**Proceedings of EWTEC 2021**

The 14th European Wave and Tidal Energy Conference was held from 5-9 September 2021 at the University of Plymouth. For the first time, in response to the global pandemic, EWTEC was held in a hybrid format, allowing attendees to present online as well as in person. There were 12 different thematic tracks:

- Wave resource characterization
- Wave hydrodynamic modelling
- Wave device development and testing
- Tidal resource characterization
- Tidal hydrodynamic modelling
- Tidal device development and testing
- Structural mechanics: materials, fatigue, loadings
- Station-keeping, moorings and foundations
- Operations and maintenance
- Grid integration, power take-off and control
- Environmental impact and appraisal
- Economical, social, legal and political aspects of ocean energy

From the 403 abstracts initially submitted, 236 full papers were finally selected by a peer-review process, during which 48 Track Directors requested 963 single blind reviews and 427 reviews were finally carried out. These papers comprise the present proceedings, totalling 1952 pages.

This USB flash drive contains the searchable conference proceedings.

On behalf of the EWTEC Committee, I would like once again to warmly thank all the reviewers and Track Directors for their essential and voluntary work, and all authors for their contribution to the scientific content of the 14th EWTEC.

I would also like to sincerely thank our Sponsors for their valuable support to the conference.

**Professor Deborah Greaves**

Chair of EWTEC 2021

1 September 2021


ISSN 2309-1983

## Local Organizing Committee

EWTEC 2021 is organized by the University of Plymouth.
Conference Chair: Professor Deborah Greaves OBE FREng FICE FRINA Head of School of Engineering, Computing and Mathematics, Faculty of Science and Engineering, University of Plymouth, UK
Rich Avery, University of Plymouth, UK
Dr Scott Brown, University of Plymouth, UK
Dr Keri Collins, University of Plymouth, UK
Professor Daniel Conley, University of Plymouth, UK
Barbara Fuller, University of Plymouth, UK
Alison Goodwin, University of Plymouth, UK
Dr Martyn Hann, University of Plymouth, UK
Kirsty Henderson, University of Plymouth, UK
Katie Rhodes, University of Plymouth, UK

## Technical Committee

| | |
|---|---|
| Prof. AbuBakr Bahaj | University of Southampton, UK |
| Prof. Jesús M. Blanco | University of the Basque Country (UPV/EHU), Spain |
| Prof. Sergio Camporeale | Politecnico di Bari, Italy |
| Dr Claes Eskilsson | Aalborg University, Denmark |
| Prof. António Falcão | Instituto Superior Técnico, Portugal |
| Dr Peter Frigaard | Aalborg University, Denmark |
| Prof. Luis Gato | Instituto Superior Técnico, Portugal |
| Prof. Deborah Greaves | Plymouth University, UK |
| Dr Cameron Johnstone | University of Strathclyde, UK |
| Prof. Tony Lewis | University College Cork, Ireland |
| Dr Claudio Lugni | Marinteknisk senter, NTNU Tyholt, Norway |
| Dr Christophe Maisondieu | Ifremer, France |
| Prof. Tim O'Doherty | Cardiff University, UK |
| Dr Anne Marie O'Hagan | MaREI Centre, University College Cork, Ireland |
| Dr Stephanie Ordóñez-Sánchez | University of Strathclyde, UK |
| Prof. Cesar Vidal Pascual | University of Cantabria, Spain |
| Prof. John Ringwood | Maynooth University, Ireland |
| Prof. António Sarmento | Wave Energy Centre, Portugal |
| Prof. Jan Sundberg | Uppsala University, Sweden |
| Dr Irina Temiz | Uppsala University, Sweden |
| Dr Gareth Thomas | University College Cork, Ireland |
| Prof. Diego Vicinanza | Università degli Studi della Campania “Luigi Vanvitelli”, Italy |

## Online platform and proceedings

Compiled by Dr. Luke Blunden (Energy and Climate Change Division at the University of Southampton)

## Track Directors

| | |
|---|---|
| Martin Attrill | University of Plymouth, UK |
| Arianna Azzellino | Politecnico di Milano, IT |

| | |
|---|---|
| AbuBakr Bahaj | University of Southampton, UK |
| James Benhin | Plymouth University, UK |
| Giovanni Besio | University of Genova, IT |
| Luke Blunden | University of Southampton, |
| Scott Brown | University of Plymouth, UK |
| Sergio Camporeale | Polytechnic of Bari, IT |
| Shanshan Cheng | University of Plymouth, UK |
| Elena Ciappi | CNR-INSEAN, IT |
| Danny Coles | University of Plymouth, UK |
| Keri Collins | University of Plymouth, UK |
| Daniel Conley | University of Plymouth, UK |
| Andrea Copping | Pacific Northwest National Laboratory, US |
| Claes Eskilsson | Aalborg University, DK |
| Peter Frigaard | Aalborg University, DK |
| Deborah Greaves | University of Plymouth, UK |
| Martyn Hann | University of Plymouth, UK |
| Joao Henriques | IDMEC/Instituto Superior Tecnico, Universidade de Lisboa, PT |
| Gregorio Iglesias | University College Cork, IE |
| Siya Jin | University of Plymouth, UK |
| Cameron Johnstone | Strathclyde University, UK |
| Tony Lewis | University College Cork, IE |
| Claudio Lugni | NTNU, NO |
| Christophe Maisondieu | IFREMER, FR |
| Allan Mason-Jones | Cardiff University, UK |
| Maozhou Meng | University of Plymouth, UK |
| Simone Michele | University of Plymouth, UK |
| Jon Miles | University of Plymouth, UK |
| Tim O'Doherty | Cardiff University, UK |
| Stephanie Ordoñez-Sánchez | University of Strathclyde, UK |
| Edward Ransley | University of Plymouth, UK |
| John Ringwood | Maynooth University, IE |
| Alessandra Romolo | Mediterranea University of Reggio Calabria, IT |
| John Ashlin Samuel | University of Plymouth, UK |
| Sanjay Sharma | University of Plymouth, UK |
| Emma Sheehan | University of Plymouth, UK |
| David Simmonds | University of Plymouth, UK |
| Tim Stallard | University of Manchester, UK |

ISSN 2309-1983

**Sponsors**

WESE
WAVE ENERGY
IN SOUTHERN EUROPE

CATAPULT
Offshore Renewable Energy

Supergen
Offshore
Renewable
Energy


ISSN 2309-1983

# On the relevant, realistic and effective criteria for wave energy technology assessment – a dialogue with EWTEC2019 paper ID 1426

Pablo Ruiz-Minguela, Jesus M. Blanco, Vincenzo Nava

*Abstract*— **The development of cost-effective wave energy technologies is a long and arduous process that entails numerous challenges. Many design decisions must be taken from the early development stages. A common evaluation framework based on objectivised criteria can contribute to keeping the right direction in the development process of wave energy technologies.**

**Building upon the well-established Systems Engineering (SE) body of knowledge, this paper aims to address a significant part of the requirements that guides the specification of wave energy technology assessment criteria, metrics and tools.**

**SE approaches such as the design domains framework, the multi-criteria aggregation logic, the fundamental relationships and utility functions can be used at different levels of system definition, technology maturity and markets to ensure a fully consistent, comparable and traceable assessment. Huge benefits can be obtained from the application of knowledge in earlier stages of wave technology development.**

**After presenting and discussing the requirements for wave technology performance assessment, the paper draws some conclusions and propose future research work.**

*Keywords*—**Wave energy, assessment criteria, metrics, Systems Engineering (SE), Design domains, Technology Readiness Levels (TRL), aggregation structure, utility functions.**

## I. Introduction

EVALUATION of technology performance is a continuous activity that should take place at all stages of the development process [1]. A commonly agreed evaluation framework can bring significant benefits for all wave energy stakeholders, including increased clarity, consistency and direction in the development [2]. Early design decisions based on objectivised criteria are key to lower development uncertainties, cost and time.

Wave energy technology development, evaluation and selection is moving progressively from simplified approaches based on technology maturity and cost to more holistic performance measures [3]. Selection at intermediate stages contributes to reducing the risks and uncertainties. Iterations at low Technology Readiness Levels (TRLs) until the desired performance is achieved also contributes to more cost-effective designs.

In the last EWTEC2019, Weber et al [4] collated a comprehensive list of considerations to characterise the requirements for relevant, realistic and effective assessment criteria of wave energy technology performance. These considerations were framed in the form of questions to show possible choices that can be made in the specification of the assessment criteria and motivate clear decisions. This paper aims to address a significant part of the requirements that guides the specification of wave energy technology assessment criteria, metrics and tools. The core contribution of the paper is to provide some answers based on the application of sound System Engineering (SE) principles.

SE approaches require that the design information is arranged in different design domains and propagated across domains to ensure full traceability of both design requirements and evaluation metrics [5]. Inherent to the evaluation process is the understanding of complex interactions and the quantification of relationships [6]. A consistent application of SE will add clarity to the specification of requirements for assessment criteria and metrics.

Building upon the well-established SE body of knowledge, the paper presents guidelines related to the targeted system and technology maturity; deployment context, market and applications; evaluation criteria hierarchy, quantification and thresholds; fundamental limits and achievability; evaluation effort and relevance; validation and supporting tools.

Having presented these guidelines for wave energy technology assessment criteria, metrics and tools, the paper draws some overall conclusions and propose future research work.

This paper is an original submission to EWTEC 2020, ID 1965 under the conference track "Wave device development and testing".

P. Ruiz-Minguela is Head of Wave Energy at TECNALIA, Basque Research and Technology Alliance (BRTA), Astondo Bidea, Edificio 700, E-48160 Derio, Bizkaia, Spain (e-mail: jpablo.ruiz-minguela@tecnalia.com).

J.M. Blanco is Senior Lecturer at University of the Basque Country, Faculty of Engineering, Plaza Ingeniero Torres Quevedo, 1, E-48013 Bilbao, Spain (e-mail: jesusmaria.blanco@ehu.eus)

V. Nava is Senior Researcher at TECNALIA, Basque Research and Technology Alliance (BRTA), Astondo Bidea, Edificio 700, E-48160 Derio, Bizkaia, Spain (e-mail: vincenzo.nava@tecnalia.com).

  

expectations. Actually, the relative time and cost to be invested in technology assessment should be higher during the initial concept and design stages.

Although the expected accuracy range will be narrowed as the wave energy technology moves to later development stages, it is important to note that decisions always need to be made under some degree of uncertainty. The modelling technique, threshold and target values should be carefully chosen to match the development stage requirements. Allocation of assessment criteria is quite challenging, but thresholds can be suggested from existing benchmarks and targets assigned considering both the most innovative features of the technology and theoretical limits. Fundamental relationships can contribute to estimating the threshold values for the key design parameters of an embodiment.

The tool implementation should be flexible to let the user represent the market application. Calibration with technology developers' data will increase confidence in the projected evaluation results. The requirements for a holistic wave energy technology performance assessment have been implemented in DTOceanPlus, a freely available open-source software that has been demonstrated with data from real case projects.

Future work should extend the international consensus on key metrics in the different levels of hierarchy, their weightings, aggregation logic and benchmark values.

## ACKNOWLEDGEMENT

This work was partially supported by the European Union's Horizon 2020 research and innovation programme under grant agreement no. 785921, project DTOceanPlus (Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment). Authors would like to thank the Basque Government through the research groups IT1314-19 and GIU19/029.

## REFERENCES

[1] INCOSE, Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities, 4.0 ed., Hoboken, NJ: John Wiley and Sons, Inc, 2015.

[2] J. Hodges, J. Henderson, L. Ruedy, M. Soede, J. Weber, P. Ruiz-Minguela, H. Jeffrey, E. Bannon, M. Holland, R. MacIver, D. Hume, J. L. Villate and T. Ramsey, "An International Evaluation and Guidance Framework for Ocean Energy Technology," IEA-OES, 2021.

[3] P. Ruiz-Minguela, V. Nava, J. Hodges and J. Blanco, "Review of Systems Engineering (SE) Methods and Their Application to Wave Energy Technology Development," *J. Mar. Sci. Eng.*, vol. 8, no. 823, 2020.

[4] J. Weber, R. Costello, K. Nielsen and J. Roberts, "Requirements for Realistic and Effective Wave Energy Technology Performance Assessment Criteria and Metrics," in *13th European Wave and Tidal Energy Conference*, Naples, 2019.

[5] A. M. Farid and N. P. Suh, Axiomatic design in large systems: complex products, buildings and manufacturing systems, Springer International Publishing, 2016.

[6] J. E. Bartolomei, D. E. Hastings, R. de Neufville and D. H. Rhodes, "Engineering Systems Multiple-Domain Matrix: An Organizing Framework for Modeling Large-Scale Complex Systems," *Systems Engineering*, vol. 15, no. 1, pp. 41-61, 2012.

[7] B. Yannou, Analyse fonctionnelle et analyse de la valeur, 1997.

[8] C. S. Wasson, System Engineering Analysis, Design, and Development: Concepts, Principles, and Practices, 2nd ed., Hoboken, NJ: Wiley, 2016.

[9] S. Burge, "A Functional Approach to Quality Function Deployment," Burge Hughes Walsh, 2007.

[10] R. Haberfellner, O. de Weck, E. Fricke and S. Vössner, Systems Engineering: Fundamentals and Applications, Cham: Birkhäuser, Springer Nature Switzerland AG, 2019.

[11] J. Chevallier and R. M. Marshall, "SpecRight: Writing correctly requirements, produce product specification and requirement justification file," in *INCOSE International Symposium*, Toulouse, 2004.

[12] L. Dahai, Systems Engineering: Design Principles and Models, Boca Raton, FL: CRC Press, 2016.

[13] J. Kaufman and R. Woodhead, Stimulating innovation in products and services: with function analysis and mapping, Hoboken, New Jersey: John Wiley & Sons, Inc., 2006.

[14] G. J. Roedler and C. Jones, "Technical Measurement: A Collaborative Project of PSM, INCOSE, and Industry," INCOSE-TP-2003-020-01, 2005.

[15] J. J. Dujmovic, "A Method for Evaluation and Selection of Complex Hardware and Software Systems," in *Procs. 22nd International Conference for the Resource Management and Performance Evaluation of Enterprise Computer Systems*, Turnersville, New Jersey, 1996.

[16] T. Saaty, The Analytic Hierarchy Process, New York, NY: McGraw-Hill, 1980.

[17] S. Mizuno and Y. Akao, QFD: The Customer-driven Approach to Quality, Tokyo: Asian Productivity Organization, 1994.

[18] V. Belton and T. J. Stewart, Multiple Criteria Decision Analysis: An Integrated Approach, Kluwer Academic Publishers, 2002.

[19] DTOceanPlus, "Advanced design tools for ocean energy systems innovation, development and deployment," 2018-2021. [Online]. Available: https://www.dtoceanplus.eu/.

[20] W. J. Fabrycky and B. S. Blanchard, Life-Cycle Cost and Economic Analysis, NJ: Prentice Hall, 1991.

[21] J. Fitzgerald and B. Bolund, "Technology Readiness for Wave Energy Projects; ESB and Vattenfall classification system," in *4th International Conference on Ocean Energy*, Dublin, Ireland, 2012.

[22] ASTM International, "E2516-11 Standard Classification for Cost Estimate Classification System," PA, USA, 2011.

[23] A. M. Trueworthy, B. L. DuPont, B. D. Maurer and R. J. Cavagnaro, "A set-based design approach for the design of high-performance wave energy converters," in *Proceedings of the 13th European Tidal and Wave Energy Conference*, Naples, Italy, 2019.

[24] M. Previsic, O. Siddiqui and R. Bedard, "Economic Assessment Methodology for Offshore Wave Power Plants," EPRI, 2014.

[25] A. Babarit, "A database of capture width ratio of wave energy converters," *Renewable Energy, Elsevier*, vol. 80, pp. 610-628, 2015.

[26] TC 114, "Marine energy - Wave, tidal and other water current converters - Part 103: Guidelines for the early stage development of wave energy converters –Best practices and recommended procedures for the testing of pre-prototype devices," IEC, 2018.