Supplementary Material to:

Full Life Cycle Assessment of Two Surge Wave Energy Converters

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S1 Key parameters

The analysis presented in this paper is an LCA of a single case-study manufacturing and installation scenario for each of two different versions of the Oyster Wave Energy Converter (WEC) - the Oyster 1 and the Oyster 800. A number of key parameters, detailed in the main text, are summarised here in order to facilitate the use of this analysis in any “meta-models” of wave energy, as suggested by Astudillo et al. [1]:

	Oyster 1	**Oyster 800**
Location	The European Marine Energy Centre (EMEC) test site at Stromness, UK	
Technological maturity	Full-scale prototype	Full-scale prototype
Installation year	2008	2012
Period of validity	2008-2011	2012-2015[2]
Capacity	315 kW	800 kW
Operating lifetime	15 years	20 years
Capacity factor	55%	55%
Annual energy production	1.52 GWh	3.85 GWh
Technology type	Attenuator-type seabed-mounted oscillating body system wave energy converter	
Data type	Empirical from cradle to completed installation, Theoretical for maintenance, decommissioning and disposal	
Plant production and decommissioning	Included	Included
Characterization factors	EDIP 2003 method, Cumulative energy demand, and total resources from EDIP 97	
Mass (device only)	116 tonnes	1284 tonnes

[2] Development of this device was halted when the manufacturer went into administration in 2015.

S2 Input data

Component			Function	Mass (tonnes)	Material	Source location
Main	Device	**Flap**	Rotates forwards and backwards due to the wave motion.	29 [2]	Mild steel [2]	Nigg [3]
		Seabed frame	A horizontal frame that stands on the seabed.	96.5 [2]	Steel [2]	Nigg [3]
		Check valve (x4)		0.177 [2]	Brass, cast iron and mild steel [2]	Birmingham (assumed)
		Connector	Joins the main frame to the flap.	2.92 [2]	Mild steel [2]	Nigg [3]
		Rams (x2)	Converts the rotational motion of the flap into hydraulic energy.	16 [2]	Steel [2]	Nigg [3]
Auxiliary	Pipeline	**Pipeline**	Contains the fresh water that moves the Pelton turbine on shore via hydraulic energy; 720 m [2]	85 Calculated from length	Stainless steel (assumed)	Birmingham (assumed)
		Concrete mattresses	Installed on the seabed to protect pipelines	45 tonnes	Concrete	Birmingham (assumed)
	Onshore	**Shipping containers (x2)**	These house the electrical and mechanical equipment necessary for power generation.	2.4 [2]	Mild steel & plywood [2]	Birmingham (assumed)
		Support frame and bearings	These support the mechanical equipment in the containers.	0.8536 [2]	Steel [2]	Frame from Birmingham (assumed) Bearings from Katowice (Timken, personal communication, 14th July 2015)
		Induction generator	Installed capacity is 315 kW	3.4 [4]	Steel, iron, aluminium and copper [4]	Helsinki, Finland (ABB, personal communication, 3rd July 2015)
		Pelton turbine	Converts hydraulic energy into mechanical energy.	0.523 [2]	Stainless steel [2]	Birmingham (assumed)
		Flywheel	Provides smoothing of power generation.	3.1 [2]	Stainless Steel [2]	Birmingham (assumed)
	Subsea infrastructure	**Subsea infrastructure**	Includes a pile connector frame forming the foundation for the seabed frame, four piles, and the pipeline system.	36 + 128 [5, 6]	Stainless steel and concrete [5, 6]	Grout from Copenhagen [6] Remainder from Falmouth [5]

Table S2.1 - Input data for Oyster 1

		Component	Function	Mass (tonnes)	Material	Source location
Main	Device	**Flap**	Rotates forwards and backwards due to the wave motion.	320 [7]	Stainless steel and glass-reinforced plastic [7]	Methil [8]
Main	Device	**Base frame**	A horizontal frame that stands on the seabed	200 [7]	Stainless steel [7]	Methil [8]
Main	Device	**Hydraulic modules**	Converts the rotational motion of the flap into hydraulic energy	90 [7]	Stainless steel [7]	Methil [8]
Auxiliary	Device	**Pipe spool assembly**	This stainless steel component connects the directionally drilled pipelines to the converter	40 [7]	Stainless steel [7]	Methil [8]
Auxiliary	Device	**Rock anchors (x2)**	These facilitate installation and decommissioning.	1 [7]	Steel and gap filling injection mortar [7]	Methil [8]
Auxiliary	Device	**Can buoys (x4)**	Installed for mooring and safety purposes.	2.5 [7]	Acrylonitrile-butadiene-styrene polymer and stainless steel [9]	Methil [8]
Auxiliary	Device	**Sacrificial anodes**	Protects against corrosion.	10 [10]	Aluminum zinc alloy [10]	Methil [8]
Auxiliary	Device	**Latching system**	Set of 4 latching anchors. Secures the flap into the maintenance position.	612 [10]	Stainless steel, rubber, cement and gravel [10]	Methil [8]
Auxiliary	Pipeline	**Pipeline (x2)**	Contains the fresh water that moves the Pelton turbine on shore via hydraulic energy; 2x600 m (high-pressure and low-pressure)	12.5 [7]	Stainless steel and glass epoxy [7]	Birmingham (assumed)
Auxiliary	Pipeline	**Concrete mattresses (x20)**	Installed on the seabed to protect pipelines.	3.6 [7]	Concrete [7]	Birmingham (assumed)
Auxiliary	Onshore	**Shipping containers (x2)**	These house the electrical and mechanical equipment necessary for power generation.	2.4 [2]	Mild steel & plywood [2]	Birmingham (assumed)
Auxiliary	Onshore	**Support frame and bearings**	These support the mechanical equipment in the containers.	0.8536 [2]	Steel [2]	Frame from Birmingham (assumed) Bearings from Katowice (Timken, personal communication, 14th July 2015)

Component		Function	Mass (tonnes)	Material	Source location
	Induction generator	Installed capacity is 800 kW	8.6 [4]	Steel, iron, aluminium and copper [4]	Helsinki, Finland (ABB, personal communication, 3rd July 2015)
	Pelton turbine	Converts hydraulic energy into mechanical energy.	0.523 [2]	Stainless steel [2]	Birmingham (assumed)
	Flywheel	Provides smoothing of power generation.	3.1 [2]	Stainless Steel [2]	Birmingham (assumed)
Subsea infrastructure	**Piles (x2)**	The Oyster 800 has 2 piles and a different foundation system.	190 (estimated from dimensions)	Stainless steel piles [7]	Falmouth [11]

Table S2.2 - Input data for Oyster 800

S3 Additional Numerical Results

This section contains additional results not presented in the main article.

S3.1 Detailed LCIA Results

Table S3.1 and Table S3.2 contain the full numerical results from the LCIA for each of the two devices, as shown graphically in Figure 3 of the main text.

Impact category	Unit	M&M	A&I	Maint.	D&D	Total
Global warming (GW)	g CO_2 eq/kWh	72	3	1	3	79
Ozone depletion (OD)	µg CFC-11 eq/kWh	2.9	0.2	0.1	0.0	3.2
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.51	0.03	0.01	0.04	0.58
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	36	2	0	3	41
Acidification (A)	cm^2/kWh	73	2	1	0	76
Terrestrial eutrophication (TE)	cm^2/kWh	56	4	1	0	61
Aquatic eutrophication - N (AEN)	mg N/kWh	24	2	0	2	28
Aquatic eutrophication - P (AEP)	mg P/kWh	26	0	0	0	26
Human toxicity air (HTA)	person/kWh	4070	60	1094	417	5642
Human toxicity water (HTW)	m^3/kWh	4.6	0.0	0.0	1.8	6.5
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	60	1	2	1	64
Ecotoxicity water - chronic (EWC)	m^3/kWh	155	2	6	132	295
Ecotoxicity water - acute (EWA)	m^3/kWh	22	0	1	18	40
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	288	4	3	1	297
Hazardous waste (HW)	mg/kWh	2.0	0.1	0.1	0.0	2.1
Slags/ashes (SA)	mg/kWh	217	6	3	177	403
Bulk waste (BW)	g/kWh	66	3	0	6	76
Radioactive waste (RW)	mg/kWh	2.3	0.3	0.1	0.0	2.7
Resources (R)	g/kWh	47	1	0	0	49
Energy (CED)	kJ/kWh	821	50	17	3	891

Table S3.1 - Full results for Oyster 1

Impact category	Unit	M&M	A&I	Maint.	D&D	Total
Global warming (GW)	g CO_2 eq/kWh	55	1	0	1	57
Ozone depletion (OD)	µg CFC-11 eq/kWh	2.4	0.1	0.0	0.0	2.5
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.37	0.01	0.00	0.01	0.39
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	26	1	0	1	28
Acidification (A)	cm^2/kWh	54	1	0	0	55
Terrestrial eutrophication (TE)	cm^2/kWh	42	1	0	0	44
Aquatic eutrophication - N (AEN)	mg N/kWh	19	1	0	0	20
Aquatic eutrophication - P (AEP)	mg P/kWh	16	0	0	0	16
Human toxicity air (HTA)	person/kWh	2495	18	287	64	2864
Human toxicity water (HTW)	m^3/kWh	2.8	0.0	0.0	0.3	3.1
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	33	0	1	0	34
Ecotoxicity water - chronic (EWC)	m^3/kWh	119	1	2	40	161
Ecotoxicity water - acute (EWA)	m^3/kWh	17	0	0	5	21
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	256	1	1	0	259
Hazardous waste (HW)	mg/kWh	1.2	0.0	0.0	0.0	1.2
Slags/ashes (SA)	mg/kWh	267	2	1	25	295
Bulk waste (BW)	g/kWh	46	1	0	9	55
Radioactive waste (RW)	mg/kWh	1.8	0.1	0.0	0.0	2.0
Resources (R)	g/kWh	31	0	0	0	31
Energy (CED)	kJ/kWh	612	15	4	2	634

Table S3.2 - Full results for Oyster 800

It is assumed that the Oyster devices are largely made from stainless or marine-grade steel. The contribution of each of these types of steel to the overall environmental impacts are detailed in Table S3.3 and Table S3.4.

Impact category	Stainless Steel M&M	Mild Steel M&M	Other M&M	A&I	Maint.	D&D
Global warming (GW)	62%	16%	14%	4%	1%	4%
Ozone depletion (OD)	58%	14%	18%	7%	3%	0%
Ozone formation - Vegetation (OFV)	60%	16%	11%	6%	1%	6%
Ozone formation - Human (OFH)	59%	16%	11%	6%	1%	7%
Acidification (A)	71%	13%	11%	3%	1%	1%
Terrestrial eutrophication (TE)	65%	15%	12%	7%	1%	1%
Aquatic eutrophication - N (AEN)	60%	14%	13%	6%	1%	7%
Aquatic eutrophication - P (AEP)	57%	27%	14%	1%	1%	0%
Human toxicity air (HTA)	34%	28%	10%	1%	19%	7%
Human toxicity water (HTW)	34%	21%	16%	1%	1%	28%
Human toxicity soil (HTS)	54%	32%	9%	1%	4%	1%
Ecotoxicity water - chronic (EWC)	34%	11%	8%	1%	2%	45%
Ecotoxicity water - acute (EWA)	32%	13%	9%	1%	2%	44%
Ecotoxicity soil - chronic (EWC)	55%	9%	33%	1%	1%	0%
Hazardous waste (HW)	50%	32%	12%	3%	3%	0%
Slags/ashes (SA)	34%	5%	15%	1%	1%	44%
Bulk waste (BW)	76%	7%	4%	4%	1%	8%
Radioactive waste (RW)	61%	11%	15%	10%	3%	1%
Resources (R)	67%	20%	9%	3%	1%	0%
Energy (CED)	65%	15%	12%	6%	2%	0%
Average	54%	17%	13%	3%	2%	10%

Table S3.3 - Contribution of different materials to the environmental impacts of Oyster 1

Impact category	Stainless Steel M&M	Mild Steel M&M	Other M&M	A&I	Maint.	D&D
Global warming (GW)	60%	2%	35%	2%	1%	1%
Ozone depletion (OD)	53%	2%	42%	2%	1%	0%
Ozone formation - Vegetation (OFV)	63%	2%	30%	3%	0%	2%
Ozone formation - Human (OFH)	63%	2%	30%	3%	0%	2%
Acidification (A)	69%	2%	27%	2%	0%	0%
Terrestrial eutrophication (TE)	64%	2%	30%	3%	0%	1%
Aquatic eutrophication - N (AEN)	59%	2%	35%	3%	0%	2%
Aquatic eutrophication - P (AEP)	65%	3%	31%	0%	0%	0%
Human toxicity air (HTA)	48%	4%	35%	1%	10%	2%
Human toxicity water (HTW)	50%	4%	36%	0%	0%	9%
Human toxicity soil (HTS)	72%	4%	21%	1%	2%	0%
Ecotoxicity water - chronic (EWC)	44%	1%	29%	0%	1%	25%
Ecotoxicity water - acute (EWA)	43%	2%	33%	0%	1%	22%
Ecotoxicity soil - chronic (EWC)	45%	1%	53%	1%	0%	0%
Hazardous waste (HW)	63%	4%	30%	1%	1%	0%
Slags/ashes (SA)	32%	1%	58%	1%	0%	9%
Bulk waste (BW)	74%	1%	8%	2%	0%	16%
Radioactive waste (RW)	58%	2%	34%	4%	1%	1%
Resources (R)	75%	2%	21%	1%	0%	0%
Energy (CED)	65%	2%	30%	2%	1%	0%
Average	58%	2%	32%	2%	1%	5%

Table S3.4 - Contribution of different materials to the environmental impacts of Oyster 800

The materials and manufacturing impacts are also broken down by component in Table S3.5 and Table S3.6.

Impact category	Device M&M	Subsea Infrastructure M&M	Pipeline M&M	Onshore M&M	A&I	Maint.	D&D
Global warming (GW)	21%	42%	26%	2%	4%	1%	4%
Ozone depletion (OD)	22%	41%	25%	3%	7%	3%	0%
Ozone formation - Vegetation (OFV)	21%	39%	24%	2%	6%	1%	6%
Ozone formation - Human (OFH)	21%	39%	24%	2%	6%	1%	7%
Acidification (A)	19%	46%	28%	3%	3%	1%	1%
Terrestrial eutrophication (TE)	20%	43%	26%	2%	7%	1%	1%
Aquatic eutrophication - N (AEN)	20%	40%	25%	2%	6%	1%	7%
Aquatic eutrophication - P (AEP)	33%	38%	23%	4%	1%	1%	0%
Human toxicity air (HTA)	30%	25%	15%	3%	1%	19%	7%
Human toxicity water (HTW)	27%	25%	16%	4%	1%	1%	28%
Human toxicity soil (HTS)	35%	35%	22%	3%	1%	4%	1%
Ecotoxicity water - chronic (EWC)	16%	21%	13%	2%	1%	2%	45%
Ecotoxicity water - acute (EWA)	19%	20%	13%	2%	1%	2%	44%
Ecotoxicity soil - chronic (EWC)	19%	47%	29%	3%	1%	1%	0%
Hazardous waste (HW)	36%	34%	21%	4%	3%	3%	0%
Slags/ashes (SA)	17%	22%	14%	2%	1%	1%	44%
Bulk waste (BW)	10%	46%	29%	2%	4%	1%	8%
Radioactive waste (RW)	18%	41%	25%	2%	10%	3%	1%
Resources (R)	25%	43%	26%	3%	3%	1%	0%
Energy (CED)	21%	43%	26%	3%	6%	2%	0%
Average	22%	36%	22%	3%	3%	2%	10%

Table S3.5 - Contribution of different components to the environmental impacts of Oyster 1

Impact category	Device M&M	Subsea Infrastructure M&M	Pipeline M&M	Onshore M&M	A&I	Maint.	D&D
Global warming (GW)	69%	24%	3%	1%	2%	1%	1%
Ozone depletion (OD)	70%	21%	3%	2%	2%	1%	0%
Ozone formation - Vegetation (OFV)	66%	24%	3%	1%	3%	0%	2%
Ozone formation - Human (OFH)	66%	24%	3%	1%	3%	0%	2%
Acidification (A)	67%	26%	3%	2%	2%	0%	0%
Terrestrial eutrophication (TE)	67%	24%	3%	1%	3%	0%	1%
Aquatic eutrophication - N (AEN)	68%	22%	3%	2%	3%	0%	2%
Aquatic eutrophication - P (AEP)	67%	25%	3%	4%	0%	0%	0%
Human toxicity air (HTA)	62%	19%	4%	2%	1%	10%	2%
Human toxicity water (HTW)	52%	21%	2%	4%	0%	0%	9%
Human toxicity soil (HTS)	65%	27%	4%	2%	1%	2%	0%
Ecotoxicity water - chronic (EWC)	54%	16%	2%	2%	0%	1%	25%
Ecotoxicity water - acute (EWA)	57%	16%	2%	2%	0%	1%	22%
Ecotoxicity soil - chronic (EWC)	72%	22%	4%	1%	1%	0%	0%
Hazardous waste (HW)	66%	25%	3%	3%	1%	1%	0%
Slags/ashes (SA)	75%	12%	2%	1%	1%	0%	9%
Bulk waste (BW)	53%	26%	3%	1%	2%	0%	16%
Radioactive waste (RW)	67%	23%	3%	1%	4%	1%	1%
Resources (R)	66%	27%	3%	2%	1%	0%	0%
Energy (CED)	67%	25%	3%	2%	2%	1%	0%
Average	65%	22%	3%	2%	2%	1%	5%

Table S3.6 - Contribution of different components to the environmental impacts of Oyster 800

S3.2 Results with mild steel

In order to test the impact of the assumption that much of the Oyster devices are made from stainless or marine-grade steel, the analysis was re-run using only input data for mild steel. The complete results are given in table Table S3.7 and **Error! Reference source not found.**.

Impact category	Unit	M&M	A&I	Maint.	D&D	Total	Difference from original
Global warming (GW)	g CO_2 eq/kWh	45	3	1	3	51	-35%
Ozone depletion (OD)	µg CFC-11 eq/kWh	1.8	0.2	0.1	0.0	2.1	-34%
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.31	0.03	0.01	0.04	0.39	-34%
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	22	2	0	3	28	-33%
Acidification (A)	cm^2/kWh	36	2	1	0	39	-49%
Terrestrial eutrophication (TE)	cm^2/kWh	30	4	1	0	36	-42%
Aquatic eutrophication - N (AEN)	mg N/kWh	14	2	0	2	18	-38%
Aquatic eutrophication - P (AEP)	mg P/kWh	23	0	0	0	23	-11%
Human toxicity air (HTA)	person/kWh	4780	60	1094	417	6352	13%
Human toxicity water (HTW)	m^3/kWh	4.7	0.0	0.0	1.8	6.6	2%
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	61	1	2	1	64	1%
Ecotoxicity water - chronic (EWC)	m^3/kWh	110	2	6	132	250	-15%
Ecotoxicity water - acute (EWA)	m^3/kWh	18	0	1	18	37	-9%
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	165	4	3	1	174	-41%
Hazardous waste (HW)	mg/kWh	2.2	0.1	0.1	0.0	2.3	6%
Slags/ashes (SA)	mg/kWh	116	6	3	177	302	-25%
Bulk waste (BW)	g/kWh	17	3	0	6	26	-65%
Radioactive waste (RW)	mg/kWh	1.1	0.3	0.1	0.0	1.5	-44%
Resources (R)	g/kWh	31	1	0	0	33	-32%
Energy (CED)	kJ/kWh	457	50	17	3	527	-41%

Table S3.7 - Full results for Oyster 1 using only mild steel. The mean reduction in environmental impacts is 26%.

Impact category	Unit	M&M	A&I	Maint.	D&D	Total	Difference from original
Global warming (GW)	g CO_2 eq/kWh	53	1	0	1	54	-5%
Ozone depletion (OD)	µg CFC-11 eq/kWh	2.2	0.1	0.0	0.0	2.3	-8%
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.36	0.01	0.00	0.01	0.38	-4%
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	26	1	0	1	27	-2%
Acidification (A)	cm^2/kWh	42	1	0	0	43	-22%
Terrestrial eutrophication (TE)	cm^2/kWh	36	1	0	0	38	-13%
Aquatic eutrophication - N (AEN)	mg N/kWh	17	1	0	0	18	-12%
Aquatic eutrophication - P (AEP)	mg P/kWh	22	0	0	0	22	37%
Human toxicity air (HTA)	person/kWh	4742	18	287	64	5111	78%
Human toxicity water (HTW)	m^3/kWh	4.6	0.0	0.0	0.3	4.9	56%
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	58	0	1	0	59	74%
Ecotoxicity water - chronic (EWC)	m^3/kWh	124	1	2	40	166	3%
Ecotoxicity water - acute (EWA)	m^3/kWh	20	0	0	5	25	17%
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	179	1	1	0	182	-30%
Hazardous waste (HW)	mg/kWh	2.1	0.0	0.0	0.0	2.2	80%
Slags/ashes (SA)	mg/kWh	215	2	1	25	242	-18%
Bulk waste (BW)	g/kWh	17	1	0	9	27	-52%
Radioactive waste (RW)	mg/kWh	1.4	0.1	0.0	0.0	1.5	-22%
Resources (R)	g/kWh	32	0	0	0	32	4%
Energy (CED)	kJ/kWh	529	15	4	2	551	-13%

Table S3.8 - Full results for Oyster 800 using only mild steel. The mean increase in environmental impacts is 7%.

S3.3 Results for an Oyster 800 installed as part of an array

In order to test the potential benefit of installing the Oyster 800 in an array with shared drive trains, the analysis was re-run with only a share of the impacts of the drive train included. The results are given in table Table S3.7.

Impact category	Unit	M&M	A&I	Maint.	D&D	Total	Difference from original
Global warming (GW)	g CO_2 eq/kWh	55	1	0	0	57	-0.9%
Ozone depletion (OD)	µg CFC-11 eq/kWh	2.4	0.1	0.0	0.0	2.5	-1.1%
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.37	0.01	0.00	0.01	0.39	-1.0%
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	26	1	0	1	27	-1.0%
Acidification (A)	cm^2/kWh	53	1	0	0	55	-1.3%
Terrestrial eutrophication (TE)	cm^2/kWh	42	1	0	0	44	-1.0%
Aquatic eutrophication - N (AEN)	mg N/kWh	19	1	0	0	20	-1.1%
Aquatic eutrophication - P (AEP)	mg P/kWh	16	0	0	0	16	-2.5%
Human toxicity air (HTA)	person/kWh	2457	17	287	63	2824	-1.4%
Human toxicity water (HTW)	m^3/kWh	2.7	0.0	0.0	0.3	3.0	-3.6%
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	32	0	1	0	33	-1.4%
Ecotoxicity water - chronic (EWC)	m^3/kWh	117	1	2	22	141	-12.3%
Ecotoxicity water - acute (EWA)	m^3/kWh	16	0	0	3	19	-9.8%
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	254	1	1	0	257	-0.9%
Hazardous waste (HW)	mg/kWh	1.1	0.0	0.0	0.0	1.2	-2.1%
Slags/ashes (SA)	mg/kWh	265	2	1	23	291	-1.6%
Bulk waste (BW)	g/kWh	45	1	0	9	55	-0.6%
Radioactive waste (RW)	mg/kWh	1.8	0.1	0.0	0.0	1.9	-1.0%
Resources (R)	g/kWh	30	0	0	0	31	-1.1%
Energy (CED)	kJ/kWh	606	14	4	2	627	-1.0%

Table S3.9 - Full results for Oyster 800 if installed in a 3-device array with a shared drive train.

S3.4 Sensitivity Analysis

Selected results of the sensitivity analysis are shown graphically in the paper, but for completeness, the numerical results are given in Table S3.10 and Table S3.11. The sensitivity of the key aspects of the input data are further investigated and presented in Table S3.12 and Table S3.13. Note that distances to Birmingham are also included in the sensitivity test of onshore distances, and travel distances for specialist sea vessels are also included in the sensitivity test of offshore distances, so these findings are not independent. They are included here to demonstrate the contribution of each of these factors to the sensitivity of the results to uncertainties in particular subsets of input data.

Impact category	Unit	Input data		Design life (years)		Capacity factor	
		90%	110%	10	20	45%	65%
Global warming (GW)	g CO_2 eq/kWh	70	87	118	59	96	67
Ozone depletion (OD)	µg CFC-11 eq/kWh	2.9	3.6	4.8	2.4	3.9	2.7
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.52	0.65	0.87	0.44	0.71	0.49
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	37	46	62	31	51	35
Acidification (A)	cm^2/kWh	68	84	114	57	93	65
Terrestrial eutrophication (TE)	cm^2/kWh	54	67	91	46	74	51
Aquatic eutrophication - N (AEN)	mg N/kWh	25	31	42	21	34	24
Aquatic eutrophication - P (AEP)	mg P/kWh	24	29	39	20	32	22
Human toxicity air (HTA)	person/kWh	4886	6465	7916	4505	6896	4774
Human toxicity water (HTW)	m^3/kWh	5.8	7.1	9.7	4.9	7.9	5.5
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	57	71	94	48	78	54
Ecotoxicity water - chronic (EWC)	m^3/kWh	264	326	440	223	361	250
Ecotoxicity water - acute (EWA)	m^3/kWh	36	45	60	31	49	34
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	266	327	443	223	362	251
Hazardous waste (HW)	mg/kWh	1.9	2.4	3.2	1.6	2.6	1.8
Slags/ashes (SA)	mg/kWh	362	445	603	303	493	341
Bulk waste (BW)	g/kWh	68	84	114	57	93	64
Radioactive waste (RW)	mg/kWh	2.4	3.0	4.0	2.0	3.3	2.3
Resources (R)	g/kWh	44	54	73	37	60	41
Energy (CED)	kJ/kWh	795	990	1328	673	1089	754

Table S3.10 - Sensitivity analysis results for the Oyster 1. Highest values for each impact category are highlighted in orange, and lowest values in green.

Impact category	Unit	Input data		Design life (years)		Capacity factor	
		90%	110%	15	25	45%	65%
Global warming (GW)	g CO_2 eq/kWh	51	63	76	46	70	48
Ozone depletion (OD)	µg CFC-11 eq/kWh	2.2	2.8	3.3	2.0	3.1	2.1
Ozone formation - Vegetation (OFV)	m^2.ppm.h/kWh	0.35	0.43	0.52	0.31	0.48	0.33
Ozone formation - Human (OFH)	$x10^{-6}$ person.ppm.h/kWh	25	30	37	22	34	23
Acidification (A)	cm^2/kWh	50	61	74	44	68	47
Terrestrial eutrophication (TE)	cm^2/kWh	39	49	59	35	54	37
Aquatic eutrophication - N (AEN)	mg N/kWh	18	22	27	16	25	17
Aquatic eutrophication - P (AEP)	mg P/kWh	15	18	22	13	20	14
Human toxicity air (HTA)	person/kWh	2527	3219	3723	2349	3501	2424
Human toxicity water (HTW)	m^3/kWh	2.8	3.4	4.2	2.5	3.8	2.6
Human toxicity soil (HTS)	$x10^{-3}$ m^3/kWh	30	37	45	27	41	29
Ecotoxicity water - chronic (EWC)	m^3/kWh	145	178	214	129	197	136
Ecotoxicity water - acute (EWA)	m^3/kWh	19	24	28	17	26	18
Ecotoxicity soil - chronic (EWC)	$x10^{-3}$ m^3/kWh	233	285	345	207	316	219
Hazardous waste (HW)	mg/kWh	1.1	1.3	1.6	1.0	1.5	1.0
Slags/ashes (SA)	mg/kWh	265	325	393	236	361	250
Bulk waste (BW)	g/kWh	50	61	74	44	67	47
Radioactive waste (RW)	mg/kWh	1.7	2.2	2.6	1.6	2.4	1.7
Resources (R)	g/kWh	28	34	41	25	38	26
Energy (CED)	kJ/kWh	568	700	843	508	775	536

Table S3.11 - Sensitivity analysis results for the Oyster 800. Highest values for each impact category are highlighted in orange, and lowest values in green.

Impact category	Transport								Mass of steel	
	Onshore				Offshore					
	Overall		From Birmingham		Overall		Specialist sea vessels			
	90%	110%	90%	110%	90%	110%	90%	110%	90%	110%
Global warming (GW)	-0.52%	0.52%	-0.020%	0.020%	-0.025%	0.026%	-0.010%	0.011%	-8.6%	8.6%
Ozone depletion (OD)	-0.90%	0.90%	-0.033%	0.033%	-0.036%	0.037%	-0.014%	0.015%	-8.4%	8.4%
Ozone formation - Vegetation (OFV)	-0.62%	0.62%	-0.026%	0.026%	-0.075%	0.076%	-0.028%	0.029%	-8.2%	8.2%
Ozone formation - Human (OFH)	-0.60%	0.60%	-0.026%	0.026%	-0.072%	0.073%	-0.026%	0.028%	-8.1%	8.1%
Acidification (A)	-0.33%	0.33%	-0.014%	0.014%	-0.061%	0.061%	-0.012%	0.013%	-9.0%	9.0%
Terrestrial eutrophication (TE)	-0.70%	0.70%	-0.031%	0.031%	-0.097%	0.099%	-0.035%	0.037%	-8.6%	8.6%
Aquatic eutrophication - N (AEN)	-0.59%	0.59%	-0.026%	0.026%	-0.079%	0.081%	-0.029%	0.030%	-8.0%	8.0%
Aquatic eutrophication - P (AEP)	-0.15%	0.15%	-0.005%	0.005%	-0.007%	0.007%	-0.003%	0.003%	-9.0%	9.0%
Human toxicity air (HTA)	-2.04%	2.04%	-0.006%	0.006%	-0.007%	0.007%	-0.003%	0.003%	-6.8%	6.8%
Human toxicity water (HTW)	-0.12%	0.12%	-0.003%	0.003%	-0.002%	0.002%	-0.001%	0.001%	-6.4%	6.4%
Human toxicity soil (HTS)	-0.44%	0.44%	-0.005%	0.005%	-0.008%	0.008%	-0.003%	0.003%	-9.1%	9.1%
Ecotoxicity water - chronic (EWC)	-0.26%	0.26%	-0.003%	0.003%	-0.002%	0.002%	-0.001%	0.001%	-4.6%	4.6%
Ecotoxicity water - acute (EWA)	-0.22%	0.22%	-0.003%	0.003%	-0.002%	0.002%	-0.001%	0.001%	-4.7%	4.7%
Ecotoxicity soil - chronic (EWC)	-0.25%	0.25%	-0.007%	0.007%	-0.014%	0.015%	-0.005%	0.005%	-8.7%	8.7%
Hazardous waste (HW)	-0.52%	0.52%	-0.013%	0.013%	-0.013%	0.013%	-0.006%	0.006%	-8.9%	8.9%
Slags/ashes (SA)	-0.21%	0.21%	-0.006%	0.006%	-0.007%	0.007%	-0.002%	0.002%	-4.3%	4.3%
Bulk waste (BW)	-0.47%	0.47%	-0.015%	0.015%	-0.001%	0.001%	-0.001%	0.001%	-8.6%	8.6%
Radioactive waste (RW)	-1.27%	1.27%	-0.049%	0.049%	-0.055%	0.056%	-0.021%	0.022%	-8.0%	8.0%
Resources (R)	-0.34%	0.34%	-0.013%	0.013%	-0.015%	0.015%	-0.006%	0.006%	-9.2%	9.2%
Energy (CED)	-0.73%	0.73%	-0.028%	0.028%	-0.032%	0.032%	-0.012%	0.013%	-8.7%	8.7%

Table S3.12 - Sensitivity of the results for the Oyster 1 to key subsets of input data. Note that these are not all independent. Highest values for each impact category are highlighted in orange, and lowest values in green.

Impact category	Transport								Mass of steel	
	Onshore				Offshore					
	Overall		From Birmingham		Overall		Specialist sea vessels			
	90%	110%	90%	110%	90%	110%	90%	110%	90%	110%
Global warming (GW)	-0.20%	0.20%	-0.033%	0.033%	-0.015%	0.016%	-0.005%	0.006%	-6.1%	6.1%
Ozone depletion (OD)	-0.32%	0.32%	-0.053%	0.053%	-0.021%	0.022%	-0.007%	0.008%	-5.6%	5.6%
Ozone formation - Vegetation (OFV)	-0.29%	0.29%	-0.051%	0.051%	-0.051%	0.052%	-0.016%	0.017%	-6.4%	6.4%
Ozone formation - Human (OFH)	-0.28%	0.28%	-0.049%	0.049%	-0.049%	0.050%	-0.015%	0.016%	-6.4%	6.4%
Acidification (A)	-0.16%	0.16%	-0.023%	0.023%	-0.039%	0.040%	-0.006%	0.007%	-6.9%	6.9%
Terrestrial eutrophication (TE)	-0.31%	0.31%	-0.055%	0.055%	-0.061%	0.063%	-0.018%	0.020%	-6.5%	6.5%
Aquatic eutrophication - N (AEN)	-0.26%	0.26%	-0.046%	0.046%	-0.050%	0.052%	-0.015%	0.017%	-6.0%	6.0%
Aquatic eutrophication - P (AEP)	-0.07%	0.07%	-0.009%	0.009%	-0.005%	0.005%	-0.002%	0.002%	-6.8%	6.8%
Human toxicity air (HTA)	-1.06%	1.06%	-0.013%	0.013%	-0.006%	0.006%	-0.002%	0.002%	-5.6%	5.6%
Human toxicity water (HTW)	-0.07%	0.07%	-0.008%	0.008%	-0.002%	0.002%	-0.001%	0.001%	-5.6%	5.6%
Human toxicity soil (HTS)	-0.22%	0.22%	-0.010%	0.010%	-0.006%	0.007%	-0.002%	0.002%	-7.4%	7.4%
Ecotoxicity water - chronic (EWC)	-0.13%	0.13%	-0.008%	0.008%	-0.001%	0.001%	-0.001%	0.001%	-4.3%	4.3%
Ecotoxicity water - acute (EWA)	-0.11%	0.11%	-0.008%	0.008%	-0.002%	0.002%	-0.001%	0.001%	-4.3%	4.3%
Ecotoxicity soil - chronic (EWC)	-0.08%	0.08%	-0.010%	0.010%	-0.007%	0.008%	-0.002%	0.002%	-5.2%	5.2%
Hazardous waste (HW)	-0.25%	0.25%	-0.029%	0.029%	-0.010%	0.011%	-0.004%	0.004%	-6.6%	6.6%
Slags/ashes (SA)	-0.08%	0.08%	-0.011%	0.011%	-0.004%	0.004%	-0.001%	0.001%	-3.3%	3.3%
Bulk waste (BW)	-0.18%	0.18%	-0.034%	0.034%	0.000%	0.000%	0.000%	0.000%	-7.2%	7.2%
Radioactive waste (RW)	-0.48%	0.48%	-0.084%	0.084%	-0.034%	0.035%	-0.011%	0.012%	-6.0%	6.0%
Resources (R)	-0.15%	0.15%	-0.025%	0.025%	-0.011%	0.011%	-0.004%	0.004%	-7.4%	7.4%
Energy (CED)	-0.28%	0.28%	-0.049%	0.049%	-0.020%	0.021%	-0.006%	0.007%	-6.6%	6.6%

Table S3.13 - Sensitivity of the results for the Oyster 800 to key subsets of input data. Note that these are not all independent. Highest values for each impact category are highlighted in orange, and lowest values in green.

S4 Detailed comparison with Walker and Howell, 2011

As noted in the journal article, the estimated global warming impact and cumulative energy demand of the Oyster 1 are significantly higher than for the earlier study by Walker and Howell [2]. As the original calculations for that study are not available, it is not possible to entirely replicate it, but this section details attempts to identify where the main differences have arisen.

One of the key differences between the study by Walker and Howell is that a number of additional components were identified that were not included in the 2011 study; namely the subsea infrastructure for fixing the Oyster to the seabed, such as the piles and the pile connector frame. Furthermore, the earlier study excluded manufacturing processes. This analysis was repeated only including the components and life cycle stages explicitly described in [2], and the results are summarised in Table S4.1.

	Analysis excluding additional components and processes	**Walker & Howell, 2011**	**Difference**
Global warming (g CO_2 eq/kWh)	37	25	47%
Cumulative energy demand (kJ/kWh	422	236	79%

Table S4.1 - Impacts excluding materials and processes not considered by Walker & Howell [2]

It can be seen that this accounts for only a portion of the discrepancies between the results of this study and that by Walker and Howell. Another key difference between the two studies is in the treatment of recycling at the end-of-life. Accounting for environmental credits due to recycling is highly debated within Life Cycle Assessment, so in the analysis presented here the cut-off method has been applied. This avoids double-counting recycling credit by only including recycled materials consumed in the product life cycle within the system boundary, while materials that are recycled at the end-of-life leave the system [12]. Walker and Howell, however, used a different method that provided a recycling credit at the end of life. Without this credit the embodied carbon and energy of the Oyster 1 as calculated by Walker and Howell become 31 g CO_2 eq/kWh and 307 kJ/kWh respectively [2], only 21% and 38% lower than the adjusted values in Table S4.1.

This final discrepancy is likely due to Walker and Howell's inclusion of only the ten most used materials by weight, coupled with differences introduced by the different source LCI data; Walker and Howell used data from the Inventory of Carbon and Energy [13], while the analysis presented here used data from ecoinvent [14]. These datasets have an associated uncertainty of around +/-30%.

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