissioning plans developed, one of the most generic options considered for offshore platform is the “cutting and removal” of the platforms from its offshore locations. This option is selected even if the jackets are in good condition for further operation or re-use for alternate functions.

At the same time due to the visible impacts and effects of climate changes globally, the focus and acceleration of global energy transition is increasing. The development of renewable energy sector will be the key driver for global decarbonization for future. The 2023 United Nations Climate Change Conference (COP28) set the goal to ensure three times more renewable energy capacity by 2030 [from 2022], or at least 11,000 GW [1].

Generation of energy from abundant offshore renewable sources is also on rapid development. Till now wind is the most matured utilized energy form from offshore. Though initially the offshore wind farms developed till now were from relatively shallow offshore regions, developments in floating wind have opened a huge opportunity to exploit this abundance of energy. The installed offshore wind capacity in 2023 is about 250 MW which is projected to increase by about 1.5 GW by 2050 [1]. Various new developments and technologies in this sector has made the Levelized Cost of Energy (LCOE) of produced energy to commercially viable levels.

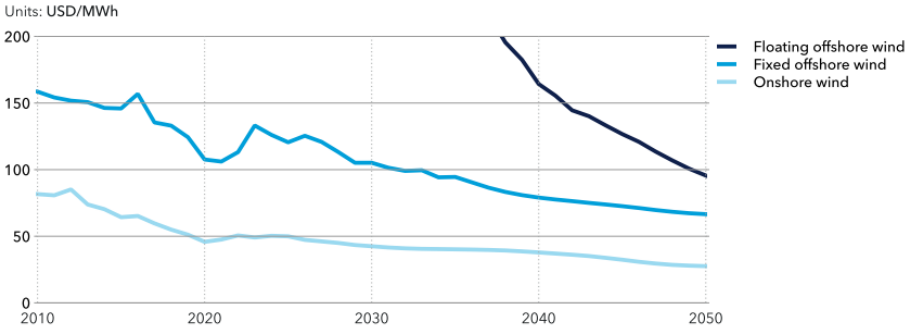

Fig. 1. LCOE trends of wind energy [1]

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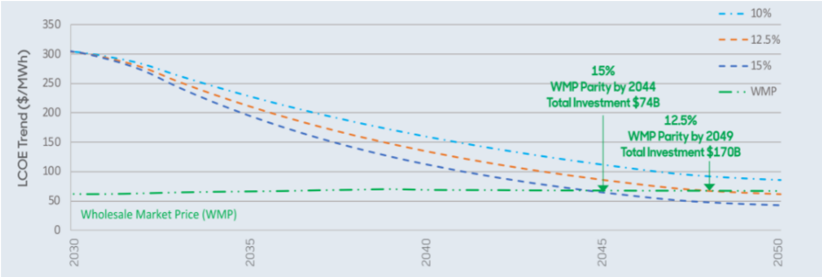

Fig. 2. LCOE trends of wave energy [2]

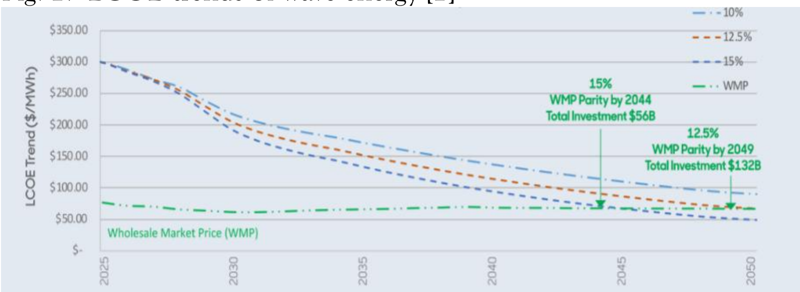

Fig. 3. LCOE trends of tidal energy [2]

There are several other types of ocean energy resources, including tidal rise and fall, tidal/ ocean current, waves, salinity gradient and thermal gradient. Of these, the tidal barrage itself has an installed capacity of 521 MW while it is 10.6 MW for tidal stream, and 2.31 MW wave power generation [1]. The technologies for energy extraction from ocean energy is still under development with a lot of bottlenecks for the developments including LCOE and with more than 100 technologies still under various stages of development, there is no technology convergence as of now. However, International Energy Association (IEA) Ocean Energy Systems (OES) has set out a roadmap to target 300 GW of renewable energy generation capacity from ocean energy technologies by 2050 [2].

In addition to the power generation, the technology development in power transmission and power storage, grid connection etc. will hugely affect the LCOE of ocean energies. Green hydrogen is one of the focus areas gaining increased attention in this transition.

Many of these developments include requirement of offshore infrastructure including platforms with jacket type substructures. In this context, evaluation of existing offshore platforms for re-use in renewable energy applications becomes relevant.

A. *Abbreviations and acronyms*

CAPEX	Capital Expenditure
CoG	Centre of Gravity
COP28	2023 United Nations Climate Change Conference
DCF	Discounted Cash Flow
EIA	Environmental Impact Assessment
FEED	Front End Engineering and Design
HVDC	High Voltage Direct Current
IEA	International Energy Agency
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
MCDM	Multi Criteria Decision Making
MRE	Marine Renewable Energy
OEM	Original Equipment Manufacturer
OES	Ocean Energy Systems
OPEX	Operational Expenses
OTEC	Ocean Thermal Energy Converter
SIM	Structural Integrity Management
SMR	Strengthening/Modification/Repair
TCP	Technology Collaboration Programme
TRL	Technology Readiness Level

EVALUATION OF RE-USE SCENARIOS

It is estimated that approximately 7500 platforms are nearing the end of its designed life and approximately USD 103 billion is expected to be spent on decommissioning between 2025 and 2034 globally [3].

Jacket type support structures are typically used for shallow water oil and gas infrastructure and used for varying functions include drilling platforms, production platforms, process platforms, accommodation platforms etc. the support structure could vary from monopods, tripods, 4/6/8-legged jackets or more complex jackets with more legs and foundation systems based on the site-specific conditions, topside facilities, environmental conditions etc.

Similarly for renewable energy applications jacket type substructures are widely used as wind turbine support structures and could be used for a lot of other offshore infrastructure like power generation/conversion stations, energy storage stations etc. Hence the possibility of re-use for such an application would be a win-win situation for various stakeholders.

This study will try to assess and compare various options for a fixed offshore platform considered for re-use as support structure for marine renewable energy applications based on various qualitative and quantitative factors.

Zanuttigh et. al [4] have proposed a novel framework for a re-use application for offshore platforms. Henrion et al [5] have developed a decision-making tool using multi criteria attributes which helps in evaluation various decommissioning options for platforms in United States of America. Martins et al [6] have also done a multi-criteria decision analysis related to oil and gas decommissioning problem. All these works include utilisation of Multi criteria decision making (MCDM), Life cycle assessment (LCA) and Discounted cash flow (DCF) techniques, however varies in the approach of the factors considered. Meanwhile, IEA [7] provides a guidance on evaluation for ocean energy technologies which follows a development process from concept stage evolving to a much more detailed and mature solution. This has been developed with involvement from various stakeholders and experts in the energy sector. The expert system proposed in this article follows the general methodology by IEA to assess and compare various options for re-use of a fixed offshore platform. Together with the expert system this also proposes the use of a concept, “Structural Reusability Index (SRI)” for the jacket which will help in easier comparison with respect to a new platform for same use.

A SYSTEMATIC APPROACH FOR COMPARING RE-USE OPTIONS

For an offshore fixed platform reaching end of its useful life can be considered for various re-use scenarios related to offshore renewable energy applications including power generation, storage, conversion, transmission, or associated infrastructure. There could be also multitude of options related to other industries including aquaculture, tourism, research, other marine uses etc. However, the options related to marine renewable energy applications and its muti-use scenarios are primarily discussed here. The reusability of the structure depends upon majorly on the below factors,

- Requirement of a re-use case
- Structural condition of the existing platform
- Feasibility of the platform for life extension

The re-use of an existing platform has multiple advantages; it will avoid the requirement of a new platform construction and it will delay the decommissioning of the platform if the existing platform is considered for re-use. Meanwhile, the existing platform considered for re-use may require modifications, upgrades etc. based on engineering assessment. It is important to compare the options considered and assess it so that it is easy for stakeholders to take calculated decisions. Hence a systematic approach is proposed to compare and evaluate between various re-use options for renewable energy applications. Fig.4 shown the phases and steps involved in the proposed evaluation method.

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Phase-A : Screening phase

Step-1: List possible options for re-use
Step-2: Screen listed options by minimum requirements and shortlist options

Phase-B : Comparison Phase

Step-3: List sub-options based on type/source of MRE considered
Step-4: Define changes modifications required for the specific new function
Step-5: Perform Structural Integrity Management assessment considering re-use
Step-6: Shortlist and finalise options for ranking
Step-7: List qualitative and quantitative factors to be considered for comparative assessment of options
Step-8: Rank options based on efforts/cost using MCDM

Phase-C : Calculate Structural Reusability Index

Step-9: Calculate Reusability Index for the shortlisted option

Fig. 4. Steps involved in systematic assessment of re-use options

Following the general methodology as per IEA, a three-phase evaluation is proposed. Table 1 shows the function of these three stages of assessment.

TABLE I FUNCTIONS OF EVALUATION PHASES

	Phase	Description	Functions
1	Phase-A	Screening	Shortlist possible re-use cases (single use/multi-use) based on minimum requirements
2	Phase-B	Comparison	Compare various re-use cases and rank best option. Each of these cases could be an independent use or a combination of different uses related to renewable energy applications. Hence various qualitative and quantitative factors are used for comparison.
3	Phase-C	Structural Reusability Index	Assign a numerical value for the reusability of the structure used as support structure to renewable energy applications. This index is defined in comparison with a new

	platform of same use. Since comparison is for the same use, quantitative values are used.

A. *Phase-A: Screening phase*

This phase considers the shortlisting of options from a wide list of possibilities. The following factors are generally considered when listing the options,

- Renewable energy availability
- Energy requirement for the region
- Power requirement for nearby infrastructure
- Self-powering for alternate use
- Offshore power generation and transmission to shore
- Energy storage
- Associated infrastructure requirements
- etc.

Wind, wave, current, solar etc would be the most probable energy sources available at locations of jacket type structures. Though there could be limited use scenarios for power generation from ocean resources like OTEC and saline gradient which requires more deepwater areas, there could be associated utilities related to energy storage and conversion applications.

Step-1: List possible options for re-use

First step would be to identify the possible options for re-use for the specific asset under consideration. Typical examples of re-use considerations for an offshore platform can be,

- Support structure for wind turbine
- Support structure for wave energy converter
- Support structure for current energy converters
- Support structure for solar energy converters
- Support structure for energy conversion systems (eg. Electrolysis plants)
- Support structure for energy storage systems
- Support structure for energy transmission systems (eg. High voltage direct current, HVDC platforms)
- Support structure for multi-use systems
- Relocation part or full platform to another location for re-use
- etc.

There could be multiple options also based on the type and size of the usages considered including new technologies, systems and multi-use options considered. It is important to identify that the re-use case may be the support structure for a renewable energy device itself of part of the support structure infrastructure required in a field. The support structure infrastructure can also consider housing of various smaller renewable energy devices for self-powering of the platform.

Step-2: Screen listed options by minimum requirements and shortlist options

The first factor which should be considered is the potential of the site for harnessing renewable energy. The re-use platform can be part of a renewable energy farm housing an independent energy device or part of the support system. In case of any consideration of using it as the support structure for any renewable energy technology device, the main factor is the availability of the energy source itself like wind, wave, current etc.

This screening is intended to rule out options which could be prima-face be disregarded based on minimum requirements. The base requirements can also vary time to time depending on the type of energy converter used, emerging technologies and multi-use cases. As the technology advances and new systems comes in place, it is envisaged that the minimum requirements on the feasible extraction of resources shall get modified and improved. Based on various literature available on listing the minimum required parameters for marine renewable energy extraction [8], a typical list of basic criteria for energy converter applications is listed in Fig. 5.

The options not meeting the minimal criteria are removed and shortlisted options are considered in further steps.

Another factor considered in this stage is the feasibility of associated infrastructure for a meaningful utilization of power. This includes factors associated with requirement for power usage in nearby assets, feasibility in conversion, storage and transmission considering requirement and infrastructure on a high-level assessment of needs and options.

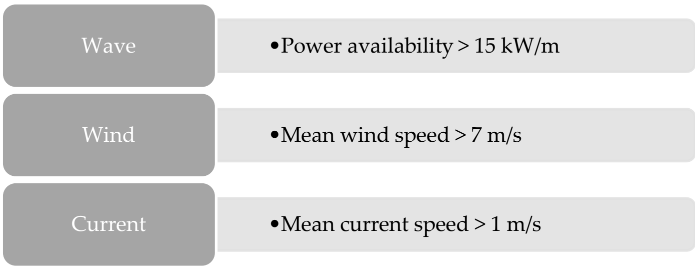

Fig. 5. Proposed minimum value of resources for multi-purpose offshore platforms [8]

B. Phase-B: Comparison phase

This phase considers the shortlisting of options from a wide list of possibilities.

Step-3: List sub options based on type/source of MRE considered

This stage will consider more defined sub options including multi-use cases to be considered including details/of sufficient definition to do engineering evaluation. Typical examples may include,

- Support structure for wind turbine combined with point absorber wave energy converter
- Support structure for energy storage station with new subsea cable system
- Support structure for electrolysis plant and transfer through existing pipeline.

Step-4: Define changes and modifications required for the specific new function

This includes definition of specific functional changes required for platform for the new re-use cases. A more detailed design information also should be developed including the below,

- General arrangement drawing
- Footprint of the Original Equipment Manufacturer (OEM) equipment
- Weights and Centre of Gravity (CoG) information of new facilities
- Local structural modifications for integration of OEM equipment.

Step-5: Perform Structural Integrity Management assessment considering re-use

a. *Condition assessment of existing offshore platform*

The condition of the existing platform will be one of the important factors in considering it for a re-use case. The original design of the platform may be based on some relevant standards (eg. API, ISO) etc. and there are guidelines available for re-use or life extension of old platforms in these standards [9], [10], [11], [12]. Typically, the condition assessment follows the Structural Integrity Management principles starting from data collection, evaluation, formulating a strategy and development of a program for asset management [10].

Data Collection

The platform condition data defines the changes to the characteristic data that have occurred during the operating life of the platform. It is also important that relevant up-to-date inspections are carried out to capture the latest as-is information of the platform. The condition data includes:

- original design data
- in-service inspection data
- damage evaluation data
- corrosion protection data
- structural assessment data
- data related to any changes in design during life
- strengthening/Modification/Repair (SMR) data during life
- above water inspections
- underwater inspections

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Together with this, the data related to the re-use case is also to be collected to establish the new design basis. This includes,

- changes in design criteria
- changes in environmental conditions
- change in location
- changes in assumptions
- relevant information related to expended life
- changes in any design guidelines
- changes in life phases for the re-use case

Data Evaluation

Once the data is collected, evaluation of data is to be carried out based on engineering judgment and industry practices, industry guidelines, methodologies etc.

Structural assessment

The evaluation establishes the requirement for structural assessment to demonstrate fitness-for-purpose. The evaluation of structure shall be based on specific parameters on the risks and consequences of the platform for the remaining life.

- Consequence of platform failure
- Requirement for platform assessment
- Risk of platform failure

The structural assessment methodology can generally follow API [9] which include the below,

- Simple Methods
- Design Level Method
- Ultimate Strength Method
- Alternative Assessment Methods

A modified assessment approach is presented in Fig.6.

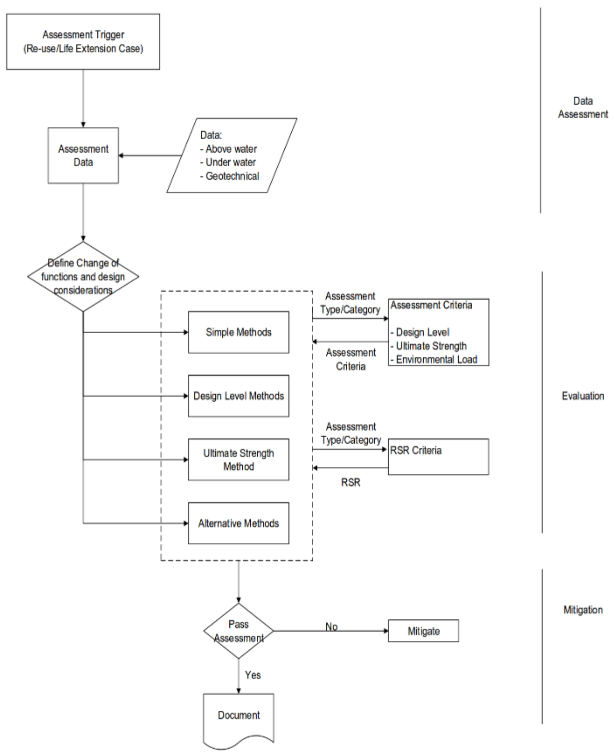

Fig. 6. Modified assessment approach, similar to API [9]

Strategy

Based on data evaluation and assessment, a strategy is developed which include,

- Inspection Planning

- Mitigation Options

Program

The program represents the execution of the detailed scope of work required to complete the activities defined in the SIM strategy. The program may include one or more of the following:

- Above water inspections
- Baseline inspections
- Periodic underwater inspections
- Special inspections
- Strengthening, modification and/or repair (SMR) activities

The structural integrity assessment procedure will also define the requirement of new structural modifications, repairs, strengthening, and inspection requirements required for the extended life during re-use.

Step-6: Shortlist and finalise options for Ranking

Based on the basic engineering assessment carried out, any further options which are considered technically not feasible can be removed and a further shortlist of options can be prepared.

Step-7: List qualitative and quantitative factors to be considered for comparative assessment of options

The shortlisted re-use cases may be distinctive in nature and the associated factors vary in nature and hence a direct comparison would normally difficult. It is hence important to define a system for comparison, analysing and ranking of options available. This comparison should be based on various qualitative and quantitative factors associated with the re-use scenarios.

IEA-OES Technology Collaboration Programme (TCP), has carried out a work under "task 12" and published a guideline for technology evaluation, and support decision making associated with technology evaluation of Ocean Energy Technologies covering the full technology development from concept creation to commercial readiness [7]. This also recommends 10 specific evaluation areas to be considered in the process. These were developed based on an iterative process from a series of workshops involving various stakeholders in the energy sector including public, private investors and technology developers.

The qualitative and quantitative factors proposed in this evaluation system also considers the same methodology and evaluation areas, however with some changes considering the different wide variety of possibilities including energy production, storage and transmission applications and multi-use cases with a combination of these. The changes are listed below,

Under the group of "Technology Effectiveness", instead of the "Power Capture" and "Power Conversion" factors proposed in IEC, an overall "Efficiency" factor is considered in this methodology which is considered as an average value of total power generation, storage and transmission using the support structure. "Controllability" as mentioned in IEC is more apt for comparison of sub systems in an energy production system. Hence it is considered together with the factor "Reliability" in this method. Also, and additional factor of "Technology Maturity" is also considered. This evaluation shall be based on the "Technology Readiness level" (TRL) as generally used to represent the stage of technology development. The definition of the areas of evaluation is suitably modified in the context of the evaluation of systems and use of support structures and is presented in Table 2. Here a "system" is defined as the combination of the power generation, storage, and transmission equipment together with the support structures which fulfils the desired level of functional requirements.

TABLE 2 DEFINITION OF ATTRIBUTES

	Attributes	Definition
1	Maturity of technology	• describes the readiness of the technology and its proven track record in industrial application • TRL scale is used to define the maturity level

2	Efficiency	• the comparative efficiency of the use related to power generation, storage, and transmission. Two factors are used as relevant • Efficiency compared as Total power (Power generated + stored + transmitted)/Total Weight of support structure for multi-purpose use • LCOE can be compared for power generation using different technologies
3	Reliability	• the probability of the energy production, storage and transmission systems performing its intended functions for the envisaged lifetime • includes average power availability over the design life, design life, controllability
4	Maintainability	• ability to be retained in, or restored to a state to perform as required of the support systems, under given conditions of the energy production, storage, and transmission systems
5	Survivability	• measure of the ability of the system to experience a survival event outside the expected design conditions, and return to an acceptable level of operation after the event have passed. • Could be associated with foundation adequacy, substructure adequacy, design life and probability level of considered survival scenario
6	Installability	• ease with which the system can be prepared, deployed, and commissioned, resulting in a condition of operational readiness including modifications and changes
7	Manufacturability	• ability for the system to be manufactured quickly, cheaply and with minimum waste, and therefore its compatibility with the supply

		chain's capability, readiness, and maturity
8	Disposability	• ease of disposal of any waste with minimal impact to nature and life. • This also considers the waste generated during conversion, emissions, environmental impacts during changes or conversion and ease of decommissioning and any further re-use scenarios for the full system during the new lifecycle considered
9	Affordability	• related to the costs involved in the new lifecycle considered for the re-use case of the system. • The cost aspects are grouped and compared in terms of CAPEX, OPEX, decommissioning costs and LCOE
10	Environmental Acceptability	• the ability to make effective use of natural resources, reduce the risks and harms to the operating environment, comply with the relevant regulations, and generate induced benefits whenever possible. • Risks related to ecological risks, marine pollution, long term impacts on flora and fauna, changes to the seabed and its impact on ecosystem • usually identified considering studies like Life Cycle Assessment (LCA) and Environmental Impact Assessment (EIA).
11	Social Acceptance	• factors related to the overall acceptance by public and mitigation of risks related to the effects on public, other users, and any legal risks

Following the factors as per IEC and changes as proposed above, a revised set of areas is developed for comparative assessment and its hierarchy is presented in Fig. 7.

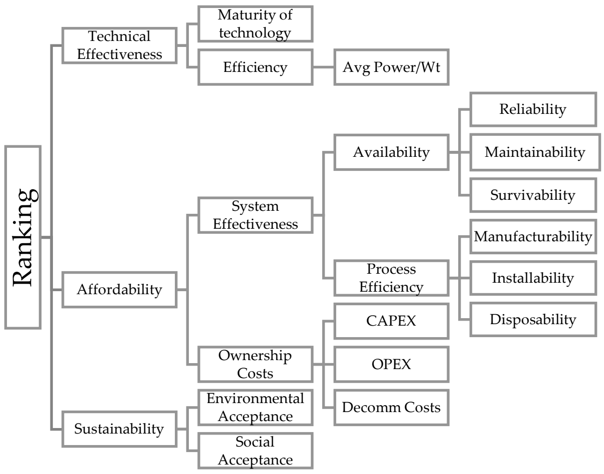

Fig. 7. Suggested qualitative/quantitative factors for comparison and its hierarchy

Step-8: Rank options based on efforts/cost using MCDM

Once the screening is completed and a shortlisted option is available, now the options are to be compared and ranked. An expert system is developed based on MCDM methodology for the comparison and ranking of the options.

Muti Criteria Decision Making (MCDM)

MCDM is a scientific method of decision-making process from a set of criteria. MCDM helps in identifying the most suitable decision form a set of defined attributes and criteria. A wide variety of decision-making methodologies are in practice and is used in different sectors and applications including engineering. From literature survey [13], a list of prominent MCDM methods identified are,

- Multi-Attribute Utility Theory,
- Analytic Hierarchy Process,
- Fuzzy Set Theory,
- Case-based Reasoning,
- Data Envelopment Analysis,
- Simple Multi-Attribute Rating Technique,
- Goal Programming,
- ELECTRE,
- PROMETHEE,
- Simple Additive Weighting

Many MCDM methods have evolved over time to apply to various types of applications. Many times, the decision making can be complex due to the variety of criteria to be considered, the number of options available, relative importance of criteria and uncertainty of several criteria etc. New and new tools related to typical applications are also developed using hybrid MCDM methods.

Qualitative MCDM methodology DEX

DEX (Decision expert) is a qualitative multi-attribute decision modelling methodology that integrates multi-criteria decision modelling with rule-based expert systems. The method was conceived in 1979 in Durham, UK, pioneered by Efstathiou and Rajkovič. [14]. It was based on the MCDM method “fuzzy set theory” however using words rather than numbers in decision models. From the inception, continuous development has happened in the method and this method has been used in hundreds of practical decision-making studies.[15]. The DEX is a decision-making methodology where alternatives are evaluated and analyzed by decomposition of the decision problem into smaller, less complex subproblems. The decomposition is represented by a hierarchy of attributes.

Expert system for Comparison of Qualitative Factors for re-using Fixed Offshore Platform as Support structures

DEXiWin [16] is a desktop computer program aimed at developing and using hierarchical qualitative multi-criteria decision models according to the method DEX. The expert system is generated in DEXiWin where the problem is modelled. The model has attributes, a defined hierarchy defined based on Fig. 7,

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scales and weightages defined for attributes. Decision rules are defined for calculate the score/rank of higher-level attributes. For the proposed expert system, weightages are considered for the qualitative factors used to incorporate relative importance of the factors used. The weightages are also generally developed with experience and inputs from expert groups. The expert system has 13 basic attributes and 21 aggregate attributes. The attributes description and model tree are as shown in Fig. 8.

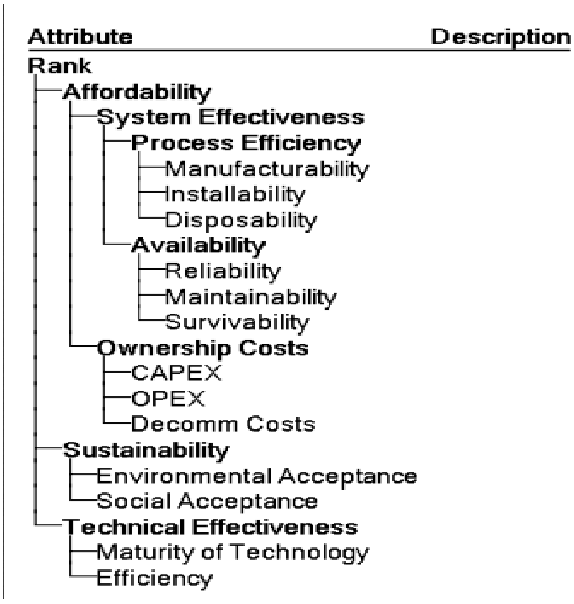
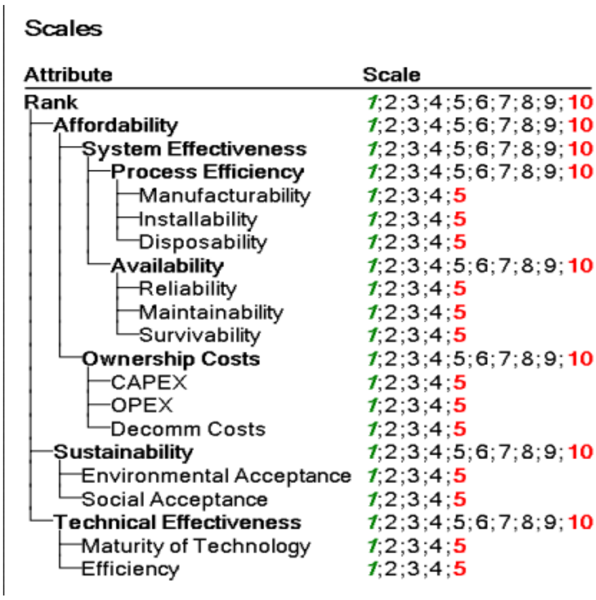


Fig. 8. Expert System: Attribute description and model tree

The scales for individual basic attributes are define on a numerical scale of 1 to 5 where, 1 represents the highest score/rank and 5 represents the worst rank when comparing the options. The higher order attributes including the final "Ranking" attribute follow a scale of 1 to 10 where 1 represents the highest score/rank and 10 represents the worst rank when comparing the options. The scale description is as shown in Fig. 9. To capture the relative importance of the individual attributes, weightages are assigned for the attributes. The weightages used are as in Fig. 10. Once the options are evaluated and ranked, it can then be compared with a new platform of same function using the Structural Reusability Index.



Scales

Attribute	Scale
Rank	1;2;3;4;5;6;7;8;9;10
Affordability	1;2;3;4;5;6;7;8;9;10
System Effectiveness	1;2;3;4;5;6;7;8;9;10
Process Efficiency	1;2;3;4;5;6;7;8;9;10
Manufacturability	1;2;3;4;5
Installability	1;2;3;4;5
Disposability	1;2;3;4;5
Availability	1;2;3;4;5;6;7;8;9;10
Reliability	1;2;3;4;5
Maintainability	1;2;3;4;5
Survivability	1;2;3;4;5
Ownership Costs	1;2;3;4;5;6;7;8;9;10
CAPEX	1;2;3;4;5
OPEX	1;2;3;4;5
Decomm Costs	1;2;3;4;5
Sustainability	1;2;3;4;5;6;7;8;9;10
Environmental Acceptance	1;2;3;4;5
Social Acceptance	1;2;3;4;5
Technical Effectiveness	1;2;3;4;5;6;7;8;9;10
Maturity of Technology	1;2;3;4;5
Efficiency	1;2;3;4;5

Fig. 9. Expert System: Attribute score/rank scale

Average weights

Attribute	Local	Global	Loc.norm.	Glob.norm.
Rank				
Affordability	60	60	60	60
System Effectiveness	60	36	60	36
Process Efficiency	50	18	50	18
Manufacturability	33	6	33	6
Installability	33	6	33	6
Disposability	33	6	33	6
Availability	50	18	50	18
Reliability	33	6	33	6
Maintainability	33	6	33	6
Survivability	33	6	33	6
Ownership Costs	40	24	40	24
CAPEX	57	14	57	14
OPEX	21	5	21	5
Decomm Costs	22	5	22	5
Sustainability	10	10	10	10
Environmental Acceptance	66	7	66	7
Social Acceptance	34	3	34	3
Technical Effectiveness	30	30	30	30
Maturity of Technology	30	9	30	9
Efficiency	70	21	70	21

Fig. 10. Expert System: Weightage of attributes

Step-9: Calculate Reusability Index for the shortlisted option

Concept of Structural Re-usability Index

To have a common ground for comparison of various options considered, the concept of "Structural Reusability Index" is introduced. The concept of this index is to have an indication of suitability of a considered re-use option in a numerical value compared to a new platform.

Index is calculated by comparing the efforts required for a re-use case with a new platform of same function. "Effort" is defined as a combination of cost, time, resources and hence is not purely defined in terms of cost, however considered as a representative number. The efforts required for each life phase activity is defined as 1 for a new platform case. Accordingly, the value for the re-use case is compared with the new platform case and assigned a specific number. For example, in case a specific re-use case requires only 50% of the efforts for a specific activity when compared to a new platform, the score for that specific activity will be 0.5 for the re-use case.

Life phases of assets

The life cycle of a new platform includes the following,

- Concept development
- FEED Eng
- Detail Engg
- Procurement
- Construction
- Loadout
- Sea transportation
- Site preparations
- Installation
- Commissioning
- Post installation surveys
- Inspections & Maintenance over life
- Decommissioning

Each of the above phase can be subdivided into various sub activities for the ease of defining the efforts. The efforts required for each of these are compared for a re-use case with that with the case of a new platform using a weighted average method.

Weightages

Considering the extend of efforts involved in the life phases a weightage can be assigned by the user. These weightages are developed by industry experience and study of associated costs for similar infrastructure developments.

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Structural Re-usability Index (SRI)

Effort scale represents the extend of efforts and ranges from numerical values 0 to infinity, where zero specifies nil efforts and infinity specifies extreme high efforts for making the platform ready for the intended use.

The total efforts of a re-use case are then calculated as weighted average of the individual activities/sub activities

$$Efforts = \frac{\sum\ (weight\ \times score)}{\sum\ weight}$$

Then the Structural Reusability Index (SRI) is defined as,

$$\text{Structural Reusability Index (SRI)} = \frac{1}{Efforts}$$

The following are the features of the proposed SRI,

- Index is a scale from 0 to infinity
- Theoretical best index value is infinity. This means a case where the platform can be re-used for the new function with zero efforts.
- Theoretical worst index value is zero. This means a case where the platform cannot be re-used even with maximum efforts.
- An index value of 1 means the re-use will require the same efforts as for a new platform of the same function.

HYPOTHETICAL CASE-STUDY

A hypothetical re-use case and its evaluation is carried out here. An oil and gas platform used as a wellhead platform considered for decommissioning is considered for re-use. Below are the basic parameters of the platform at present

- Function: Wellhead platform
- Configuration: 4 Legged jacket with pile foundation and topside deck
- Life spent as WHP: 25 years
- Distance from shore: 25 nautical miles
- Associated Infrastructure available: an existing oil pipeline connection to shore, a subsea cable to nearby oil and gas platform
- Need scenarios: An offshore wind farm is planned near to the location, other oil & gas platforms which requires additional power is available nearby, space available for floating solar plant nearby or in conjunction with the wind farm planned.

A. Evaluation using Expert System

Following the stages as proposed in the systematic approach, the options initially considered are,

- As support structure for an offshore wind turbine and use the power generated for nearby O&G assets
- As support structure for wave energy converters and use the power generated for nearby O&G assets
- As support structure for ocean current energy converters and use the power generated for nearby O&G assets
- As support structure for combination of wave energy converters and solar panels and use the power generated for nearby O&G assets
- As support structure for a H_2 electrolysis plant for converting the energy generated from nearby floating solar farm and wind farm
- As support structure for a HVDC platform for converting the energy generated from nearby offshore wind farm and transmission to shore

Based on the steps involved in the evaluation, the following options were shortlisted for further steps,

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1) Re-use Case-1: Housing offshore wind turbine of 5MW and use the power generated for nearby O&G assets.
The wind turbine specifications are as below,
- Turbine : 5 MW
- Rotor diameter: 126 m
- No of blades: 3
- Hub height : 82 m
- Capacity factor : 0.4
- Average Energy production: 17500 MWh/year
- Topside weight: 1000 T
- Power transmission by existing subsea cable

2) Re-use Case-2:Using the platform as support structure for wave energy converters, store energy on deck and use the power generated for nearby O&G assets
- Type: Point absorber type
- Floater width: 5 m
- Rating : 300 kW (6 floats at 50 kW per buoy)
- Capacity factor : 0.2
- Average Energy production: 525 MWh/year
- Storing energy on topside using battery packs
- Energy storage : 750 MWh/year
- Topside weight : 1500 T

3) Re-use Case-3: Using the platform as support structure for combination of wave energy converters and solar panels and use the power generated for nearby O&G assets
- Type: Point absorber type
- Floater width: 5 m
- Rating: 300 kW (6 floats at 50 kW per buoy)
- Capacity factor: 0.2
- Average Energy production: 525 MWh/year
- Deck space considered for solar panels = 400 m2
- Average Energy production: 120 MWh/year
- Topside weight : 1200 T

4) Re-use Case-4: Using the platform as support structure for a Hydrogen electrolysis plant for converting the energy generated from a nearby floating solar farm
- Electrolyser Rating: 50 kWh/kg
- Plant Rating: 100MW (at 800 kg/h H_2 production)
- Average Energy conversion: 400,000 MWh/year
- Topside weight: 3500 T
- Foundation: Additional strengthening required

After completing a FEED level engineering assessment and completing up to step-7 of the process, these are used in Expert system for comparison and ranking as per MCDM. Comparison of options using the Expert System and the final ranking is as shown in Fig. 11 and Fig. 12.

Alternatives

Attribute	Reuse Case-1	Reuse Case-2	Reuse Case-3	Reuse Case-4
Manufacturability	2	3	2	4
Installability	5	1	2	3
Disposability	3	2	1	5
Reliability	3	4	3	1
Maintainability	5	3	2	1
Survivability	3	2	1	5
CAPEX	5	2	1	4
OPEX	5	1	2	3
Decomm Costs	5	1	2	3
Environmental Acceptance	5	2	1	3
Social Acceptance	3	2	1	1
Maturity of Technology	1	5	4	1
Efficiency	2	4	5	1

Fig. 11. Expert System: Score/rank of individual attributes

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Evaluation results

Attribute	Reuse Case-1	Reuse Case-2	Reuse Case-3	Reuse Case-4
Rank	7	6	5	4
Affordability	8	5	3	6
System Effectiveness	3	3	2	4
Process Efficiency	3	2	2	6
Manufacturability	2	3	2	4
Installability	5	1	2	3
Disposability	3	2	1	5
Availability	3	4	2	2
Reliability	3	4	3	1
Maintainability	5	3	2	1
Survivability	3	2	1	5
Ownership Costs	10	2	1	5
CAPEX	5	2	1	4
OPEX	5	1	2	3
Decomm Costs	5	1	2	3
Sustainability	10	2	1	2
Environmental Acceptance	5	2	1	3
Social Acceptance	3	2	1	1
Technical Effectiveness	3	9	10	1
Maturity of Technology	1	5	4	1
Efficiency	2	4	5	1

Fig. 12. Expert System: Final ranking of re-use options considered

B. Structural Reusability Index (SRI)

Reuse Case-4 is further selected to calculate the Structural Reusability Index to compare with the efforts required for a new platform of the same function. The effort score for Reuse Case-4 is presented in Table 3.

TABLE 3 EFFORT SCORE FOR RE-USE CASE-4

Life Phase	**Weightage (%)**	**Efforts**		
		Effort score (New Platform)	Effort Score (Re-use Case)	Description of Efforts
Concept development	0.5%	1.0	0.80	Efforts for re-use case is limited for the definition of facilities and requirements related to the new functions
FEED Eng	1.5%	1.0	0.40	Engineering related to life extension, modification and upgrade for new functions.
Detail Engg	3.0%	1.0	0.30	Engineering related to life extension, modification and upgrade for new functions.
Procurement	20.0%	1.0	0.10	Procurement of new items related to energy production. Physical changes, repairs, strengthening related to integration, modifications and life extensions.
Construction	10.0%	1.0	0.10	Construction of new items related to energy production. Strengthening structures related to integration, modifications and life extensions.
Loadout	1.0%	1.0	0.05	Loadout of new items to be installed
Seatransportation	3.0%	1.0	0.05	Sea transportation of new items to be installed
Site preparations	8.0%	1.0	0.10	Repair works, removal of obsolete items, surveys
Installation	15.0%	1.0	0.50	Demolition, repairs and modifications primarily offshore work
Commissioning	5.0%	1.0	0.20	Commissioning of new functions
Post installation surveys	3.0%	1.0	0.10	Surveys after installation

Inspections & Maintenance over life	15.0%	1.0	3.00	For new facilities as per prescribed inspection regime for remaining life and increased inspection requirement for support structures
Decommissioning	15.0%	1.0	1.30	At end of new specified life.

$$Efforts = \frac{\sum (weight \times score)}{\sum weight}$$

$$Efforts = 0.79$$

$$\text{Structural Reusability Index (SRI)} = \frac{1}{Efforts}$$

SRI = 1/0.79 = 1.26

This means that the re-use case needs lesser efforts than a new platform and in numerical terms, 26% better than a new platform. This shows a promising case of re-use rather than going for a new platform for same function.

DISCUSSIONS

A framework for systematic evaluation of various options when existing offshore fixed type platforms are considered for renewable energy re-use applications is presented here. This includes listing of various renewable energy applications, listing of various qualitative and quantitative factors and finally calculating a Structural Reusability Index (SRI) for the option considered. This procedure is expected to help the stakeholders in decision making. An expert system based on MCDM is also developed based on computer program DexiWin. The factors involved in the framework will need to be updated based on developments in the industry and the weightages considered in comparison and ranking also may vary based on user preferences and policies. Accordingly, the expert system also will expect to have periodical updates.

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