EcoWatt 2050

– Summary of the EcoWatt2050 research consortia approaches and findings

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Jonathan Side

Heriot-Watt University, Orkney Campus
Stromness, Orkney. KW16 3AW
<j.c.side@hw.ac.uk>

The EcoWatt2050 Consortium gratefully acknowledges financial support for this work from the EPSRC Grand Challenge II award (EPSRC Grant Ref: EP/K012851/1), and contributions from Marine Scotland Science and the Marine Alliance for Science and Technology in Scotland (MASTS). We acknowledge the support of the various representatives who have served on the Steering Group for this research and would like to thank the numerous industry personnel who have contributed to these meetings and our workshops and discussions, from the software, marine renewables device and project developer community. A special thanks should go to those organisations who provided data for the research.
Simple taxonomy of principal impacts from wave and tidal development

- Removal of energy
- Physical presence of installations
- Creation of new ecological space
- Impacts on other users and other human activities

**TERAWATT** ~ Investigation of impacts of wave and tidal energy development in Scotland at the present envisaged scale of development.

**ECOWATT2050** ~ Impacts of very large scale wave and tidal arrays in all potential development areas in Scottish waters assessed in the light of climate change effects.
A “toolbox” of methods to better understand and assess the effects of tidal and wave energy arrays on the marine environment. Published in book and electronic versions by MASTS.


Provides a full and detailed account of the “toolbox” methodologies developed by the TeraWatt Consortium.
Introduction to and Overview of the TeraWatt Research
J Side (Heriot-Watt University) M James (Marine Alliance for Science and Technology Scotland) I Davies (Marine Scotland Science) M Heath (University of Strathclyde), H Karunathra (University of Swansea) V Venugopal (University of Edinburgh) A Vögler and M Burrows (University of the Highlands and Islands)

Data acquisition and the development of realistic tidal and wave energy scenarios for numerical modelling of Orkney Islands waters, Scotland
Lead Author: Rory O’Hara Murray (Marine Scotland Science)

Implementation of tidal turbines in MIKE3 and Delft3D models of Pentland Firth & Orkney Waters
S Waldman, S Baston, J Side (Heriot-Watt University), R Nemalidinne, V Venugopal (University of Edinburgh), A Chatzirodou (Swansea University)

Numerical modelling of wave energy resources and assessment of wave energy extraction by large scale wave farms
V Venugopal, R Nemalidinne (University of Edinburgh), R MacIver, A Vögler (University of the Highlands and Islands) and Tay Zhi Yung (University of Edinburgh)

Effects of marine energy extraction on non-cohesive sediment transport and morphological change in the Pentland Firth and Orkney Waters.
I Fairley, A Chatzirodou and H Karunarathna (Swansea University)

Modelling the effects of energy extraction on spatial patterns of suspended sediment.
A Sabatino, M Heath, D McKee, C McCaig (University of Strathclyde)

Summary of TeraWatt conclusions of relevance to the governance of marine energy development
Authors ALL – Lead Author J Side (Heriot-Watt University)

Contains headline findings for regulatory authorities and industry consenting activities, demonstrating the application of the “toolbox” methodologies
ECOWATT2050 – responding to science questions posed by the regulator, Marine Scotland:

1. The role of marine spatial planning for very large scale wave and tidal array deployments.
2. Criteria to determine the ecological limits for very large scale energy extraction.
3. How to differentiate the effects of climate change from energy extraction?
4. How might very large scale array deployments ameliorate or exacerbate climate change effects?

OR: How can marine planning and policy maximise the potential marine renewables extraction while minimising environmental impacts and ensuring that these meet the requirements of European law?

Following TeraWatt research the consortium was extended to include others with climate change and marine mammal and seabird interests.
EcoWatt2050 Partners and Management:

Multi-institution EPSRC research project established under the Marine Alliance for Science and Technology Scotland (MASTS), involving the Universities of:-

- Heriot-Watt,
- Edinburgh,
- Aberdeen
- Highlands and Islands (LCC and SAMS),
- Swansea,
- Strathclyde
- National Oceanography Centre
- and with Marine Scotland Science as full consortium partners.

MASTS play a key role in organising Steering Group Meetings and participation in outreach activities.
Tidal energy
TeraWatt - Round One array scenario for PFOW

• PFOW contains a number of tidal energy lease sites

• This is a realistic near future scenario

• What about very large scale 2050 scenario across the whole of Scotland?
Areas of search for tidal stream energy from the Scottish Government’s National Marine Plan

- 10 sites across Scotland
- Different levels of resource in each area
- Pentland Firth the most important and complex
- Detailed study of the Pentland Firth required
Modelling the near-field changes to tidal speed due to tidal energy extraction

- PFOW hydrodynamic model with tidal turbines
- Large array scenario in Pentland Firth
- Different number of turbines considered
- Changes to tidal currents
- Scale/intensity of change varies with different scenarios
Modelling Present and Future climate scenario

Present hydrodynamic conditions and one single, physically plausible, representation of the future conditions in 2050 were reproduced by the Scottish Shelf Model and compared with ocean state perturbed by tidal stream energy extraction.

SCOTTISH SHELF MODEL:
Unstructured 3D FVCOM ocean model with variable resolution down to 500 m – 1km close to the coast and 20 vertical levels, forced by tides and atmospheric model output.

FUTURE CLIMATE SCENARIO:
• Use one single climate model and one emission scenario – HadGEM2-ES with RCP8.5
• Use Delta-change approach – adjust present-day field to future by applying a multiplicative or additive factor for each variable.
• Sea level increases approximately 25 cm.
The ocean response to very large tidal stream turbine arrays and climate change RCP8.5 future scenario

- 3.7 GW tidal energy extraction was simulated by representing very large tidal stream farms around Scotland
- Be careful! No present plan to deploy such a big number of turbines, this is an extreme best (worst) case scenario to explore the environmental impacts.

**Energy Extraction (EE) effects:**

- Far-field detectable changes in tidal range (±1-6 cm) that mainly increase “upstream”
- decrease “downstream”
- Tidal currents could also be affected with ± 0.02 m/s far-field changes:
  - slowing down due to the turbines
  - speeding up due to flow diversion and blocking
The ocean response to very large tidal stream turbine arrays and climate change RCP8.5 future scenario

- **Energy Extraction (EE) vs Climate Change (CC) effects:**
  - The strength of summer stratification was found to slightly increase (< 20%) to tidal energy extraction in present climate conditions:
  - this is due to the decrease of tidal mixing energy
  - Future hydrodynamic conditions in 2050 showed a future increase in summer water column stratification driven by the temperature increase
  - the change in stratification is one order of magnitude larger and over a much wider area than the one generated by tidal stream energy extraction.

**Summer Water stratification**

How does the ocean response translate into impacts on ecosystem habitats and animals’ behaviour?
Impact of large scale arrays on shelf-wide turbidity distributions

Seabed mud%

Mathematical model of turbidity profiles – inputs: bed shear stress and seabed mud%

FVCOM simulations – with and without tidal arrays (+ wave climatology)

Model sea surface turbidity – baseline

Predicted CHANGE in turbidity due to arrays

Satellite sea surface turbidity – baseline calibration

CONCLUSION – arrays could cause up to 15% change in sea surface turbidity, >20% in terms of light penetration
Responses of benthos to climate change and tidal energy extraction: Priority Marine Habitats

Outputs from physical models allow us to describe the environmental conditions associated with the presence of a given habitat.

Sea-pen and burrowing megafauna PMH

- Climate change has much larger influence than energy extraction
- Potential winners and losers – modest losses in this example
- Details hazardous to interpret
- Working towards greater realism in models

EcoWatt2050 ~ Heriot-Watt University
The effect of Climate Change (CC) and large scale Energy Extraction (EE) on Mobile Marine Species: The effects on both Predators and their Prey

Choice of physical and biological Parameters that change with BOTH CC and EE
BT, PEA, SP, NPP, max CHL

Seals & Porpoise: Grey, Harbour, (up to 10 years tagging/survey)
> 20 km
> 60 km
> 100 km

Birds: Gannets, Kittiwakes, Guillemots
(> 30 years ESAS survey data)
Pursuit diver
Plunge diver
Surface feeder

Fish: Herring, Sandeels
(20-50 years of survey/CPR data)
Highly mobile
limited mobility
Metrics of change: 3 Methods
Degree of joint predator prey (JPP) spatial overlap (common spatial trend), movement of centre point of JPP and movement of single species

Climate change predictions of changes in spatial overlap

Distance (km) of movement of centre point of JPP and Single species

<table>
<thead>
<tr>
<th>Species</th>
<th>EE</th>
<th>CC</th>
<th>CC+EE</th>
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<tr>
<td>Grey Seals</td>
<td>0.5</td>
<td>6.8</td>
<td>7.0</td>
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<tr>
<td>Herring (age 2&amp;3)</td>
<td>19.8</td>
<td>72.7</td>
<td>72.5</td>
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<tr>
<td>Grey Seals + Herring</td>
<td>9.6</td>
<td>56.9</td>
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<tr>
<td>Kittiwakes</td>
<td>1.2</td>
<td>19.1</td>
<td>18.4</td>
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<tr>
<td>Sandeels</td>
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<td>37.6</td>
<td>33.7</td>
</tr>
<tr>
<td>Kittiwakes + Sandeels</td>
<td>3.7</td>
<td>50.5</td>
<td>48.9</td>
</tr>
</tbody>
</table>
Wave energy
Assessment and optimisation of large wave arrays performance

WAMIT used to predict detailed behaviour of wave devices.

This used to parameterise devices in MIKE.

MIKE used for simulations of large arrays in real location.

Wave Energy Convertor Arrays
Large scale wave arrays

West Orkney: Jan-June, 2010

Baseline  
1 Row  
2 Rows  
3 Rows
Defining ecological niches for habitat-forming species

UK: 6000 surveys

Linked to large-scale environmental patterns (temperature, ocean colour, waves)

Gives models for habitat suitability for kelp

Laminaria hyperborea
Change in habitats around extraction devices: waves and climate

Change in biomass of kelp

Climate change
- Cold-water species decrease (-21 to -53%)
- Warm-water species increase (+19%)

Wave extraction effects
- Wave-exposed species decline (-1-2%)
- Sheltered species increase (+0.8 to +2.9%)
**Tidal Energy Extraction**

- Tidal energy extraction will change the tides. Energy extraction from the Pentland Firth will alter the transport through the channel, the tidal range and the speed of the currents. The level of change will depend on the amount of power extracted and the positioning and layout of tidal turbine arrays.

- Far-field changes suggest an upstream increase in tidal range from energy extraction and a downstream decrease; slight far-field changes in tidal current are also observed.

- Installing tidal energy arrays in the areas identified for exploitation to the west and north of Scotland will result in widespread changes in turbidity and corresponding penetration by sunlight. At turbidity levels typical of inshore waters, this change may result in a 25-30% change in light intensity at any given depth.

- Climate change and energy extraction both increase stratification, however in the climate change scenario considered the change is an order of magnitude greater.

- Tidal energy extraction will alter circulation around seabed features, which may lead to changes in bed level. In our study of sandbanks in the Inner Sound, we have shown that wave action during storms increases the magnitude of the predicted change from tidal energy extraction.

- Decrease in turbidity may offset the increase in stratification caused by climate change.
Tidal Energy Extraction (contd)

• Our study of the effects of energy extraction on the predator prey relationships of marine mammals and seabirds suggest that energy extraction will have negligible consequences, whereas the impact of climate change could be up to ten times more severe.

• Tidal energy extraction is predicted to have only negligible effects on Priority Marine Features such as seapen and burrowing megafauna communities, whereas climate change is predicted to result in far more significant shifts and in the availability of suitable habitats for these.

• It is important that marine planners consider where tidal energy developments should be sited, and the array configurations, in order to maximise the energy extracted and minimise environmental change.

Wave Energy Extraction

• In contrast, the predicted effect of climate change in the foreseeable future on waves in these areas of Scotland is small and much less than the effect of wave energy extraction. A reduction in up to 50% of mean wave height is predicted in the lee of large wave energy converter arrays. Effects, however, are limited to the envelope between the arrays and the shoreline, and in some cases a reduction in mean wave height may serve to protect coastal heritage.

• An examination of the patterns of kelp distribution suggest that climate change will have a far greater effect, with significant decreases in cold water species and increases for warm water species that are far greater than any changes predicted from wave energy extraction.
THANK YOU.....

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