Life cycle assessment of the wave energy converter: Wave Dragon

Hans Chr., Sørensen; Stefan, Naef; Stefan, Anderberg; Hauschild, Michael Zwicky

Publication date:
2007

Document Version
Early version, also known as pre-print

Link back to DTU Orbit

Citation (APA):
Hans Chr., S., Stefan, N., Stefan, A., & Hauschild, M. Z. (2007). *Life cycle assessment of the wave energy converter: Wave Dragon*. Poster session presented at Conference in Bremerhaven.

Title: Life Cycle Assessment of the Wave Energy Converter: Wave Dragon

Author: Hans Chr. Soerensen, Wave Dragon ApS, Copenhagen, Denmark
Co-Authors: Stefan Naef, University of Copenhagen, Denmark
Stefan Anderberg, University of Copenhagen, Denmark
Michael Z. Hauschild, Technical University Denmark, Lyngby, Denmark
Address for correspondence:
Name: Hans Chr. Soerensen
Affiliation: Wave Dragon ApS
Address: Blegdamsvej 4, 2200 Copenhagen N, Denmark
Telephone/Mobile/Fax number: +45 3536 0219 / +45 2811 0219 /+45 3537 4537
Email address: hcs@wavedragon.net

Topic Number: 7, Environment **Kind of presentation**: Poster

Abstract

Any power production technology should be able to demonstrate that it’s able to comply with current and future environmental regulation and that it demonstrates a considerable surplus in the energy balance being a part of the entire power system. This means that the energy used throughout all the lifecycle stages; from provision of materials over manufacturing of components and assembly, to deployment and use and eventually the disposal stage, is considerably less than the energy produced by the device during its use/production stage. With this paper, Wave Dragon is the first wave energy developer to publish figures of the energy balance of its technology[1]. An LCA conducted at the Technical University of Denmark demonstrates that the energy consumed during Wave Dragons life cycle may be returned 20 times throughout its anticipated lifetime of 50 years, according to the EDIP LCA method. But if Wave Dragons power production is compared to production of electricity using fossil fuel the energy can be returned 50 times.

Introduction

Exploitation of the energy bound in ocean waves is making technological and economical progress with different emerging concepts and devices. The potential of harnessing near shore waves is to supply up to 50 % of the World's demand for electricity[2]. Still, the different wave energy converters need to show more modest production costs in order to be able to compete with other matured renewable energy technologies.

Wave Dragon

Wave Dragon is a floating wave energy converter functioning by extracting energy principally by means of waves overtopping into a reservoir. A 1:4.5 scale prototype has been tested for 21 months in corresponding sea conditions at a less energetic site between 2003 and 2005[3].

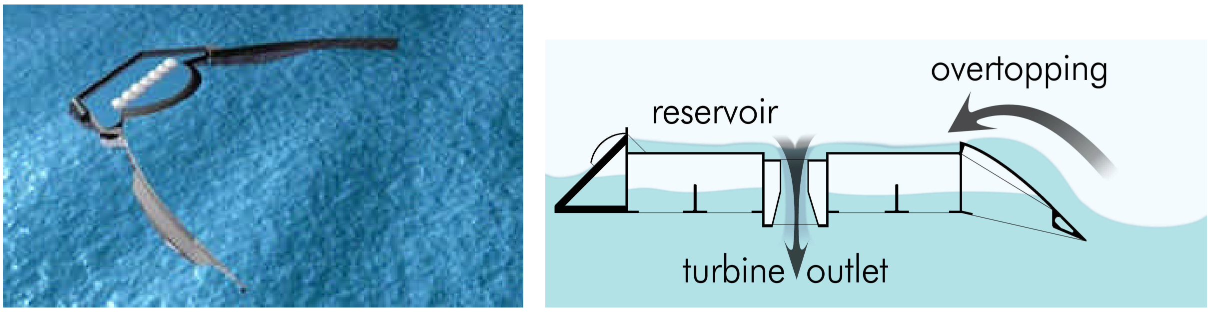

Figure 1: The Wave Dragon principle

Figure 2: Wave Dragon prototype. Approaching waves are concentrated by the reflector towards the ramp

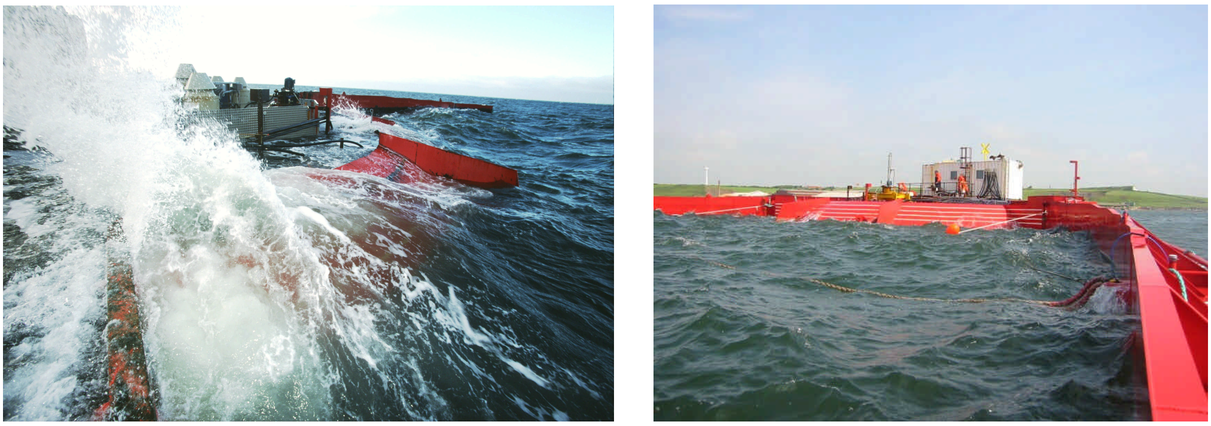

Figure 3: Wave Dragon in good waves (left) and in smaller waves (right)

The LCA method

In early 2005, the company Black & Veatch[4] (on behalf of the British Carbon Trust) made a review of the entire concept including a first attempt to provide an "embedded carbon assessment" and in the autumn 2005, this study was followed by a full LCA conducted at the Technical University of Denmark[1]. Both studies are based on a rather time consuming process of modeling the life cycle of Wave Dragon and obtaining the required data. It can be done in a program called GABI, where it's organized in "plans" and "processes". The LCA assessment is following the EDIP-methodology[5], including *normalization* and *weighting*.

The functional unit is 1kWh like in other power plant LCA's, in order to make the assessments comparable. All electrical power used and produced is based on a process called Danish power grid mix by consumption, 2001.

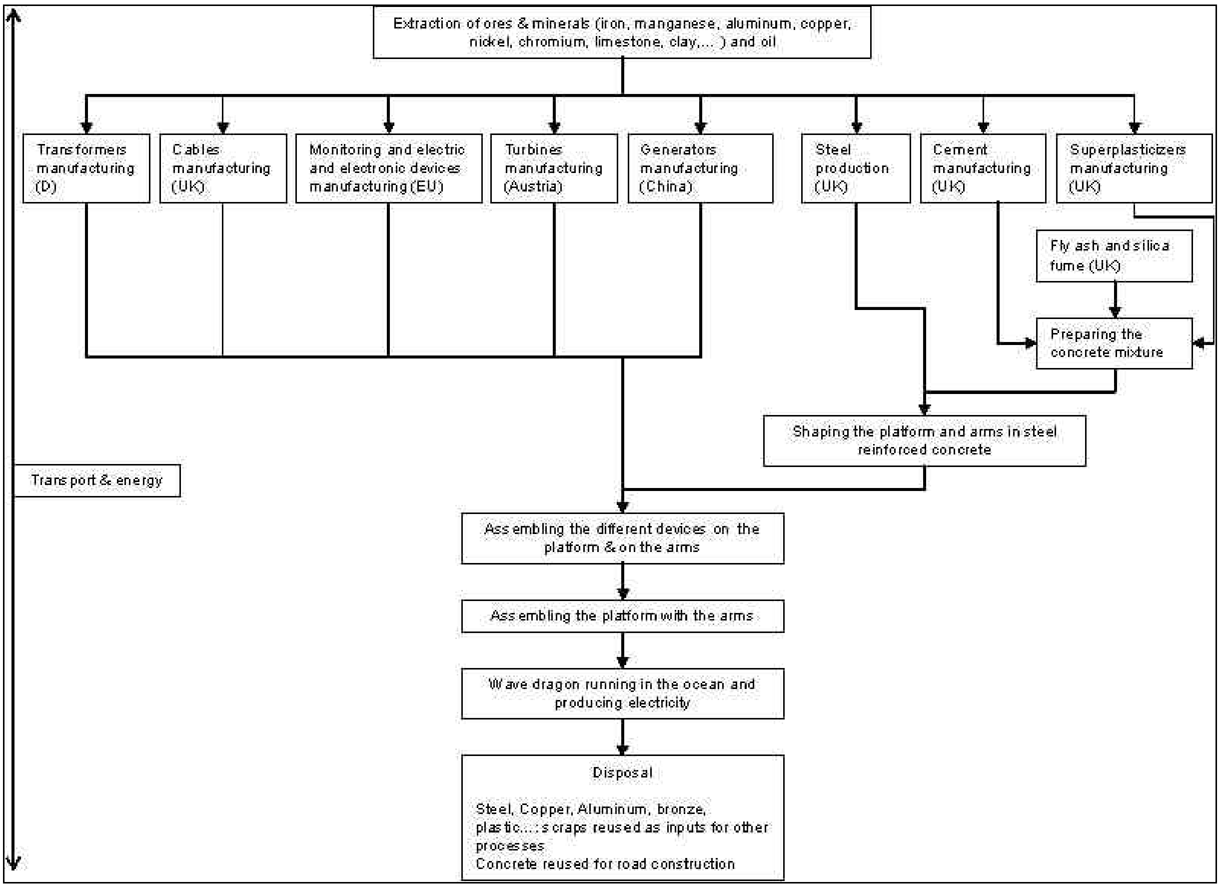

Figure 4: Flow chart of the life cycle of Wave Dragon[1]

LCA results

The following graph represents the normalized and weighed values of the environmental impact potentials and the resource consumption for the *basic scenario*[1] for the entire life cycle. Separate graphs exist for all four stages.

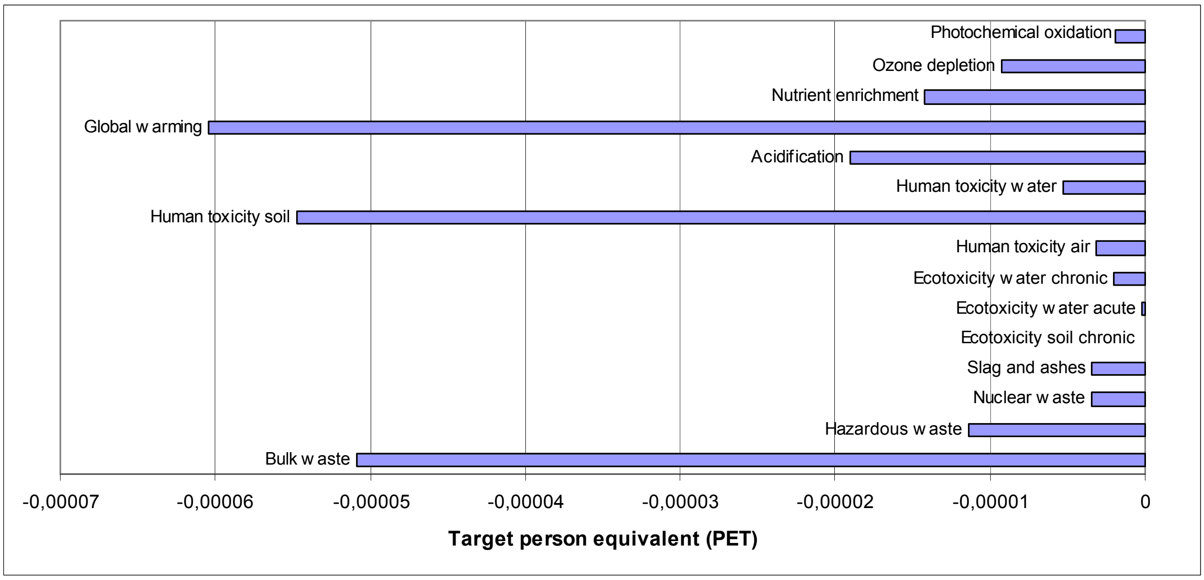

Figure 5: Weighted environmental impact potentials for the whole life cycle[1]

The weighted values for the environmental impacts are all negative. From the bar chart in Figure 5, it can be noticed that the most serious avoided impacts are: global warming, human toxicity soil, bulk waste and acidification.

The reason for negative values is that the electricity production from Wave Dragon circumvents both consumption of various fossil fuels and contributions to other environmental impacts like emissions of greenhouse gases, bulk waste and dangerous chemicals.

The following graph Figure 6 represents the normalized and weighted values of the environmental impact potentials and the resource consumptions for the basic scenario over the entire life cycle.

Concerning the consumption of resources, tin is by far responsible for the most serious impact. Tin is a constituent in bronze, which will probably be used for the turbine propellers. Bronze is almost completely recyclable but according to the available “processes” in GABI tin will not be recovered. Similarly nickel is not recovered though it might be recycled as stainless steel.

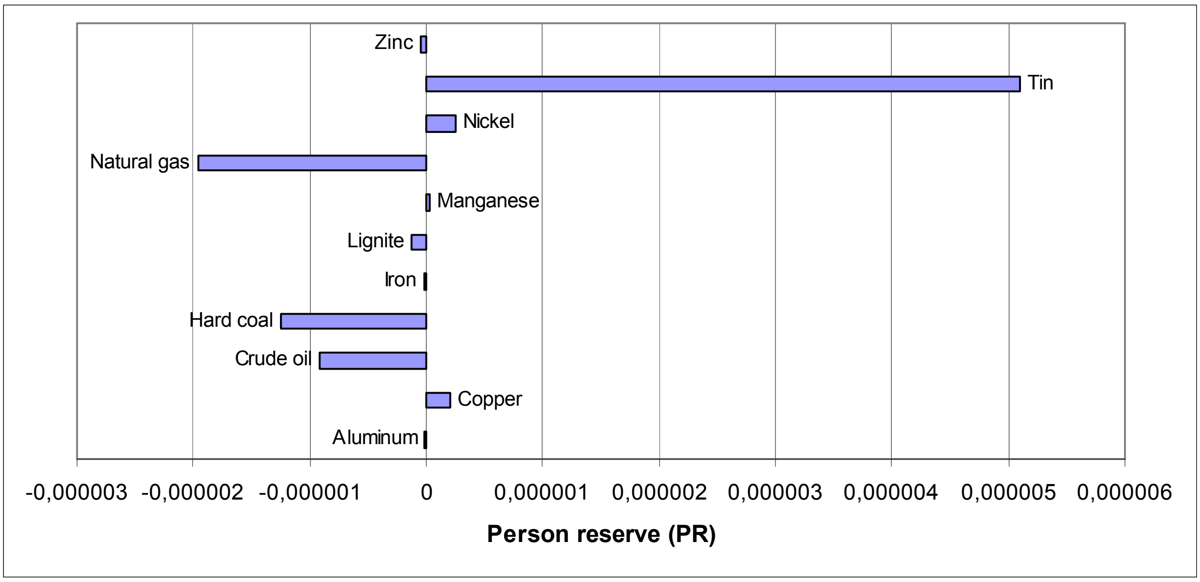

Figure 6: Weighted resource consumptions for the whole life cycle[1]

Indeed, tin is a scarce resource with a supply horizon of only 27 years and a known global reserve around 1,1kg/person. Crediting of tin through recycling of the bronze or using an alternative material will most likely make this impact insignificant, but using alternative materials may cause new impacts to consider.

More important, there is still a substantial negative consumption of fossil fuels, in descending order: natural gas, hard coal, crude oil and eventually lignite. The supply horizons of the various fossil fuels are relatively small (43 years for crude oil for example). Furthermore, taking the scarcity of different resources into account, the consumption of both iron and aluminum is unimportant.

Sensitivity analysis

It is crucial to make different sensitivity analyses since the outcome of the analysis of the energy balance is highly dependent on different assumptions and prerequisites about; the actual and eventual composition of Wave Dragon, the lifetime of different components, the actual wave height, the power production achieved, changes in the environmental profile of the power being displaced by wave power – with time and different locations, the need for maintenance, the path of decommissioning and disposal etc.

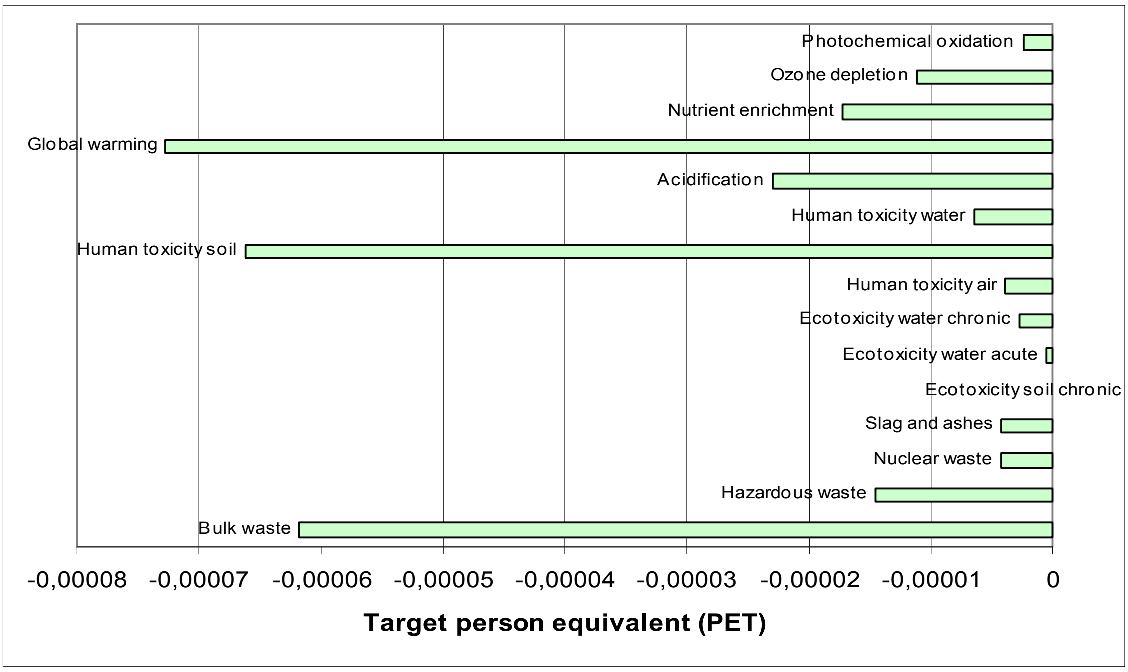

Figure 7: Weighted resource consumption for the entire life cycle with 60 years[1]

Actually, the structure can probably last for more than 50 years (similar concrete structures in marine environments are known to last for 70-80 years) but some of the electronic devices on board are expected to be replaced more than once due to wear out, upgrades etc. Turbines used in hydro power stations usually have a lifetime longer than 50 years.
One example of a chosen scenario with 60 years lifetime is shown in Figure 7.

When increasing the lifetime of Wave Dragon, the overall production of electricity rises and more resource consumptions and environmental impacts are avoided. For example, copper is not consumed anymore by the system but credited. Analogous a 20% higher production will make the same picture, so it should even be considered to make a, less likely, ± 45% production scenario.

Comparison to wind energy and other renewables

The Wave Dragon LCA[1] used an LCA of a 3 MW wind turbine, which was conducted and published in 2005 by the wind turbine manufacturer[6], as reference study. The Wave Dragon LCA was as far as possible conducted in the same way with the same categories e.g. the same Danish power mix has been used as a process in GABI in order to make the analyses comparable. Actually Danish power production is more efficient and has less environmental impacts than in Wales, making the energy balance somewhat better for Wave Dragon.

Calculated in accordance with the EDIP method, as for the LCA for the wind turbine, it looks like below.

RE devise	**Power**	**Life time**	**Payback**	**Earned in lifetime**
Wave Dragon	7 MW	50 y	2.42 y	20
Wind turbine	3 MW	20 y	0.57 y	35

Figure 8: Comparison between wind energy and wave energy[1]

Similar figures[7] for small hydro are 40-100, for biomass heating 10-20 and for solar photo voltage 3-5.

In order to make a more comprehensive and useful energy balance or embedded carbon assessment, it is needed to distinguish between one kWh of electrical power and one kWh/3,6 MJ of different sources of primary (fossil) energy, co-generated heat etc. used by Wave Dragon in it's life cycle and electrical power production avoided by Wave Dragon. Thus it's possible to make a separate balance for each type of primary fuel (or to some extent CO_2). A more simple way to do this is simply to multiply the investigated power production with a factor 2.5 (if the average degree of efficiency for avoided production is 40%) in order to deal with the loss of energy in the conversion process in power plants. This is reasonable as long as the production of wave power is marginal to fossil power production without utilization of heat. If doing so the energy payback time for Wave Dragon is just one year, changing the energy return from 20 times to 50 times.

Other differences between the impacts of different technologies occur because wind turbines are mainly made of steel while Wave Dragon of concrete. Another difference is that offshore wind turbines have a considerably higher impact during the use/production stage.

Acknowledgement

The prototype project has only been possible with generous support funding from the European Commission (Contract No: ENK5-CT-2002-00603) and the work carried out by the 5 MSc students: Anne-Laure Grozellier, Jerome Morgen, Finn Mejdahl Nielsen, Stefan Naef and Yi Xu from the Danish Technical University, Denmark.

Further information

More information about Wave Dragon can be found on the project at the website www.wavedragon.net and www.wavedragon.co.uk

References

[1] Naef, S. et. al.: *Life cycle assessment of Wave Dragon, A wave energy converter*, Copenhagen, November, 2005, Technical University of Denmark, 67 pp.

[2] Soerensen, H.C.: *World's first offshore wave energy converter, Wave Dragon, connected to the grid*, World Energy Council Conference, Sydney Australia, September, 2004, 12 pp.

[3] Soerensen, H.C. et. al.: *Sea Testing and Optimisation of Power Production on a Scale 1:4.5 Test Rig of the Offshore Wave Energy Converter Wave Dr*agon, Final Technical Report for the period October 2002 to March 2006, European Commission Contract No: ENK5-CT-2002-00603, SPOK, Copenhagen, Denmark, 82 pp.

[4] Black & Veatch Consulting: *Wave Dragon – Cost Reduction and Performance Optimisation*, Report 107799/D/4200/01/0, Section 7, Embedded Carbon and Energy Pay-back, Report for Carbon Trust, Marine Energy Challenge, May 2005, 48 pp.

[5] Wenzel H., Hauschild M., Alting L.: *Environmental Assessment of Products*, Vol.1, Chapman & Hall. 1997.

[6] Vestas: *Life cycle assessment of offshore and onshore sited wind power plants based on Vestas V90-3.0 MW turbines*, March 2005, Vestas Wind System, Randers, Denmark, 59 pp.

[7] Cap, F.: Österreichische Zeitschrift für Elektrizitätswirtschaft, J45, H12, December 1992 and http://de.wikipedia.org/wiki/Erntefaktor