**SANDIA REPORT**
SAND2016-8612
Unlimited Release
September 2016

# Technology Performance Level (TPL) Scoring Tool

Jochem Weber (PI), Jesse Roberts (co-PI), Ronan Costello, Diana Bull, Aurelien Babarit, Kim Neilson, Claudio Bittencourt, Ben Kennedy

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.



Sandia National Laboratories

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.



Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Facsimile: (865) 576-5728
E-Mail: reports@osti.gov
Online ordering: http://www.osti.gov/scitech

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Rd
Alexandria, VA 22312

Telephone: (800) 553-6847
Facsimile: (703) 605-6900
E-Mail: orders@ntis.gov
Online order: http://www.ntis.gov/search

SAND2016-8612
Unlimited Release
September 2016

# Technology Performance Level (TPL) Scoring Tool

Jochem Weber (PI)
National Renewable Energy Laboratory, Golden CO USA

Jesse Roberts (co-PI)
Sandia National Laboratories, Albuquerque NM USA

Ronan Costello
Wave Venture, Cornwall, UK

Diana Bull
Sandia National Laboratories, Albuquerque NM USA

Aurélien Babarit
LHEEA Lab., Ecole Centrale de Nantes – CNRS, Nantes, France

Kim Neilson
Ramboll, Copenhagen, Denmark

Claudio Bittencourt
DNV GL, London, UK

Ben Kennedy
Wave Venture, Cornwall, UK

Sandia National Laboratories
P.O. Box 5800
Albuquerque, New Mexico 87185-MS1124

# ACKNOWLEDGMENTS

This study was supported by the Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), Wind and Water Power Technologies Office (WWPTO).

## Contents

# 1 INTRODUCTION:

Three different ways of combining scores are used in the revised formulation. These are **arithmetic mean, geometric mean** and **multiplication with normalisation**.

**Arithmetic mean** is used when combining scores that measure similar attributes, e.g. used for combining costs. The arithmetic mean has the property that it is similar to a logical OR, e.g. when combining costs it does not matter what the individual costs are only what the combined cost is.

**Geometric mean** and **Multiplication** are used when combining scores that measure disparate attributes.

**Multiplication** is similar to a logical AND, it is used to combine 'must haves.' As a result, this method is more punitive than the geometric mean; to get a good score in the combined result it is necessary to have a good score in ALL of the inputs. e.g. the different types of survivability are 'must haves.'

On balance, the revised TPL is probably less punitive than the previous spreadsheet, multiplication is used sparingly as a method of combining scores. This is in line with the feedback of the Wave Energy Prize judges.

# 2 OVERALL STRUCTURE:

The overall TPL score is calculated from scores for the seven high level capabilities arranged in in three categories as follows.

| **Capability** | **Category** |
|---|---|
| C1: Have market acceptable LCoE. | Economics |
| C2: Provide a secure (low risk) investment opportunity. | Economics |
| C3: Be reliable for grid operations. | Benefits |
| C4: Be beneficial to society. | Benefits |
| C5: Be acceptable to permitting & certification. | Acceptability |
| C6: Be acceptable with respect to safety. | Acceptability |
| C7: Be globally deployable. | Economics |

The overall TPL is calculated as a weighted average (arithmetic mean) of the scores for these three categorizations. The weightings for the categories are 0.7:0.2:0.1 for economics, acceptability, and benefits respectively. The equation is:

$$TPL = 0.7 \cdot TPL_{eco} + 0.2 \cdot TPL_{acc} + 0.1 \cdot TPL_{ben} \quad (1)$$

The combined scores for each of the categories that are passed as inputs to equation 1 are calculated as a geometric mean of their respective inputs. The equations used are:

$$TPL_{eco} = \left(TPL_{C1} \cdot TPL_{C2} \cdot TPL_{C7}\right)^{1/3} \quad (2)$$

$$TPL_{acc} = \left(TPL_{C5} \cdot TPL_{C6}\right)^{1/2} \quad (3)$$

$$TPL_{ben} = \left(TPL_{C3} \cdot TPL_{C4}\right)^{1/2} \quad (4)$$

# 3 CAPABILITIES SCORING:

### C1 Have market competitive cost of energy

The $TPL_{C1}$ value is calculated from two levels of nested sub-capabilities that have been identified through a systems engineering process. The sub-capabilities within C1 are:

| | | |
|---|---|---|
| **C1** | **Have market competitive cost of energy** | |
| **C1.1** | Have as low CAPEX as possible | |
| **C1.1.1** | | Be a low cost design |
| **C1.1.2** | | Be manufacturable at low cost |
| **C1.1.3** | | Be inexpensive to transport |
| **C1.1.4** | | Be inexpensive to install |
| **C1.2** | Have as low an OPEX as possible | |
| **C1.2.1** | | Be reliable (cost of maintenance) |
| **C1.2.2** | | Be durable over the lifetime of the plant |
| **C1.3** | Be able to generate large amount of electricity from wave energy | |
| **C1.3.1** | | Absorb large amounts of wave energy |
| **C1.3.2** | | Have high energy conversion efficiency of extracted energy to electrical energy |
| **C1.4** | Have high availability | |
| **C1.4.1** | | Be reliable (lost revenue w.r.t time taken) |
| **C1.4.2** | | Be durable over the lifetime of the plant |

C1 is scored as the geometric mean of the TPL scores for total cost, generation, availability, with equal weighting to each.

$$TPL_{C1} = \left(TPL_{COST} \cdot TPL_{C1.3} \cdot TPL_{C1.4}\right)^{1/3} \quad (4)$$

The score for total cost is a combination of the CAPEX and OPEX scores and relies on a CAPEX:OPEX weighting of 70:30.

$$TPL_{COST} = \frac{1}{\frac{0.7}{TPL_{C1.1}} + \frac{0.3}{TPL_{C1.1}}} \tag{4}$$

C1.1 is scored as a weighted sum of the individual cost TPL scores in CAPEX.

$$TPL_{C1.1} = \frac{1}{\frac{0.36}{TPL_{C1.1.1}} + \frac{0.36}{TPL_{C1.1.2}} + \frac{0.09}{TPL_{C1.1.3}} + \frac{0.18}{TPL_{C1.1.4}}} \tag{4}$$

C1.2 is scored as a weighted sum of the individual cost TPL scores in OPEX.

$$TPL_{C1.2} = \frac{1}{\frac{0.7}{TPL_{C1.2.1}} + \frac{0.3}{TPL_{C1.2.2}}} \tag{4}$$

C1.3 is scored as the product of the inputs and then scaled to a range of 1-9. Each input is equally important.

$$TPL_{C1.3} = \left(TPL_{C1.3.1} \cdot TPL_{C1.3.2} - 1\right)\left(\frac{8}{9^2}\right) + 1 \tag{4}$$

C1.4 is scored as the weighted average (arithmetic mean) of its inputs. Weights are 50:50.

$$TPL_{C1.4} = 0.5 \cdot TPL_{C1.4.1} + 0.5 \cdot TPL_{C1.4.2} \tag{4}$$

**C2 Provide a secure investment opportunity**

The $TPL_{C2}$ value is calculated from two levels of nested sub-capabilities that have been identified through a systems engineering process. The sub-capabilities within C2 are:

| | | |
|---|---|---|
| **C2** | **Provide a secure investment opportunity** | |
| **C2.1** | Be survivable | |
| **C2.1.1** | | Be able to survive extreme loads/responses |
| **C2.1.2** | | Be able to cope with grid failures, |
| **C2.1.3** | | Be able to avoid and survive to collisions |
| **C2.1.4** | | Be survivable in installation (& temporary conditions) |
| **C2.2** | Be low risk under design conditions | |
| **C2.2.1** | | Be low uncertainty on OPEX |
| **C2.2.2** | | Be low uncertainty on availability |
| **C2.2.3** | | Be low uncertainty on energy production |
| **C2.2.4** | | Be low uncertainty on CAPEX |

C2 is scored as the geometric mean of its inputs. Each input is equally important.

$$TPL_{C2} = \left(TPL_{C2.1} \cdot TPL_{C2.2}\right)^{1/2} \quad (4)$$

C2.1 is scored as the product of its inputs scaled to a range of 1-9. Each input is equally important.

$$TPL_{C2.1} = \left(TPL_{C2.1.1} \cdot TPL_{C2.1.2} \cdot TPL_{C2.1.3} \cdot TPL_{C2.1.4} - 1\right)\left(\frac{8}{9^4}\right) + 1 \quad (4)$$

C2.2 is calculated to reflect the impact of the inputs on cost of energy. It is the geometric mean of 1/combined cost, availability and energy production. Within the total cost the CAPEX:OPEX weighting is 70:30.

$$TPL_{C2.2} = \left(\frac{1}{\frac{0.3}{TPL_{C2.2.1}} + \frac{0.7}{TPL_{C2.2.4}}} \cdot TPL_{C2.2.2} \cdot TPL_{C2.2.3}\right)^{1/3} \quad (4)$$

**C3 Be reliable for grid operations**

The $TPL_{C3}$ value is calculated from a single level of sub-capabilities that have been identified through a systems engineering process. The sub-capabilities within C3 are:

| | | |
|---|---|---|
| **C3** | **Be reliable for grid operations** | |
| **C3.1** | | Be forecastable |
| **C3.2** | | Have stable annual power production |
| **C3.3** | | Be useful to the grid |

C3 is scored as a weighted average (arithmetic mean) of its inputs.

$$TPL_{C3} = 0.33 \cdot TPL_{C3.1} + 0.33 \cdot TPL_{C3.2} + 0.33 \cdot TPL_{C3.3} \quad (4)$$

**C4 Be beneficial to society**

The $TPL_{C4}$ value is calculated from a single level of sub-capabilities that have been identified through a systems engineering process. The sub-capabilities within C4 are:

| | | |
|---|---|---|
| **C4** | **Be beneficial to society** | |
| **C4.1** | | Be beneficial to local communities |
| **C4.2** | | Be low carbon emission energy source |
| **C4.3** | | Be a low polluting energy source |
| **C4.4** | | Minimize impact on taxpayers |

C4 is scored as a weighted average (arithmetic mean) of its inputs.

$$TPL_{C4} = 0.25 \cdot TPL_{C4.1} + 0.25 \cdot TPL_{C4.2} + 0.25 \cdot TPL_{C4.3} + 0.25 \cdot TPL_{C4.4} \quad (4)$$

**C5 Be acceptable for permitting and certification**

The $TPL_{C5}$ value is calculated from a single level of sub-capabilities that have been identified through a systems engineering process. The sub-capabilities within C5 are:

| | | |
|---|---|---|
| **C5** | **Be acceptable for permitting and certification** | |
| **C5.1** | | Be environmentally acceptable |
| **C5.2** | | Be acceptable to other users of the area |
| **C5.3** | | Be grid compliant |

C5 is scored as a geometric mean. Each input is equally important.

$$TPL_{C5} = \left(TPL_{C5.1} \cdot TPL_{C5.2} \cdot TPL_{C5.3}\right)^{1/3} \quad (4)$$

**C6 Be acceptable with respect to safety**

The $TPL_{C6}$ value has no sub-capabilities its value is determined by the assessor in consideration of the questions under this capability.

**C7 Be deployable globally**

The $TPL_{C7}$ value has no sub-capabilities its value is determined by the assessor in consideration of the questions under this capability.

# DISTRIBUTION

| | | | |
|---|---|---|---|
| 1 | MS0899 | Technical Library | 9536 (electronic copy) |


Sandia National Laboratories