Biomimicry for Coastal Eco-Cities:

Towards a Carbon Neutral Dover, UK

Anjali Deshpande · Aik Ling Goh · Adriaan Goossens · Saeed Javdani

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Foreword

The Lloyd's Register Foundation (LRF) in collaboration with the University of Southampton instituted a research collegium in Southampton between 18 July and 11 September 2013.

The aim of the research collegium has been to provide an environment where people in their formative post-graduate years can learn and work in a small, mixed discipline group drawn from a global community to develop their skills whilst completing a project on a topic that represents a grand challenge to humankind. The project brief that initiates each project set challenging user requirements to encourage each team to develop an imaginative solution, using individual knowledge and experience, together with learning derived from teaching to form a common element of the early part of the programme.

The collegium format provided adequate time for the participants to enhance their knowledge through a structured programme of taught modules which focussed on the advanced technologies, emerging technologies and novel solutions, regulatory and commercial issues, design challenges (such as environmental performance and climate change mitigation and adaptation) and engineering systems integration. Lecturers were drawn from academic research and industry communities to provide a mind-broadening opportunity for participants, whatever their original specialisation.

The subject of the 2013 research collegium has been systems underpinning coastal eco-cities.

The 24 scholars attending the 2013 collegium were teamed into five groups. The project brief included: (a) quantification of the environmental challenge; (b) understanding of the geo-political legal-social context; (c) one integrated engineering system for a coastal eco-city; (d) economics and logistics challenges.

This volume presents the findings of one of the five groups.

R A Shenoi, P A Wilson, S S Bennett (University of Southampton)
M C Franklin, E Kinghan (Lloyd's Register Foundation)
2 September 2013

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We are thankful to our home universities for their understanding and willingness to support this opportunity and grant us the time investment needed for this Research Collegium.

No Research Collegium is complete without Mrs. Aparna Subaiah-Varna and Mrs. Sandra Emmerson. We thank them for the love, care and all the effort they have invested to make our stay as pleasant and enjoyable as possible.

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We could not have done this without the support of all the Research Collegium scholars and the support from our families back home. Two months is a long time, but with friends to build on, every obstacle can be overcome.

And finally, special thanks go to Julio Salcedo Castro, who had to leave us mid-way, but did not give up and kept supporting us to the best of his ability.

Anjali Deshpande, Aik Ling Goh, Adriaan Goossens, Saeed Javdani

2nd September 2013

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Executive summary

In 2004, the 30-year update to the 1972 report 'The Limits to Growth' has reiterated the Malthusian proposition that current industrial practices could lead to a sudden and uncontrollable decline in population and industrial capacity. Today, rising sea levels, biological extinction rates and soil degradation all point towards the world being in a state of overshoot. The most vulnerable cities are those on coastlines, which face flooding risks. As such, it is imperative that coastal cities develop into coastal eco-cities, which aim to reduce environmental impact, improve human well-being and life, and stimulate growth through a harmonious relation between the land and the sea.

Dover is the focus of coastal eco-city development in this book due to its role as one of the UK's main trade gateways with continental Europe. As a busy international commercial port, Dover produces significant carbon emissions, arising from high levels of transportation activity. In addition, a flood risk assessment concluded that Dover port has low risk of flooding due to geological protection from the white cliffs. Therefore, the focus is to work towards a carbon neutral Dover. In this respect, this book looks at solutions using biomimicry, the practice of developing sustainable human technologies inspired by nature.

This book identifies two most significant means of reducing Dover's carbon footprint, namely through the use of renewable energy and carbon management. The development of a 2.4 MW near-shore marine energy harvesting plant using the Oyster Wave Power technology at the port leads to estimated savings of 3200 tonnes of CO_2 per year. This offsets the port's carbon emissions by about 25%. A 40 MW Oyster farm along the white cliffs also protects the cliffs from coastal erosion on top of providing energy. In terms of carbon management, the eco-cement concept produces calcium carbonate from carbon emissions and seawater at the CEMEX Dover plant. Calculations show that 0.5 tonnes CO_2 is sequestered per tonne of eco-cement, while CEMEX emits 0.612 tonnes CO_2 per tonne of conventional cement. This implies that eco-cement could possibly reduce the industry's effective CO_2 emissions to 0.112 tonnes CO_2 per tonne of cement.

Indeed, the transition to a carbon neutral Dover is a challenging long-term process. It requires an active decision to switch to systems thinking and re-design society's way of living. Nonetheless, it is of utmost importance that leaders in politics, industry and academia collaborate to bring about a world that is not only functional and sustainable, but also deeply desired by all.

1 Introduction

Since the earliest settlements, living near oceans, rivers and lakes have had obvious advantages: they provided water and food, trade and travel, and strategic strongholds in times of turmoil (Timmerman & White, 1997). This has served the human race well for many centuries, but nowadays these settlements are facing problems: not only current problems, but also problems in the foreseeable future.

Timmerman and White (1997) identified seven potential issues that coastal cities face concerning city-coast interaction:

- “cities around the world are rapidly degrading and simplifying their coastal ecosystems;
- the ecological reasons why cities were originally located on coastal zones are under threat;
- there is a relationship between the quality of city life and the quality of the local natural ecosystem, and it is likely that the city changes the mix of what it requires from the coastal ecosystem incrementally as that system degrades;
- the city ecosystem and the coast ecosystem will have different, but connected, cycles of operation. These relationships will be complex;
- there will be different patterns of coast/city evolution;
- the social response to the deterioration of the urban ecology will often encourage the private replacement of public services for individual households. This is individually beneficial, but likely to contribute to the spiralling down of overall social and ecological decline;
- the policy responses to changes in coast-city interactions will be complicated by multiple jurisdictions and hindered by a ‘mental map’ that separates the coastal ecosystem from the city.”

This is not all. The urban population is growing, and, for the first time in history, our immediate environment will be the built environment. However, we remain dependant on our environment, and cities are becoming major drivers for ecological change. Because, as the inhabitants lose their sense of direct connection to nature, the city demands ever-more resources from that very same nature (Rees, 2001). Sawada, Murata, and Fujii (2004) reach the same conclusion and find that, because of the population and industry concentration and overdevelopment in coastal cities, all over the world coastal cities both have caused and are causing coastal environmental and pollution problems, leading to the deterioration of the comfort and amenity of these coastal cities for human life.

Adding to that, Hunt and Watkiss (2011) elaborate on the threats to cities by the effects of climate change. They stress the value of the city, because of their high population densities, their importance for many economic and social activities and their roles as centres of governance, and continue to summarize the most important effects of climate change likely to threaten cities:

- “effects of sea level rise on coastal cities (including the effects of storm surges);
- effect of extreme events on built infrastructure;
- effects on health arising from higher average temperatures and/or extreme events;
- effects on energy use;
- effects on water availability and resources.”

Yao (2013) adds to the list:

- changes in demands for goods and services to this list.

He continues to explain that the main causes for climate change are considered to be the greenhouse gas emissions due to burning fossil fuels, mainly being carbon dioxide (CO_2). However, besides climate change he also identifies resource depletion and energy supply as key issues. He finally stresses that these issues need to be overcome if mankind is to thrive on Earth.

As shown, although the city itself may be considered a great achievement of mankind, cities – and especially coastal cities – are facing important and urgent issues. To address these issues, Timmerman and White (1997) proposed an ecosystem approach. They see the ecosystems approach as the appropriate integrator for the issues coastal cities are facing. Devuyst, Hens, and Lannoy (2001) argue that sustainable urban development will reduce our impact on the environment and help create sustainability. Yao (2013) states there are two ways to deal with these issues and create sustainability: adaptation or mitigation. Adaptation involves improvement by design and mitigation looks at reducing energy consumption in existing urban environment. To execute either, he proposes a systemic, holistic and integrated approach, because sustainable urban environments are systems.

It is our view that coastal cities should move towards coastal eco-cities. Moving towards coastal eco-cities, these cities will find a drive and learn a way to work with nature, rather than against it. These cities will continue to prosper and benefit from the advantages the coasts have to offer. Such cities must be coastal eco-cities, designed, built and evolved in harmony with nature. These are the cities that will be able to meet the new rules and survive. Coastal cities should, step by step, pave their ways and advance towards becoming eco-cities.

First, this book will propose a means for developing coastal eco-cities: biomimicry. Biomimicry is the study of nature and its principles in order to solve our human problems.

Second, this book will demonstrate the use of biomimicry for developing coastal eco-cites by means of a case study of Dover, UK. Investigated is how biomimicry can be used to progress towards a carbon neutral Dover. This is done by researching the possibilities for carbon management and renewable energy generation.

The contents of this book are as follows:

- Chapter 2 introduces the definition of city, coastal city, eco-city, and subsequently coastal eco-city.
- Chapter 3 presents the concept of biomimicry along with some of its applications.
- Chapter 4 describes the physical and environmental constraints, the economic impact and legislative issues pertaining to Dover.
- Chapter 5 discusses the renewable energy possibilities in Dover, and presents a project proposal for harvesting marine energy using the Oyster Wave Power Technology
- Chapter 6 presents the carbon emissions levels in Dover, along with current efforts in carbon management. Thereafter, the application of the eco-cement concept in Dover is reviewed.
- Chapter 7 provides the conclusion and future work of the study.

2 Coastal Eco-Cities

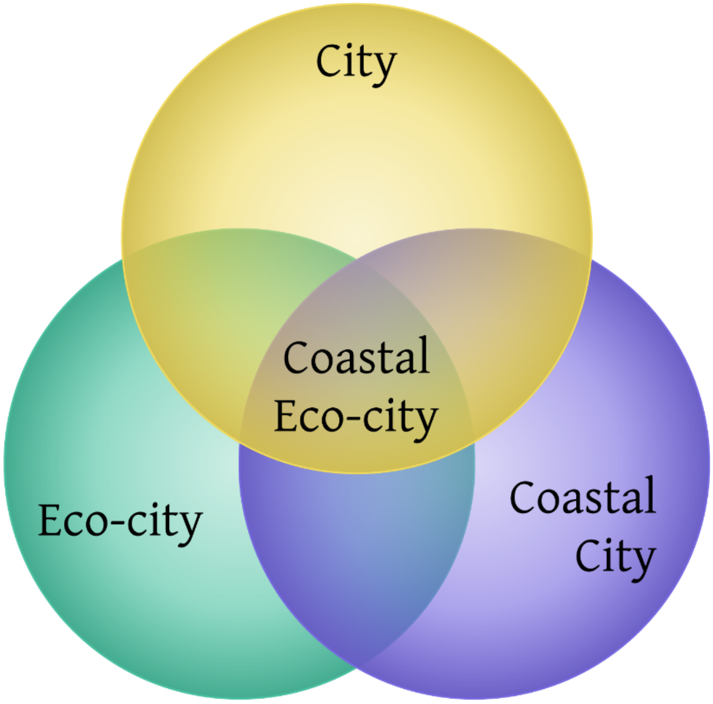


Figure 1: The coastal eco-city as combination of the city, the coastal city and the eco-city.

It has to be clear what a coastal eco-city actually is, before any research on coastal eco-cities can be started. For this a combination of the definitions of a city, a coastal city and an eco-city is used, as shown in Figure 1. These three, the city, the coastal city and the eco-city, are discussed in the following sections.

2.1 The City

It is tempting to try defining a city by the number of residents or its area, but there is no single definition of a city when it comes to size or number of residents. Current dictionaries define a city as a large or important town. In the United Kingdom such a town is historically considered a city when it contains a cathedral, in the United States of America the town needs to be incorporated by the state or province (Merriam-Webster, 2013a; Oxford Dictionary, 2013a).

These definitions are more historical than they are current. So, at the core of the city lie not these arbitrary features, but a social fundament, where the size should always be expressed a function of the social relationships to be served (Mumford, 1937).

Bridge and Watson (2000) state that it is no longer possible to look at cities from one perspective now that the cultural, social, political and economic aspects of cities are so related and intertwined. They argue that only if cities are considered in this complexity, it will be able to address the urgent social, economic and environmental problems cities nowadays face.

It is clear a city cannot be defined by its size or number of inhabitants, rather it needs to be considered in terms of its social and economic significance, where a city is an urban area that fulfils a significant role within its surroundings.

2.2 The Coastal City

As with the city, coastal – or even coast – is also ill-defined as it generally means land adjoining or near the sea or a shore (Merriam-Webster, 2013b; Oxford Dictionary, 2013b). Timmerman and White (1997) are more specific. They define a coastal city as "conurbations of more than 100,000 people contiguous with, significantly oriented towards, and/or actually or potentially affected hydrodynamically by an extensive body of surface fresh or salt water," (p. 210) and a coastal-urban zone as "a bi-polar area, bounded on the landward side by the local hinterland of the cityscape, and on the waterward side by the functional ecosystemic integration of the coastal littoral zone" (p. 210).

Although the number 100,000 seems arbitrarily chosen, and Timmerman and White already state their definitions are "obviously controversial", the important point is that they focus on the relation the urban area has with the water, as shown in Figure 2. Not so much the size of the coastal city or the mere fact that a city is next to some body of water, but the relationship with the water is the main classifier for a coastal city. This relation between the water and land must not be underestimated, as coastal zones contain many of the world's most complex, diverse and productive ecosystems, in both biological as economic sense (Fazi & Flewwelling, undated).

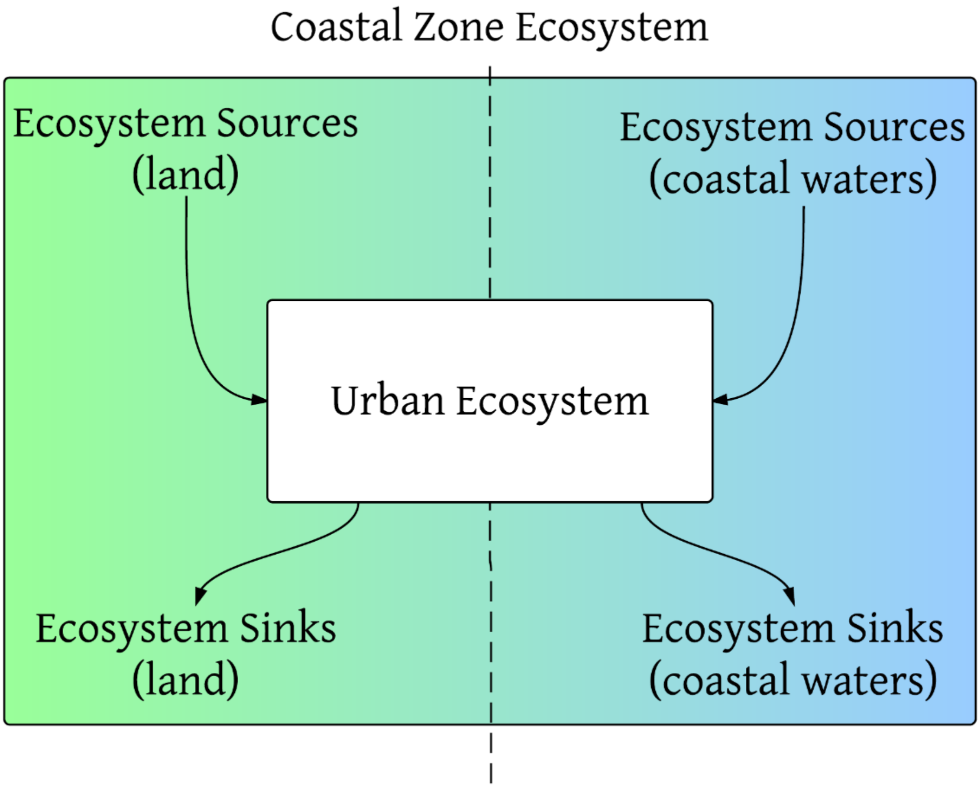


Figure 2: The urban-coastal model (Timmerman & White, 1997).

However, for the body of water, Timmerman and White (1997) include rivers, lakes and oceans. This is too broad, for rivers and lakes can lie far inland, many hundreds of kilometres away from the actual coast. Therefore, only the ocean (or sea) should be the leading body of water for a city to be classified as a coastal city.

In conclusion, for a city to be a coastal city, its size is of limited importance. Rather the relation it has and maintains with the sea is the important classifier for the coastal city.

2.3 The Eco-City

The concept of eco-city is researched extensively by various scholars the past 40 years. Roseland (1997) explains the origins of the term eco-city, stating that Richard Register was the first man to coin this term in 1975, and elaborated on it in his 1987 book 'Eco-city Berkeley.' From that point the eco-city vision gained popularity throughout the years.

According to Roseland, Urban Ecology (Register's company), stated in 1996 that it wanted to create ecological cities following ten basic principles:

1. “revise land-use priorities to create compact, diverse, green, safe, pleasant and vital mixed-use communities near transit nodes and other transportation facilities;
2. revise transportation priorities to favour foot, bicycle, cart, and transit over autos, and to emphasize ‘access by proximity’;
3. restore damaged urban environments, especially creeks, shore lines, ridge lines and wetlands;
4. create decent, affordable, safe, convenient, and racially and economically mixed housing;
5. nurture social justice and create improved opportunities for women, people of colour and the disabled;
6. support local agriculture, urban greening projects and community gardening;
7. promote recycling, innovative appropriate technology, and resource conservation while reducing pollution and hazardous wastes;
8. work with businesses to support ecologically sound economic activity while discouraging pollution, waste, and the use and production of hazardous materials;
9. promote voluntary simplicity and discourage excessive consumption of material goods;
10. increase awareness of the local environment and bioregion through activist and educational projects that increase public awareness of ecological sustainability issues.”

However, Roseland states that, at the time of writing, there is no single accepted definition of ‘eco-city’ and that the eco-city theme does not stand alone, but is part of a bigger, more complex concept.

One year after Roseland, in his review of eco-neighbourhoods, Barton (1998) presented two – more or less – formal definitions of similar concepts. Firstly, one of the Forest Village, which would be ‘a balanced community for people of all ages and incomes, where people can live, work and enjoy a vibrant community life, the majority without the need to commute and where everyone could feel a sense of personal belonging. It would provide affordable housing, work opportunities, food production, energy and water conservation as well as self-reliance for its residents in an ecologically aware and sensitive way.’ Secondly, he presents the principles proposed by the 1995 Freiburg Statement on New Urban Neighbourhoods:

- “heterogeneous social composition, with special attention to the needs of children, elderly and low-income groups;

- a pedestrian-dominated public realm to facilitate ‘good social life’ and provide an attractive human-scale environment;
- diversity of use – housing, work, shopping, civic, cultural and health facilities – in a fine-textured, compact, low-rise urban fabric;
- active and frequent participation of all segments of the population in planning and design of the area, thus an incremented not authoritarian design process;
- architectural identity that is rooted in the collective memory of the region, reflecting characteristics most valued by the local community;
- pedestrian, bicycle and public transport networks within the neighbourhood and linking to the city as a whole, discouraging automobile use;
- ecologically responsible development principles consistent with social responsibility and cutting energy use and pollution.”

Furthermore, Barton categorizes eco-neighbourhoods in six types.

1. Rural eco-villages: rural, land based villages where the economy is provided by farming, small-holdings, fuel crops and on-site tourism, also many energy, water and food loops are closed.
2. Televillages: not necessarily land-based villages that rely on telecommunications and the Internet for home or locally based work, outsourcing and freelancing.
3. Urban demonstration projects: experimental projects, for example as part of a competition or research project, promoted by local or national governments.
4. Urban eco-communities: eco-communities inspired by social ideals of conviviality and mutual support.
5. ‘New urbanism’ development: this are projects on a larger scale, promoting the concept of transit oriented developments, compact pedestrian-scaled neighbourhoods focussed on transit stations for local accessibility by foot and regional accessibility by public transport.
6. Ecological townships: the objectives of the transit oriented developments are translated to an even larger scale, so whole urban neighbourhoods, townships, towns and cities evolve towards sustainability.

In a more recent attempt to grasp the concept of eco-cities, Kline (2000) defines four characteristics of eco-cities, and proposes to use indicators to measure these characteristics. The characteristics she proposes are (a) ecological integrity; (b) economic security; (c) quality of life; and (d) empowerment with responsibility. She then provides five guides for creating eco-city indicators.

1. Focus on core concerns, rather than symptoms.

2. Address a community's assets rather than its deficits.
3. Look at the city in its neighbourhood and regional contexts.
4. Choose indicators that respond to people's own sense of their priorities.
5. Craft indicators that raise questions rather than answer them.

Later, Roseland (2001) again argues that eco-cities are part of a larger concept, and can be used as a framework to integrate seemingly disconnected ideas about urban planning, transportation, public health, housing, energy, economic development, natural habitats, public participation, and social justice. He places eco-cities in the context of several other related movements or paradigms: (a) healthy communities; (b) appropriate technology; (c) community economic development; (d) social ecology; (e) the Green movement; (f) bioregionalism; (g) native world views; and (h) sustainable development.

In a global survey, Joss (2010) identified 79 eco-city initiatives throughout the world, and recognizes the emerging trend concerning eco-cities, some parts of it even becoming increasingly mainstream. However, he found that both conceptually and in practice, eco-cities come in many varieties and flavours, and a single, standard definition has yet to emerge. He does suggest three criteria define eco-cities: (a) scale – in terms of area, infrastructure and innovation; (b) sectors – eco-cities develop across multiple sectors, such as housing, energy, transport etcetera; and (c) policy – they are formulated as, embedded in, and supported by a policy process. Finally, Joss underlines the use of the term eco-city for branding and marketing purposes as one of the current driving phenomena.

One of the most recent definitions of eco-cities comes from Register's current company, Ecocity Builders, where the original list is shortened to four points (Ecocity Builders, undated), in which an eco-city is:

- “an ecologically healthy human settlement modelled on the self-sustaining resilient structure and function of natural ecosystems and living organisms;
- an entity that includes its inhabitants and their ecological impacts;
- a subsystem of the ecosystems of which it is part — of its watershed, bioregion, and ultimately, of the planet;
- a subsystem of the regional, national and world economic system.”

In conclusion, although extensive thinking has been done on what an eco-city is, a coherent single definition of the concept has yet to emerge. However, there seem to be three concepts that grasp the core values and lie at the base of an eco-city: human well-being, sustainable growth and harmony. These are the three concepts that resonate throughout all the definitions formed.

2.4 The Coastal Eco-City

Literature specifically on coastal eco-cities is rare. However, Sawada et al. (2004) elaborate on coastal eco-cities in relation with the Osaka Bay area, and propose a model for coastal eco-cities shown in Figure 3. They state that the coastal area has certain characteristics, mostly overlooked by current economic views. Based on these characteristics is the space needed for the coastal eco-city, where cooperation and interdependence of land and sea are a must. Lastly, they mention the functions of the coastal eco-city. According to them, these three factors together form the coastal eco-city.

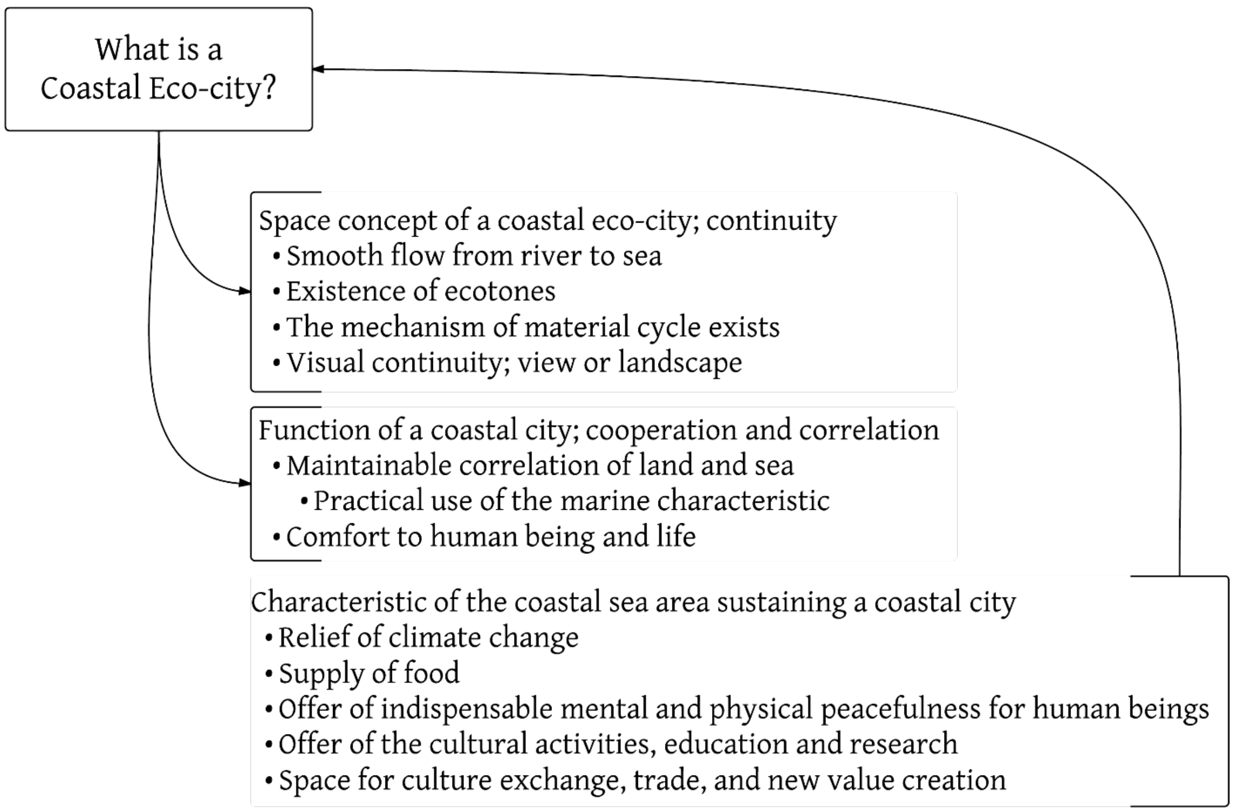


Figure 3: The coastal eco-city model by Sawada et al. (2004)

In the light of the above and combining the above findings on the city, the coastal city and the eco-city, a definition of the coastal eco-city can be formed. A city is an urban area that fulfils a significant social and economic role, a coastal city has an intricate relationship with the sea, and an eco-city aims for human well-being, sustainability and harmony. These three aspects are formalized in the following definition of the coastal eco-city:

- a coastal eco-city is a socially and economically significant urban area near the sea, which aims to reduce environmental impacts, improve human well-being and life, and stimulates growth through a harmonious relation between the land and the sea.

This definition by no means pretends it is the only one, single, perfect definition. However, it is a both concise and workable definition, serving as a starting point for not only this book, but hopefully also for a broader discussion on coastal eco-cities.

2.5 Legal and Policy Challenges to Developing Coastal Eco-Cities

There is a general agreement among scholars, scientist and policymakers that the development of eco-cities is perhaps one of the most reliable responses to climate change issues. Nevertheless, conversion of existing cities into eco-cities is not a simple task. The conversion will be even more complex in coastal cities, due to existence of ecotones, where land and water meet and integrate and many problems such as water level rise, coast erosion and marine and terrestrial biodiversity decline often arise.

It is estimated that today approximately 3 billion people, about half of the world's population live within 200 kilometres of coastlines and this figure is believed to double by 2025 (Creel, 2003). Coastal areas have always been attractive regions for urban development due to their economic benefits and food production. The coastal population growth during the last century, accompanied by economic and technological developments, which is consequently threatening the existing ecosystems, has raised concerns among policymakers and coastal resource managers.

Development of coastal eco-cities requires enormous financial and technological resources. It must be kept in mind that successful completion of such projects is highly dependent on their acceptance by public and long term maintenance of their sustainable features. Besides, presence of a suitable and reliable regulatory and administrative framework during the development and future maintenance of the city are important considerations. (Gunawansa, 2011).

During the transformation of a coastal city, timescale is probably one of the main issues. In most jurisdictions, planning cycle is mostly happening in 20 to 30 years; whilst in city transformation the timescale is much longer and sometimes maybe 100 years. The bigger challenge in policy making for this transformation is the political system which is a 4 to 5 years cycle. Therefore, planning for development of eco-cities has to be dynamic. The problem is emphasised even more with enormous cities where there are different jurisdictions adding to the complexity.

In order to define a regulatory framework for developing coastal eco-cities, all the regulations and guidelines that directly or indirectly influence urban planning, onshore and offshore constructions in a region must be considered. To provide a meaningful and suitable sample of those legislations, all the laws and regulations for sustainable development in the following areas must be studied:

- urban planning;
- environmental law and policy on sustainable development;
- climate change and energy;
- waste management law and policy;
- protection of natural areas (including aquatic environment);
- natural resource management;
- environmental assessment and justice;
- housing;
- other laws that make explicit reference to sustainability.

In this book only those areas which are related to the proposed projects have been assessed.

3 Biomimicry

3.1 Definition

In a very simplified way biomimicry or biomimetics could be defined as the use of nature in its most natural form to create man-made objects. The term comes from a combination of Greek words, bios meaning life and mimesis meaning to imitate. The Merriam Webster uses the word biomimetics and defines it as, "the study of the formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones" (Biomimicry 3.8, 2012). It is to use nature as model, measure and mentor (Benyus, 1997).

3.2 Frontrunners, Propagators and Leaders

In the 1960's Schmitt suggested the word Biomimetics. It was listed in the Webster's dictionary in 1974 (Swiegers, 2012). The popularization of 'Biomimicry', is largely credited to Janine Benyus . Widely known as the woman who has opened our eyes to the possibility of modelling technology using nature. Some of the other pioneers in the field are : Wes Jackson – for agriculture, Thomas Moore and others – energy, Jeffrey Brinker – manufacturing, Herbert Waite – underwater glue, Peter Steinberg – communication or biosignal, Bruce Roser – refrigeration, Knight and Vollrath – manufacturing fibres, Daniel Morse – energy, Joanna Aizenberg – lenses, Jay Harman – propellers, A.K.Geim – physical adhesion, Richard Wrangham – medicine, Thomas Eisner – medicine, Jeremy Mabbit – optimization. In the field of Industrial Ecology there are many researchers who are trying to find methods to apply biomimicry to economy, efficiency and co-operation.

3.3 Examples of Biomimicry

3.3.1 Architecture

Some of the examples are like the East gate Centre in Harare, Zimbabwe, which has used a combination of traditional masonry and the mounds of African termites which are self-cooling (Doan, 2012), shown in Figure 4. The building has no air conditioning or heating but stays regulated throughout the year with a substantial savings on energy. It is estimated that the energy usage is 10% lower than that used by a building of the same size. In the industrial district of Izola on the Slovenian coast there is a sea side structure which has been build using guidelines from the modular honeycomb structure which we see in a beehive. This is a low income residence in the area (Chino, 2011).

Figure 4: Eastgate Centre Harare Zimbabwe (Doan, 2012).

3.3.2 Energy

A team in Tel Aviv University has shown that the Oriental hornet uses solar energy and converts it to electricity by using the brown and yellow parts of its body, which act as a photovoltaic cell (ScienceDaily.com, 2011). A Japanese researcher Akira Kobata found that swirling vortices are created after air passes by a dragonfly's wings, since they have tiny peaks on their surface. He and his colleagues used this property to develop a low cost micro wind turbine model. During trials wind speeds varied from 24 to 145 kms per hour and it was found that the flexible blades bent into a cone instead of spinning faster. This technology developed could find possible application to develop turbines which can withstand gale force winds (Energy Harvesting Journal, 2011). A team at the Auckland Bio engineering Institute is harvesting the latent energy of human motion into power for other uses. The focus of the team is on creating new technology using biomimicry. They have developed electronics solutions for artificial muscles which are made of stretchy rubber. These can then be converted into sensors, power generators and actuators. The idea here is that the artificial muscle has mechanical properties similar to human muscle and can generate electricity when stretched (University of Auckland, 2012). A UK based plant Solar Botanic Ltd. Is looking to develop artificial trees which will utilise renewable energy from both the sun and the wind to provide electricity. In this instance biomimicry is used by fitting the trees with nanoleaves which are a combination of nano-photovoltaic, nano-thermovoltaic and nano-piezo generators which convert light, heat and wind energy into electricity. An artist impression is shown in Figure 5.

Figure 5: Artificial Trees (Zimmer, 2011).

3.3.3 Transport

The life line of any city is the way things and people move around and how quickly and efficiently. It’s called the transport system. Frank Fish studied the flipper of the humpback whale. He believed that it could be used to reduce drag or stall. After testing he found it reduced drag on an airplane wing by 32%. Teaming up with an entrepreneur he created what is called Whale Power (Biomimicry Institute, undated). The fastest train in the world at 200 miles per hour is the Shinkansen Bullet train in Japan, see Figure 6. But the problem is that of noise caused when the train emerges from a tunnel thereby troubling residents located one quarter of a mile away. The chief engineer of the train Eiji Nakatsu was interested in birds. So he used biomimicry to model the front end of the train in the shape of the beak of kingfishers. It is well known that the kingfishers catch fish with their beaks with very little noise and splash.

This produced tangible results like a quieter train, 15% less use of electricity and a train which travels 10% faster (Biomimicry Institute, undated).

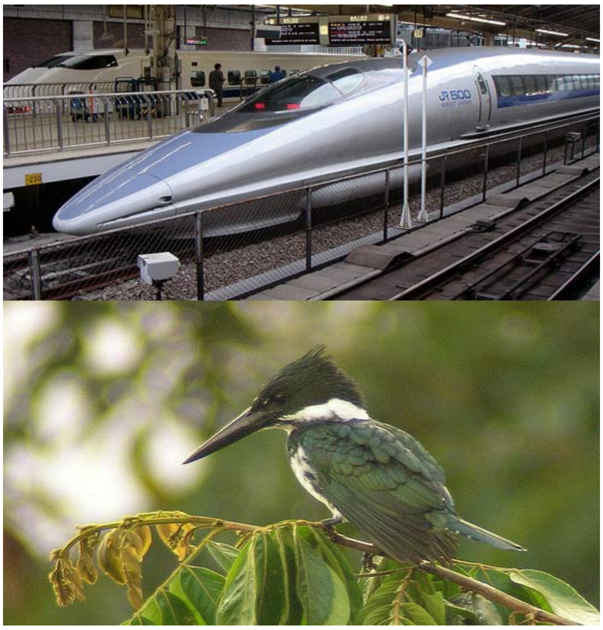


Figure 6: Shinkansen Bullet train (Wordpress.com, 2012).

3.3.4 Others Areas

One of the most famous examples of biomimicry is the invention of Velcro which got its design inspiration from burrs. The Swiss engineer got the idea from the fact that the burrs stuck to his dog's coat. After examining the burrs microscopically he found that the end of each spine had tiny hooks. He used this design to create the Velcro which is used to in clothing, footwear, etc (Paul, 2013).

Moth eyes have got little pillars on their eyeballs which are spaced at a specific distance. This ensures that the light entering the eyes is not reflected back hence during night the moth cannot be seen by a predator. This anti-reflective property could be used for developing a film for windows on buildings (AskNature.org, 2013).

3.4 Difference between Biomimicry and Other Bio-Approaches

The major difference between Biomimicry and other Bio approaches is that it is based on learning and not extracting from nature. The other approaches consist of using natural resources to produce articles useful for human consumption. For example using wood for making furniture or plants to make medicine. This is called Bio-utilization. Using bacteria to purify water and breeding cows to produce milk can be categorized under Bio assisted technology. Biomimicry is inspiration drawn from nature. The inspiration could come from a chemical reaction, part of an organism, or a principle like cycling of nutrients. So the organism or process itself is not modified but just copied. It therefore is possibly one of the best forms of sustainable development.

3.5 Conclusion

Nature can help us to reduce the amount of waste that we produce and to cut down the usage of non-renewable energy. The examples and applications mentioned in this review are some of the more prominent ones. Even as this is being written scientists are working upon ways and means to harness the amazing designs that nature has to offer us.

The fascinating possibilities that biomimicry offers also produces the risk of thinking that whatever process is followed by nature can easily be replicated in the human world. It will be worth remembering that the natural forms are very complex and cannot be easily replicated. Biomimetic inventors often get results which are similar to that of nature like reduced toxicity, greater efficiency but not to the extent which the original organism has been able to achieve.

4 Dover, UK

4.1 Introduction

Dover for variety of reasons namely, topography, tidal range, strong currents in the Strait of Dover and its strategic location is an interesting case study for sustainable developments at the local level. However, geographical and environmental constrains within the region make further developments in this area a complex and challenging process.

One of UK's most important gateways with continental Europe is the port of Dover. Trade to the extent of about £80 billion is done through the port in one year at any given time. Hence it is an asset of immense significance at the local, regional, national and international level. The Port of Dover handles almost 13 million passengers and about 5 million vehicles per year. It is the second busiest cruise port in the UK and also the fourth largest in the nation for import of fresh produce. Around 22,000 jobs are generated by the port of Dover chiefly in the local community (Buczek, 2012).

4.2 Physical and Environmental Constrains in the Strait of Dover

This study is addressing Dover; a town lies adjacent to Strait of Dover, which is the busiest strait in the world in terms of shipping (see

Figure 7). Ports of Dover and Calais which are the major connecting location of the UK to the European continent are Europe's busiest passenger ferry ports, despite the opening of the Channel Tunnel 1994 (European Straits Initiative, 2013). Therefore it would be necessary to investigate the Strait from geo-political and ecological point of views.

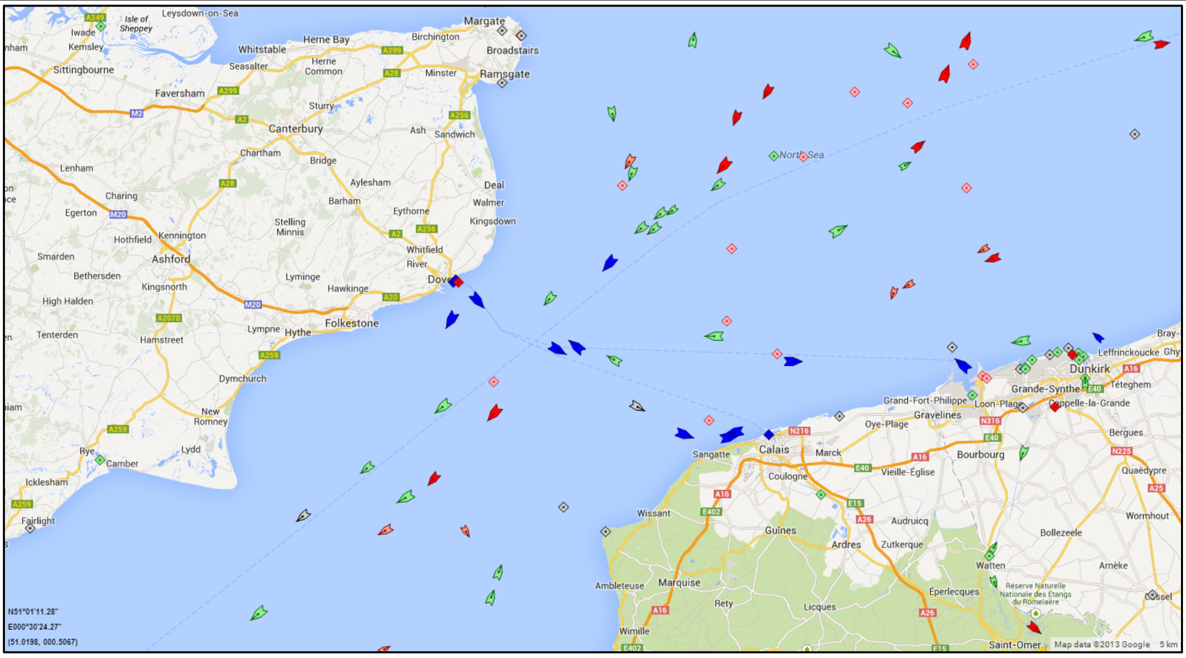


Figure 7: Example of marine traffic in the Strait of Dover (MarineTraffic.com, 2013)

Renewable energy sources, especially marine energy namely tidal stream, tidal range and wave energy, are becoming more attractive and reliable as future source of energy with everyday technological advancements. In the case of Strait of Dover there are a number of legislative, geographical and operational limitations in terms of offshore constructions. In Atlas of the Tidal Energy Resource on the South East Coast of England, a report which was prepared by Marine and Technical Marketing Consultants (MTMC, 2007), a detailed map of Locations of physical and environmental constraints in the Straits of Dover was provided as illustrated in Figure 8. MTMC's report specified the key constrains on tidal stream energy development as, congested shipping routes with traffic separation scheme, subsea power cables, protected historic wrecks on the Goodwin Sands, and Dover to Kingsdown Cliffs Special Area of Conservation (SAC) – chalk cliff exposure.

4.2.1 Physical and Environmental Constrains in Dover (Land-Side)

Dover comprises of incredible landscapes, recognised by the Kent Downs AONB (Area of Outstanding Natural Beauty), along with Heritage Coasts (Dover-Folkestone white cliffs). Dover also encompasses other designations such as SACs, SPAs, Ramsar sites, SSSIs and National Nature Reserves (NNRs). Figure 9 and Figure 10 show the designations in district of Dover.

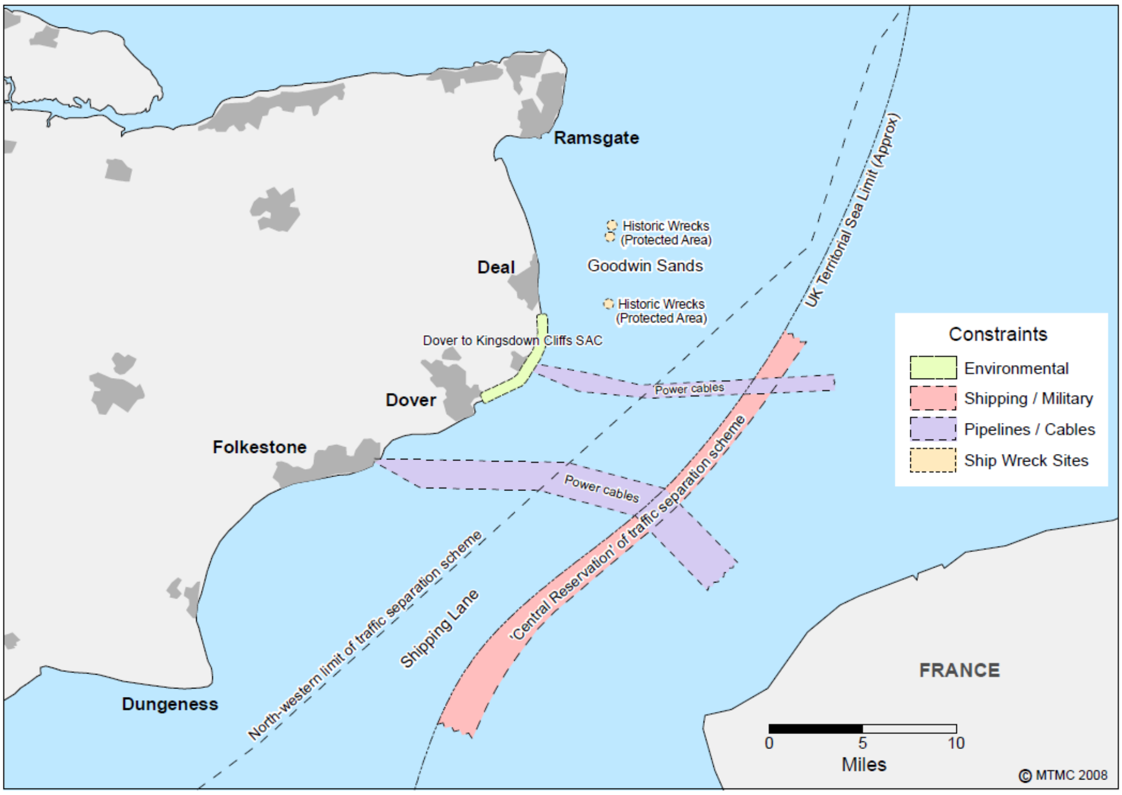


Figure 8: Locations of physical and environmental constraints in the Straits of Dover (MTMC, 2007).

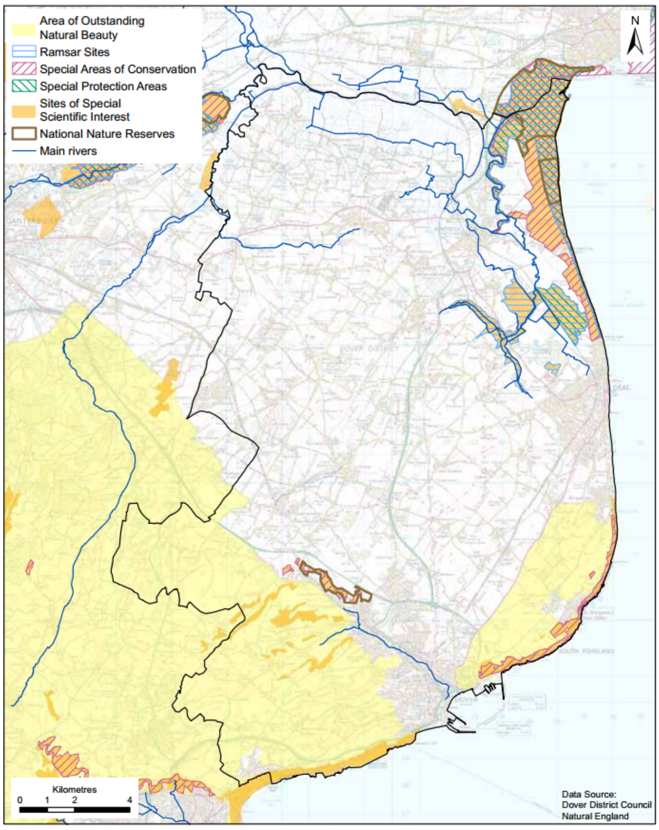


Figure 9: Conservation areas in District of Dover (Dover District Council, undated-c).

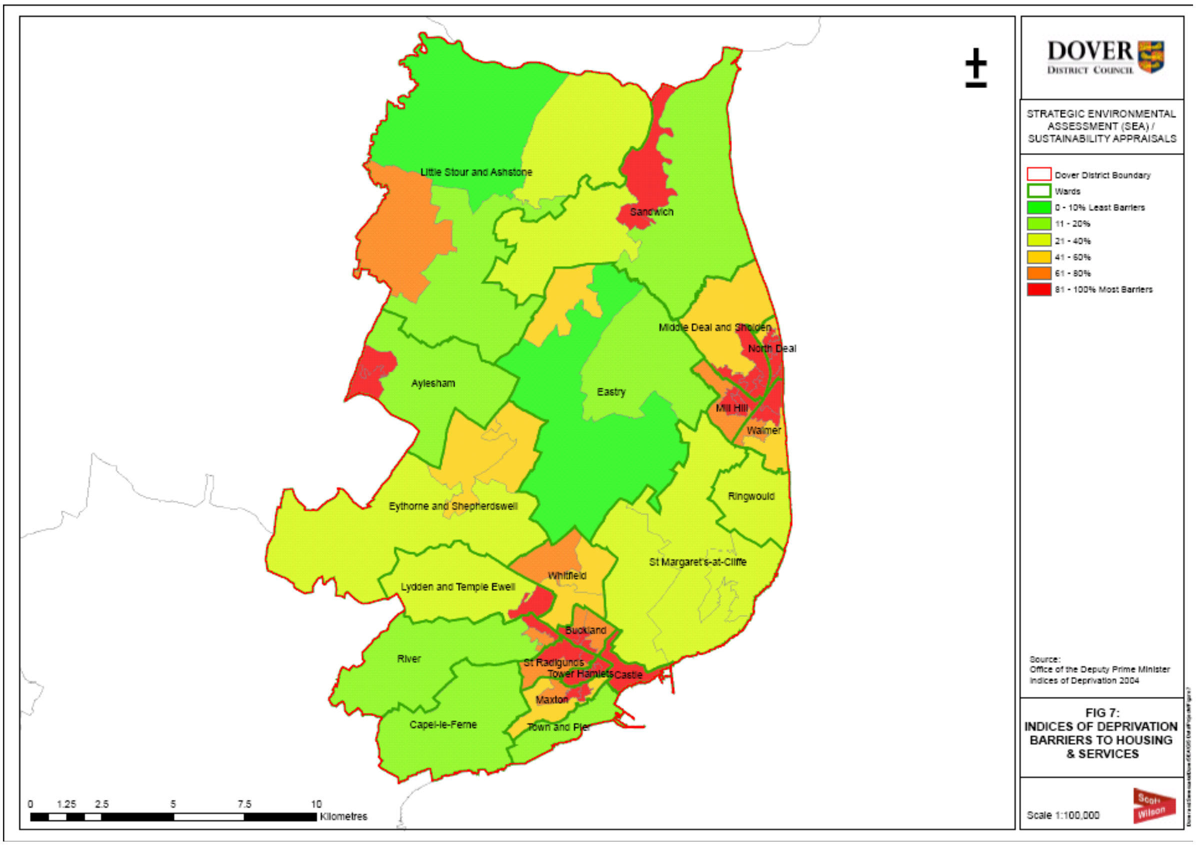


Figure 10: Barriers to Housing and Service (Scott Wilson Business Consultancy, 2005).

4.3 The Economic Impact of Port of Dover on the Region

A report for Maritime UK (including regional breakdown) published in February 2013 shows that the port of Dover handles about 3.8 per cent of total freight transhipment among the UK freight ports; an equivalent of 24,251,000 tonnes of cargo, as illustrated in table 1, which puts the port in the 9th place among the top UK ports (Oxford Economics, 2013). The data in 2011 also shows that the port performs as the main international passenger port in the UK by transferring 48.13 per cent of passengers (including cruises).

Considering the above mentioned figures, port of Dover is expected to have a considerable contribution to the economy of the region. ARUP's report in 2006 on port of Dover economic Impact assessment, stated that the port's contribution to GDP is estimated to be a total of £190 million, based on estimated employment supported and local GVA (Gross Value Added). "The figure represents around 1.1per cent of total GVA for Kent and 14 Per cent of estimated GVA for Dover" (ARUP, 2006). Since it is not the purpose of this report to investigate the economic impact assessment on port of Dover further information can be found on ARUP report.

Table 1: Freight and passenger data in 2011 (Department of Transport, 2012, reviewed in Oxford Economics (2013)).

Port	Freight '000 tonnes	Share of total	International passengers (inc cruises) '000 people	Share of total
Belfast	13,561	2.6%	0	0.0%
Bristol	8,202	1.6%	0	0.0%
Clyde	13,431	2.6%	0	0.0%
Dover	24,251	4.7%	12,769	55.9%
Felixstowe	26,817	5.2%	6	0.0%
Forth	27,878	5.4%	1	0.0%
Grimsby and Immingham	57,227	11.0%	69	0.3%
Holyhead	3,148	0.6%	2,020	8.8%
Hull	9,286	1.8%	970	4.3%
Liverpool	32,660	6.3%	118	0.5%
London	48,796	9.4%	14	0.1%
Medway	16,076	3.1%	0	0.0%
Milford Haven	48,699	9.4%	313	1.4%
Orkney	2,344	0.5%	0	0.0%
Portsmouth	3,772	0.7%	2,065	9.0%
Southampton	37,878	7.3%	1,315	5.8%
Sullom Voe	10,153	2.0%	0	0.0%
Tees and Hartlepool	35,198	6.8%	0	0.0%
Total of 18 ports	**419,379**	**80.7%**	**19,660**	**86.1%**
UK	**519,495**		**22,824**	

4.4 Flood Risk Assessment

4.4.1 Regional Flood Risk Assessment for South East England

Flood zones have been defined by The Environment Agency as areas that refer to the probability of sea and river flooding ignoring existing defences, see Figure 11 (Dover District Council, 2007a):

- Zone 3 – It is an area of high risk flooding. It could be affected by a sea flood with a 0.5% or greater chance or river flood that has a 1% or greater chance of happening each year.

- Zone 2 – It is an area that could be affected by flooding with up to a 0.1% chance of occurring each year.
- Zone 1 – It is an area that has a smaller annual chance of flooding than Zone 2.

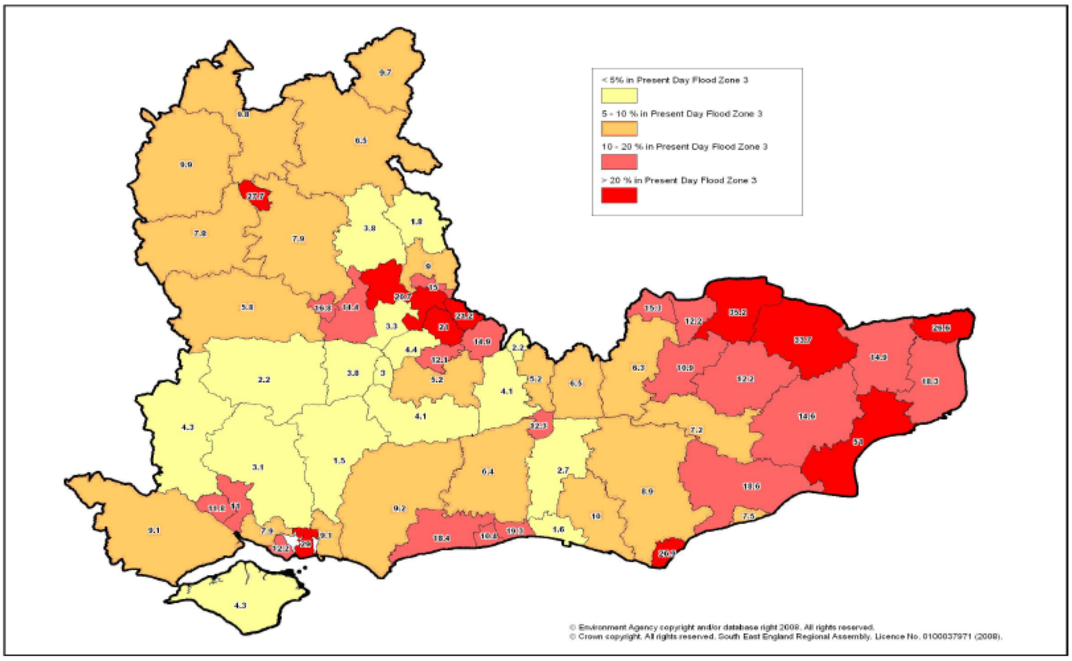


Figure 11: Regional Flood Risk Zones South East England (Dover District Council, 2007a)

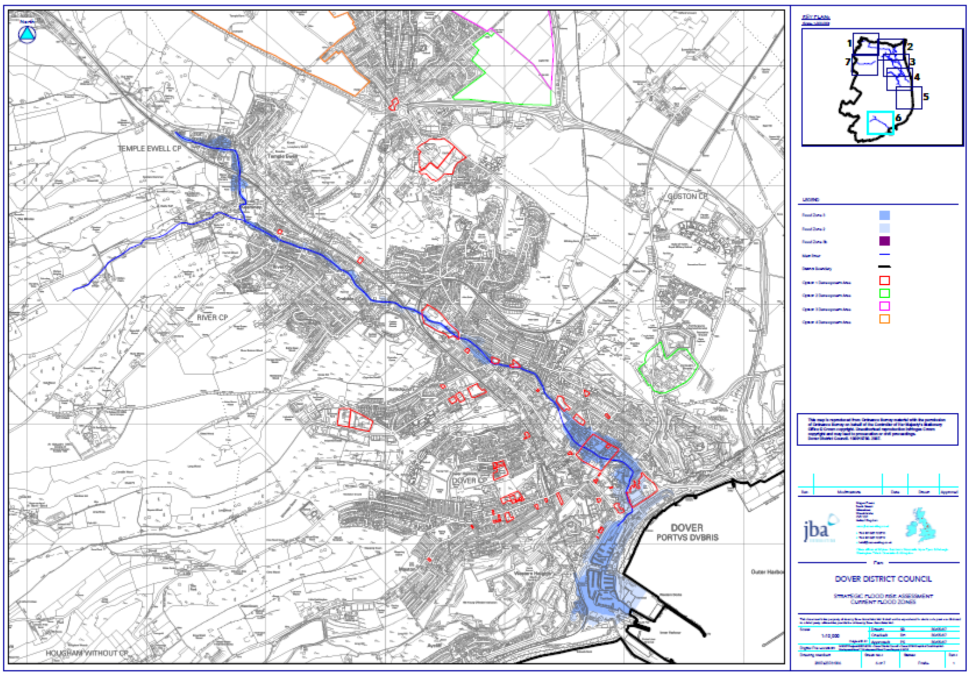


Figure 12: Strategic Flood Risk Assessment Current Flood Zones (Dover District Council, 2007b).

According to Figure 12 the Dover harbour area falls under Flood Zone 2, indicating the low flood risk as per the flood zone classification given in the preceding discussion.

The area of Dover is approximately 31,930 ha and has a population of 111,700. The urban development is predominantly along the coast with some development in the smaller villages. The main urban areas within the district are Dover, Deal and Sandwich as shown in the Figure 13. The other important site which lies outside the Flood Risk Zone is Whitfield.

Flood Risk Assessment: According to the Dover District Council there is minimal risks to human life from flood risk. The Geology is comprised mainly of chalk downland which is capable of absorbing rainfall. Although there appears to be the risk of fluvial flood it appears to be comparatively lower in the Dover harbour area and than other areas in Dover district (Scott Wilson Business Consultancy, 2005), see Figure 14.

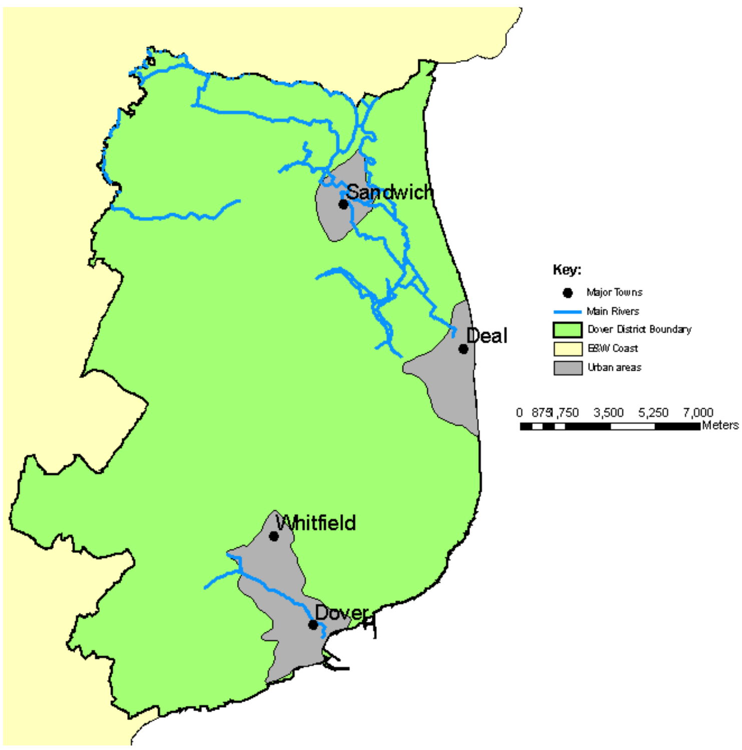


Figure 13: Dover District (Dover District Council, 2007a).

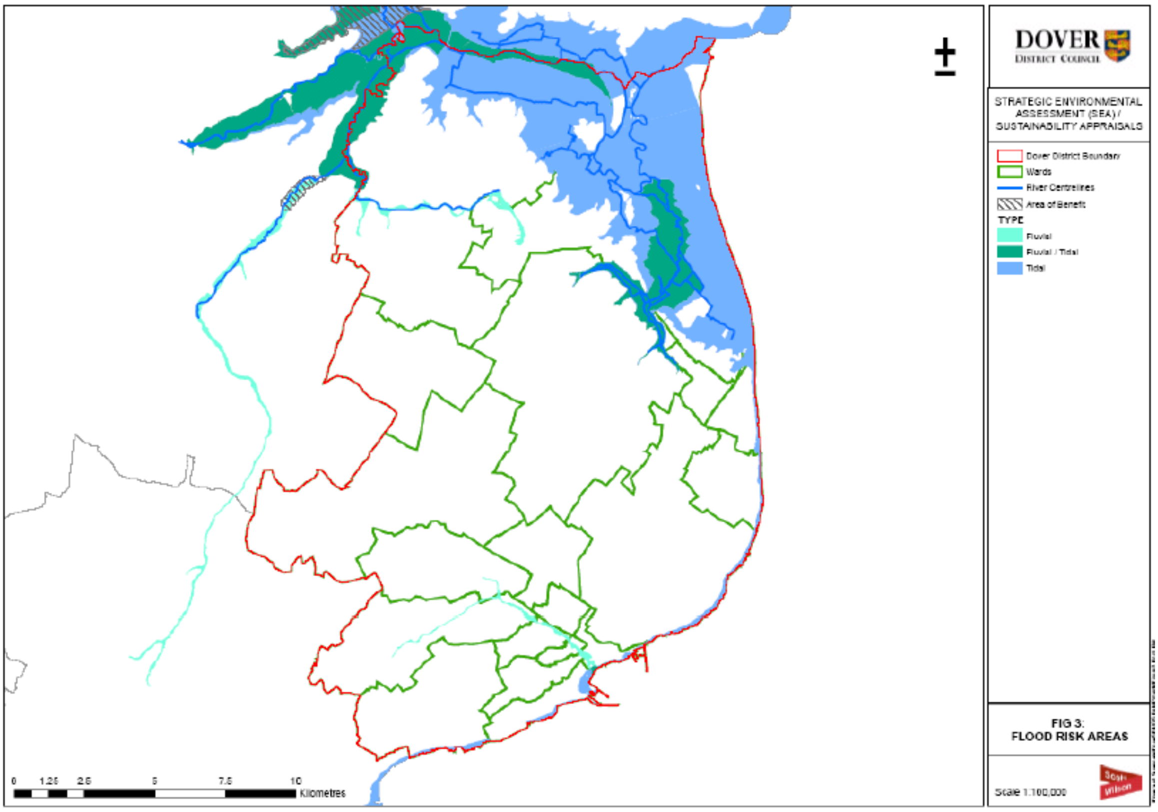


Figure 14: Flood Risk Areas (Scott Wilson Business Consultancy, 2005)

Tidal flooding is the main flood risk to the district. In addition to this Dover and Sandwich have the risk of fluvial flooding from the rivers Dour and Stour respectively. Along with this a large part of the coastal plains area is characterised by marshy areas consisting of drains, presenting a different type of flood risk. The lower lying areas face the risk of groundwater flooding due to the chalk geology.

The topography of the region is fluvial wherein there are valleys which are typically ‘u-shaped’ with very flat bottoms and steep valley sides. This feature of the landscape has an impact on flooding in the region as the extent is constrained by the steep valley sides, so once the valley bottom is flooded with water any further increase in flooding generally leads to greater depths rather than an increase in the latitudinal extent.

The main cause of flooding in the Dover District are the sea and to a lesser extent, the River Dour through Dover. The Dover District coastline is exposed to exceptional sea levels arising from a combination of high tides, storm surge, and action of exceptional wave heights and the joint impacts of fluvial and tidal levels. In urban areas flooding can be associated with the surcharge of subsurface drainage systems or the blockage of structures for instance culverts, outfalls or bridges.

4.5 Legislations

The UK is a signatory to the EU Renewable Energy Directive, which includes a UK target of 15% of energy from renewables by 2020. The UK Government has set an additional target of obtaining 10% of their electricity from renewable sources by 2010, increasing to 15% by 2015.

4.5.1 Legal and Regulatory Framework

In general, there are a number of policies, guidance documents, leasing requirements and legislation which have to be considered regarding Offshore Renewable Energy Installations.

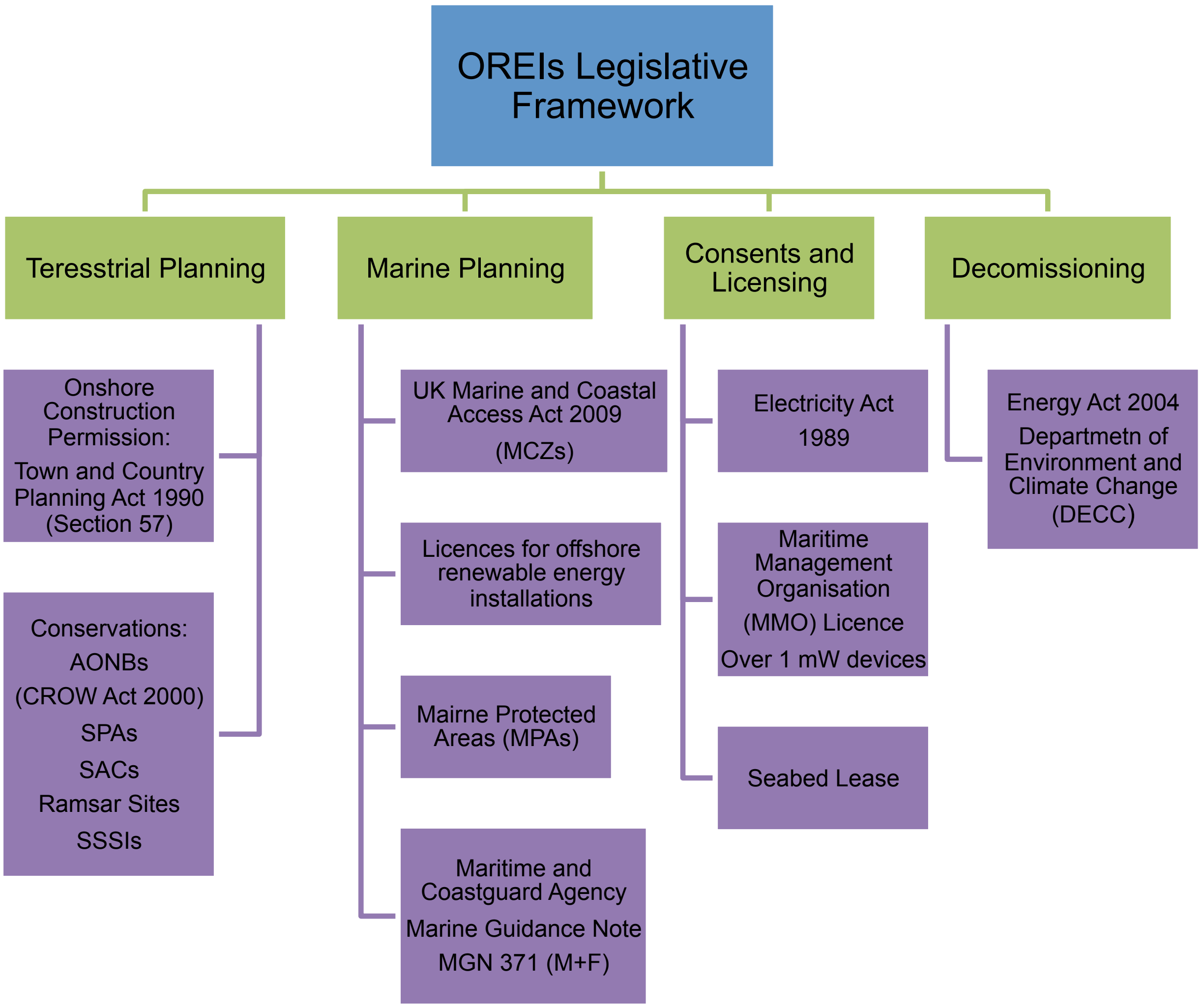


Figure 15: Legislative framework affecting the area of Dover.

4.5.2 Terrestrial Planning

Under the section 57 of Town and Country Planning Act 1990, the Oyster 800 project has to be granted a planning permission for the permanent and temporary onshore components namely, construction site, mechanical and electrical plants. Besides the development of M&E plants should take place within the area of the port, to avoid conflicts with conservations areas such as AONBs, SPAs, SACs and SSSIs in Dover.

4.5.3 Marine Planning

UK Marine and Costal Access Act 2009

Part 5 of the Marine and Costal Act 2009 enables ministers in the UK to designate and protect Marine Conservation Zones (MCZs) in English inshore and English and Welsh offshore waters. MCZs are part of Marine Protected Areas (MPAs) network in the UK, which protects important marine species and habitats. The MCZ project was set up in 2008 and required to follow Natural England and Joint Nature Conservation Committee's *(*JNCC) Ecological Network Guidance (ENG) in order to include the specific features and the geographic properties of habitats in the network and recommend MCZs to the government (BalancedSeas, 2011). The project consists of four regional projects covering the south-west, Irish Sea, North Sea and south-east.

The Balanced Seas was a project working in partnership with the Regional Stakeholder Group (RSG), representing all key stakeholder interests, to identify and recommend MCZs for inshore and offshore waters of the south-east England. Figure 1 shows the recommended MCZs in south-east England

Under the Marine and Coastal Access Act, there are currently six recommended Marine Conservation Zones (rMCZ) in the Strait of Dover. It is critical for the proposed Oyster technology for the port of Dover to consider those rMCZs in boundaries of the project's location namely, Dover to Deal (rMCZ 11.1) and Dover to Folkestone (rMCZ 11.2). Dover Harbour has already raised particular concerns about the recommended zones as it will affect the work required to maintain the harbour walls and future expansion within the harbour. Therefore, it was agreed in the RSG meeting that the boundaries for both rMCZ 11.1 and 11.2 would start 50m away from the harbour walls (BalancedSeas, 2013). Figure 17 shows the rMCZ from Dover to Deal considering redefined boundaries.

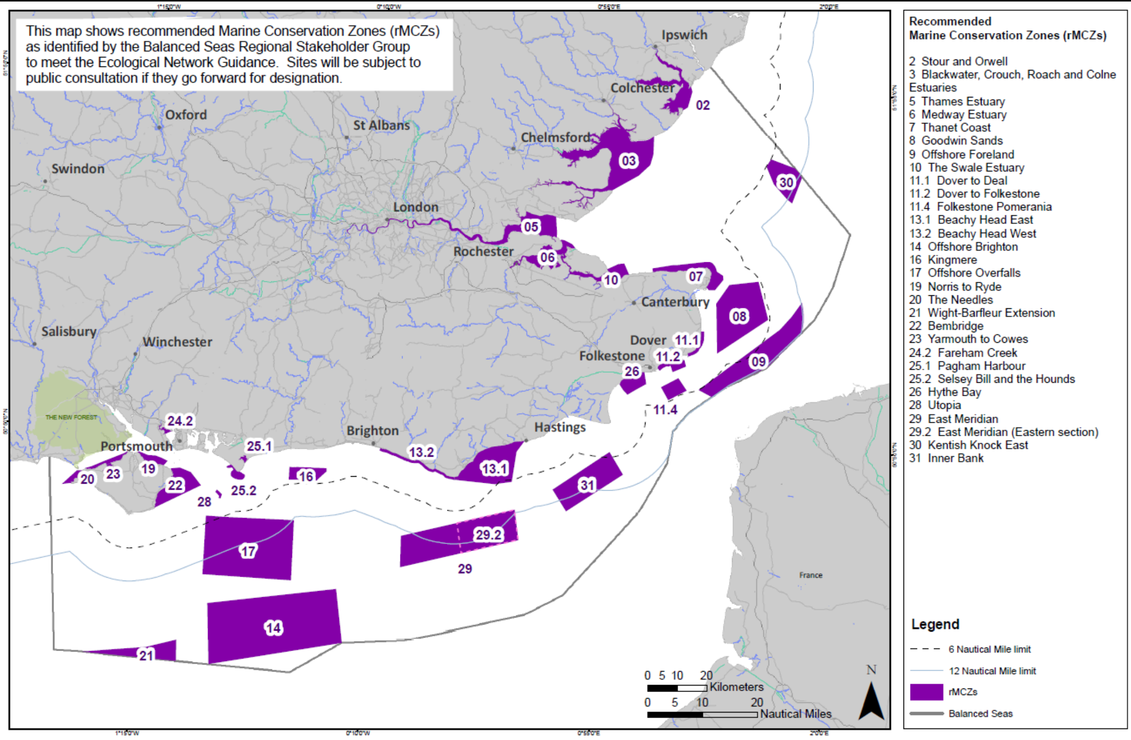


Figure 16: Recommended Marine Conservation Zones (rMCZs) (BalancedSeas, 2011).

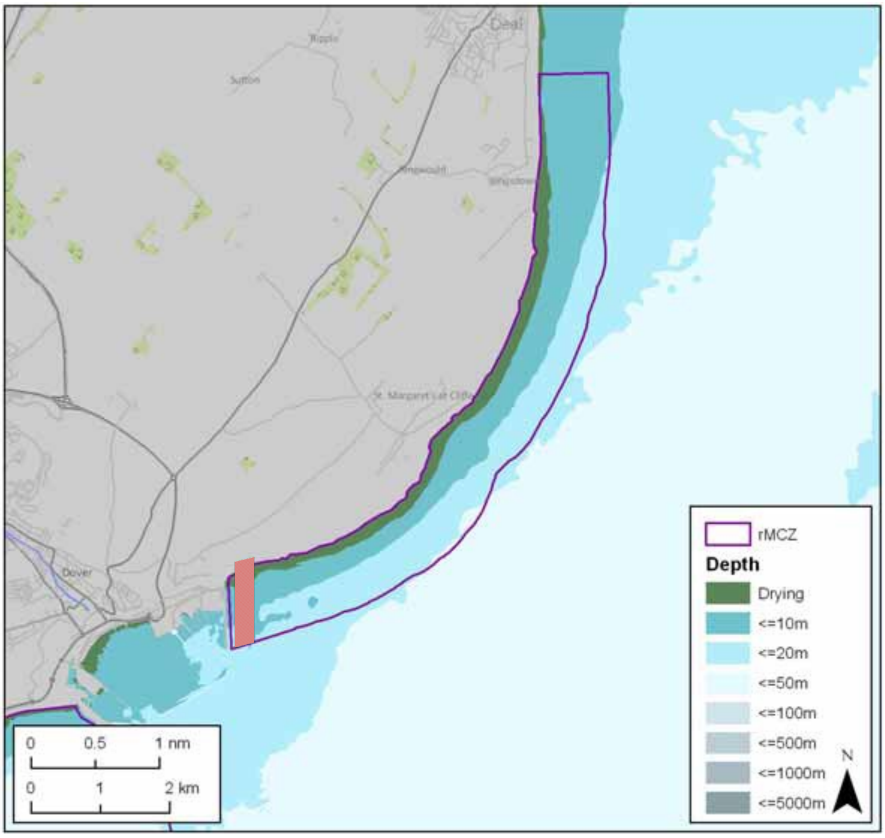


Figure 17: rMCZ Dover to Deal no 11.1. The red striped area ( ) shows 50m distance from the harbour walls, hich can be used to cross the high and low pressure water pipes to the shore (BalancedSeas, 2013).

New boundaries provides the required space for crossing the high and low pressure pipes to the port area where the mechanical plant is located.

4.5.4 Legislation and Consents

An Environmental Statement (ES) is required to accompany consent applications for the proposed development, under the following legislation.

Projects have historically been required to gain consent under several pieces of legislation before development can proceed. Prior to the introduction of the Act, developers would submit applications for consent to a number of authorities under various pieces of legislation.

Number of applications for consents (under the Electricity Act, the Coastal Protection Act, and the Food and Environment Protection Act) has to be obtained from the government and legislative authorities.

Wave Power developers must consider the following guidelines:

- Marine Renewable Licensing Manual (final draft available for consultation);
- Guidance on survey and monitoring for marine renewables deployments in the UK
- A review of the potential impacts of wave and tidal renewable energy developments on UK's marine environment.

Electricity Act 1989 ('S36 Consent')

Section 36 of the Electricity Act 1989 (Consent required for construction etc. of generating stations) is the primary consent required for the construction and operation of a wave power generating station with a capacity of 1 megawatt (MW) or more.

The capacity of the proposed wave array for port of Dover is approximately 2.4 MW and consent for the construction and operation of the development has therefore be sought under Section 36.

Consent to construct and operate the onshore components of the project have to be obtained under the same Section 36 application under the deemed planning powers contained within Section 36 to enable the consenting of a power generation scheme.

4.5.5 The Electricity Works (Environmental Impact Assessment) (Wales and England) Regulations 2000

These Regulations implement the European EIA Directive 1985 (as amended, 2009), and provide the requirement for assessment of the effects of certain public and private projects on the environment. Under sections 36 and 37 of the Act such projects include the construction, extension and operation of a power station or overhead electricity lines. According to the EIA regulations guidance the developer should also submit a draft outline of the Environmental Statement, giving an indication of what they consider to be the main issues.

Seabed Lease

The Crown State manages almost the entire out seabed around the UK up to the 12 nautical mile territorial limit, as well as around half of the foreshore. Over the last few years the Crown State has leased a number of areas of seabed for wave and tidal projects.

Energy Act 2004

Sections 105 – 114 of the Energy Act 2004 introduce a decommissioning scheme for offshore wind and marine energy installations. In commencing the decommissioning programme, the site developer will meet all requirements for navigational safety, environment protection and health and safety in accordance with current relevant legislation. Decommissioning vessels namely, Tug, Multi-Cat and Dive Team, used in the operations have to be marked as per the International Regulations for the Prevention of Collisions at Sea, 1972. Besides, a temporary safety zone and navigational markers will be established in accordance with marine safety legislation.

Marine Protected Areas

"Marine Protected Areas (MPAs) are areas where specific living and sometimes non-living resources are legally protected. To ensure this protection, restrictions may apply to some activities in these areas of our seas. In the UK, MPAs have primarily been set up to help conserve marine biodiversity, in particular species and habitats of European and national importance" (Defra, 2013).

The UK MPAs network, as indicated in Figure 18, includes a number of designations namely, European Marine Sites (also known as Natura 2000 sites) which are Special Areas of Conservations (SACs) for habitats of European importance (EU Habitats Directive) and Special Protection Areas (SPAs) for birds (EU Wild Birds Directive); Marine Conservation Zones (MCZs) for protection of nationally important marine wildlife, habitats, geology and geomorphology (The National Archives, 2013); Ramsar sites for conservation and wise use of all wetlands (Ramsar Convention on Wetlands); and finally Sites of Special Scientific Interest (SSSI) which are the UK's very best wildlife and geological sites and many of these sites are also National Nature Reserves (NNRs) or Local Nature Reserves (LNRs) and defined under Wildlife and Countryside Act 1981.

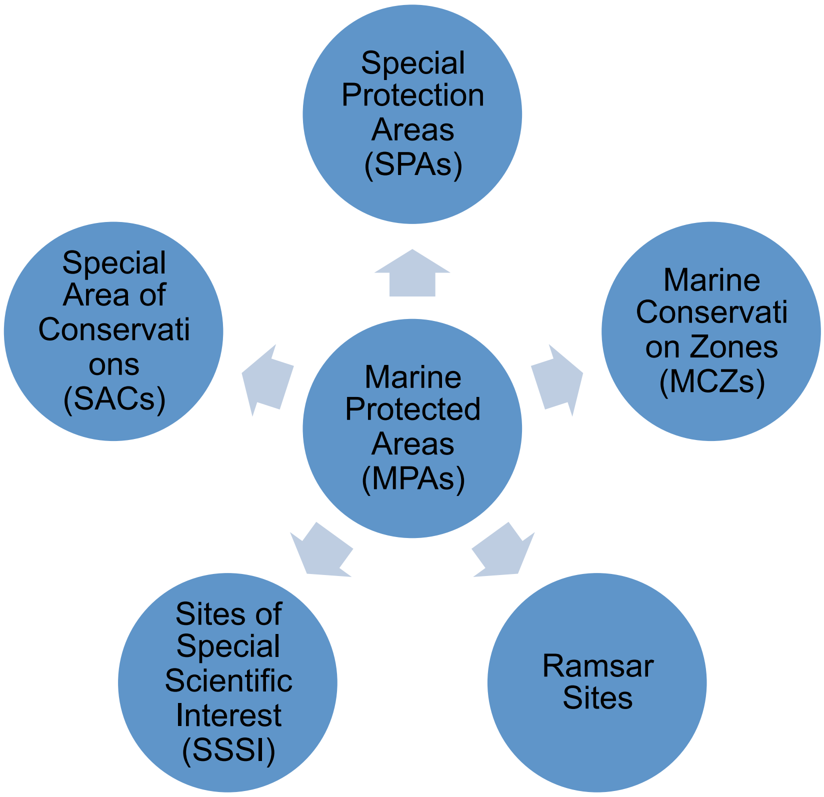


Figure 18: Marine Protected Areas (MPAs).

5 Renewable Energy Possibilities in Dover

5.1 Introduction

Prior to putting forth a project proposal for use of renewable energy leading to a carbon neutral Dover it was necessary to evaluate the opportunities and constraints related to the project. According to a study carried out for the whole of the South East Region in 2008, the opportunities for renewable energy in the region are at least 80m tall turbines, wind power, biomass and solar technologies (Dover District Council, 2009).

5.2 Biomimicry as a Solution

Some of the wave energy converters (WEC's) which are based on biomimicry inspired designs have been reviewed here.

5.2.1 Anaconda

Another important invention is that of a type of device called Anaconda, named after the giant sea snake – see Figure 19. The inventors of the device feel that considerable power could be harnessed from the sea in times to come. This is a new type of wave energy generator showcased by Checkmate Sea Energy in 2009. Several experts see the device as one of the first of the next generation of robust and cheap wave power machines which could bring down the costs of producing renewable energy considerably.

The Anaconda is made from a composite of fabric and natural rubber. "The device mimics the giant snake by riding the oncoming waves and uses the motion to drive a turbine in its tail" (Jha, 2009b). The prototype device is 9 m in length. Developers of the device say that a full scale device would be up to 200 m in length and would be capable of producing 1MW of power which would be sufficient to provide power to around a thousand homes. The cost of building the device is around £2m. Fifty or more of these could be placed underwater a few miles from the coast.

The UK has a target of producing 15% of its energy from renewable sources by 2020. The harnessing of wave power could greatly contribute to achieving this target. According to the findings of the Carbon Trust, wave and tidal stream technologies from areas such as north-west Scotland and south-west England could provide 10 to 20 GW of electricity to the UK by 2050 (Jha, 2009b).

Wave energy machines tend to deteriorated over time in the underwater environment. The non-mechanical design of the Anaconda together with the material it is mainly made of natural rubber, gives it resilience and the advantage of less maintenance of moving parts.

Each device is attached to the sea bed and is positioned head on into the coming waves. The water filled rubber swims with the waves and as a swell hits the front of the device it creates a bulge that travels to the back of the tube. The mechanism is similar to the manner in which blood travels along an artery. When the bulge wave reaches the Anaconda's tail the energy generated is used to run a turbine and produce electricity.

The Carbon Trust has placed a lot of faith in the device. It hopes that the device can be used commercially in order to encourage low carbon technology. The main attraction is its simplicity of design. Potentially it can be robust and cheap and easy to manufacture. This is emphasized even more so by the problems faced by wave and tidal devices due to severe offshore conditions. Wave energy in general costs around 25p per KWh to make but the Anaconda can reduce the prices to around 9p per KWh (Jha, 2009b).

The designers of the device lay great stress upon its ability to survive in even extreme weather conditions. In the worst case scenario it will just be washed up on the beach and it can be patched up and reinstalled. If everything goes according to plan the Checkmate thinks that the first devices in commercial production could be floating in the seas off Britain as early as 2014 (Jha, 2009a).

Figure 19: Anaconda, bulge wave sea energy converter (Checkmate Sea Energy, undated)

5.2.2 Pelamis Wave Power

The Pelamis was first tested at the European Marine Energy Centre in August 2004. It was the world's first wave energy device to be launched on a commercial scale and generate electricity for the national grid. Figure 20 shows the device.

The Pelamis is a wave energy machine that coverts the motion of waves into electricity. Typically, this machine is installed in water depths > 50 m and 2-10 km from the coast. The estimated capacity of the machine is 750 kW. One of these machines could provide power equivalent to the annual demand of approximately 500 homes.

Figure 20: Pelamis wave machine (Pelamis Wave Power, 2013)

The Pelamis concept itself was developed after extensive research making use of numerical modelling and tank testing of scale models. After the testing of the prototype successfully the Agucadoura Wave Farm located off the northwest coast of Portugal was opened officially. The farm had a total capacity of 2.25MW.

Being one of the first wave energy generator devices its development phase is at a mature stage and can be pivotal in making commercial wave farms a reality.

The Pelamis Wave Power has raised approximately £45m to date for funding the development of the technology from several financial and industry supporters. About £19m has been raised from sales and services and a certain degree of government funding (Pelamis Wave Power, 2013).

5.2.3 Oyster Wave Power

The Oyster wave power machine obtains energy from near shore waves and converts it into electricity. This device is based on a wave-powered pump that pushes pressurized water to drive an onshore hydro-electric turbine. The device is a buoyant, hinged flap attached to the seabed at depths of between 10 and 15 meters and about 500 meters from the shore, shown in Figure 21. The model Oyster 800 has a maximum generating capacity of 800kW and has a width of 26 m. A detailed report on the Oyster has been given in another section of this book (Aquamarine Power, 2013).

Figure 21: Oyster wave power machine (Aquamarine Power, 2013)

5.2.4 BioWAVE

The bioWAVE system is inspired in nature (biomimicry). This device is mounted on the bottom and operates as a pivot, shown in Figure 22. The array consists of buoyant floats moved by the up-and-down sea surface motion (potential energy) and the back-and-forth water movement (kinetic energy). The motion is finally converted to electricity by an onboard self-contained power conversion module. This module converts the mechanical motion into fluid pressure to spin a generator. The bioWAVE is currently a pilot project and it is estimated that it will operate at a depth of about 30 m and produce 250 kW. A projected 1 MW model is planned to operate at 40-45m depth.

Figure 22: The bioWAVE machine (BioPower Systems, 2013)

Marine energy devices that are nearing commercial reality today include the SeaGen and Pelamis, a tidal and wave generator respectively. Both went into trials in the sea last year, SeaGen in Strangfod Lough and Pelamis off the coast of Portugal. Like Anaconda, Pelamis also uses a snake-like motion to capture wave energy by flexing its articulated metal sections on the sea surface. Both devices have had technical problems however, mainly due to the harsh conditions at sea (Aquamarine Power, 2013; BioPower Systems, 2013).

5.3 Project Proposal for Port of Dover

5.3.1 Oyster Wave Power Technology

All over the world there are concerns about the depleting sources of fossil fuel. Hence there appears to be a paradigm shift in moving towards sustainable energy production which is largely perceived and accepted to be efficient and cost effective. Presently the solar, wind and bio-fuel industries have gained public trust. However over a period of time other technologies could also be maturing and soon could be gaining acceptability as a source of sustainable energy. This also includes wave and tidal energy. Wave energy has the advantage of being both clean and renewable form of energy. Waves once generated can travel large distances with minimal loss of energy. Meteorological forecasts and direct satellite readings can predict wave forms a couple of days in advance. Wave energy can assist in balancing output variability from other renewable sources and make best use of the effective utilization of electricity networks. Waves can average out the wind that creates them over large regions resulting in greater reliability in comparison with wind or solar energy. Days on which electricity will not be generated due to weak waves are rare (Pelamis Wave Power, undated). After researching on and reviewing the various WEC's as mentioned in Chapter II, it was concluded that the appropriate technology to use in the case study for Dover would be the Oyster WEC.

Development

The Oyster is a wave energy generator which has been developed by Aquamarine Power. This is a device of huge dimension but is simple in operation. The first 315kW Oyster wave energy device was installed off the coast of Orkney in 2009. It was called Oyster 1. The device could positively establish the hydroelectric wave energy concept and could deliver more than 6000 off shore operating hours in a period of two winters. In June 2012 the testing of the second generation Oyster 800 started. The Oyster 800 has a maximum generating capacity of 800kW at any point in time. The device has a width of 26 metres and is installed at a depth of approximately 13 metres at a distance of 500 metres from the shore. The next generation will be called Oyster 801 and it is planned to install it beside the Oyster 800. Figure 23 shows the evolution of the Oyster. Both the machines will be connected to the same offshore hydroelectric power station. Thus leading to a wave farm of several Oysters. The wave farm can be a huge and endless source of clean and sustainable electricity. Approximately 80,000TWh of electricity could be produced in this wave farm.

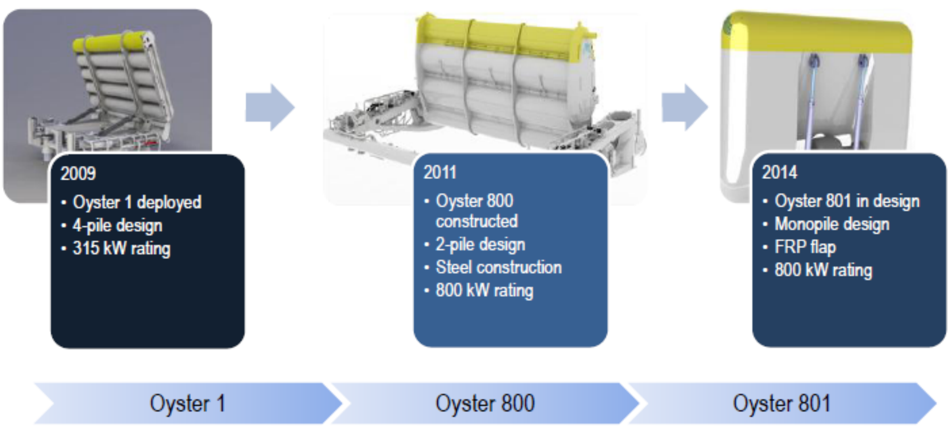


Figure 23: Evolution of the Oyster (McAdam, undated).

In this report the device under consideration is the Oyster 800. This device is based upon what Aquamarine calls the three S's – simplicity, survivability and shore based electricity generation. The device is simple as it is a mechanical offshore device with minimal underwater moving parts with no control system, gearbox or shut down mode and also does not involve complex offshore electronics. It is survivable because it has hinged flaps which can duck under the largest waves, it has a near shore location with a robust offshore structure which can operate even in stormy conditions (Aquamarine Power, undated).

Near Shore Technology

A majority of the wave technology manufacturers develop deep water or shoreline devices. The Oyster on the hand has been defined as a 'near shore' device. Near shore is characterised as an area which has a water depth of 10-20 m. The near shore location of the Oyster makes it a unique design of WEC (Wave Energy Converter). The near shore region is considered to be at depths of 10 to 25 m. This location is not popular because it is perceived to a low energy area. But there are arguments that this is untrue and that there are many benefits with near shore installations which are ignored. The shore based electricity generation has advantages like keeping electricity out of the water, minimal ecological impact on the marine environment, ease of access and a reliable hydro-electric plant (Aquamarine Power, undated).

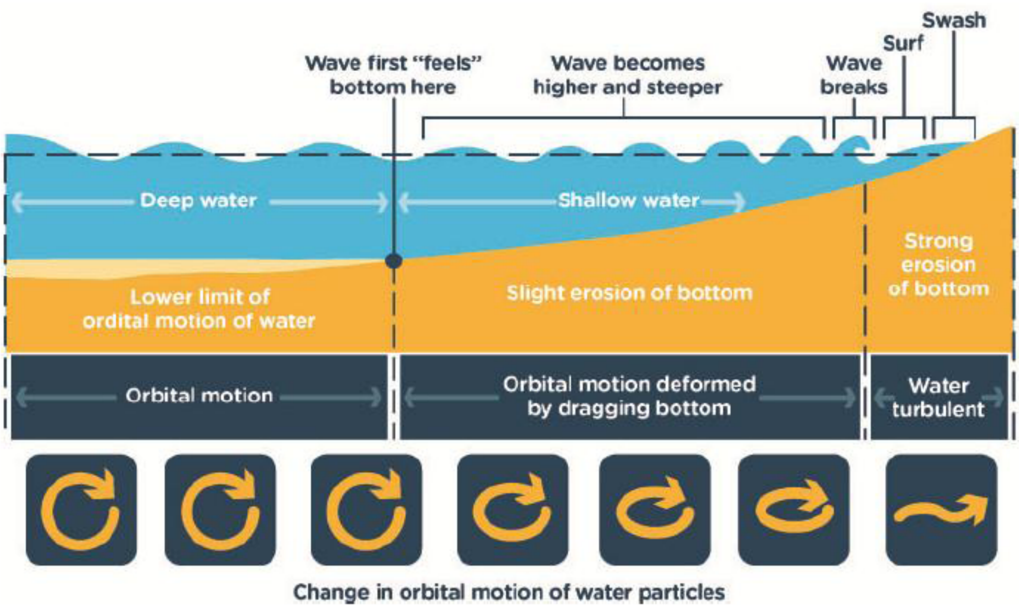


Figure 24: Advantages of Near shore Technology (O'Kane, 2011).

Folley and Whittaker (2009) have outlined the characteristics of the near shore as follows.

a) Amplified wave force in surge direction: 'Shoaling' leads to amplified wave force in the surge (beach) direction. In deep water the motion of orbital particles is mostly circular. But in the near shore region this motion gets distorted on account of sea bed interaction. Hence forces are amplified by about 50% in the surge direction, as shown in Figure 24.
b) Filtering of the largest ocean waves: Before reaching the near shore areas the biggest storm and rogue waves are filtered out due to the wave breaking action. Hence there is a considerable reduction of extreme forces on a wave energy converter making the device survivable and also reducing the cost of manufacturing it.
c) Narrower directional spread: The waves located in the near shore region are directed towards the beach and have a tight directional spread as against those in deep water, which are omni-directional. Due to this the Oyster is able to capture energy more efficiently.
d) High net power capture capability: Earlier there was agreement that the level of gross wave energy is low in the near shore region. However no quantification of the ratio of 'exploitable wave energy' versus gross energy in the two regions had been done. In other words the level of energy that can be rationally extracted from the waves. Folley and Whittaker (2009) calculated this level is only 10-20% less at 10m as compared to a 50m depth.
e) Lower power transmission losses: The distance of a near shore site with a depth of 10 – 15m is about 500m from the shore as compared to several km for a deep water (50m) site. This leads to lower transmission losses for an equivalent near shore site.

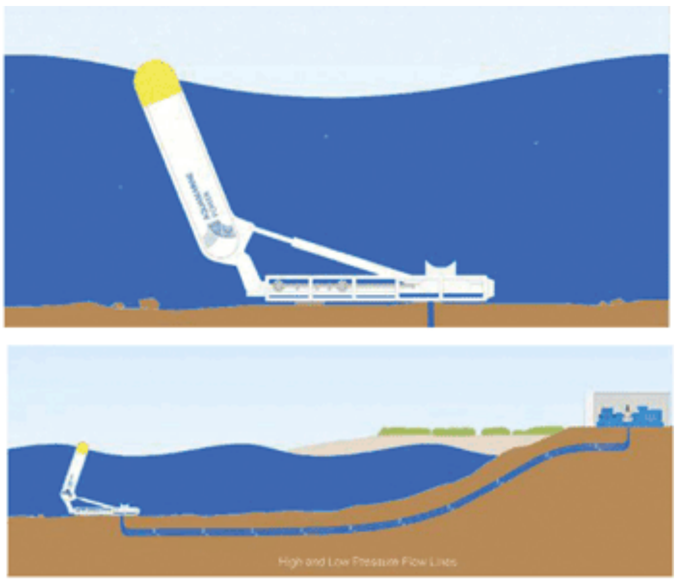
According to the Carbon Trust UK the contribution of the near shore wave energy devices is around 6 TWh/y (Carbon Trust, 2012).

Directionality of Waves

An important consideration in using any WEC is the directionality of waves. It is well known that wave energy is made up of several superimposed wave fields which come from different directions. A swell could arrive from one direction whereas a wind driven sea can arrive from another direction simultaneously. At any given time the sea consists of different wave heights and periods with different directions. The directional spread of waves tends to reduce towards the shore. This is minimal near the shore where the waves are almost perpendicular to the coast.

Design

The dimensions of the Oyster 800 machine are a width of 26 metres and height of 12 metres. It consists of two offshore parts which are sunk in 30 feet of water about 500 metres out in the sea. A rigid frame is put on the sea floor using bolts. A big float on hinges pivots back and forth in the waves, thereby pumping compressed sea water to a hydroelectric power station on the shore. The onshore hydroelectric plant converts the hydraulic pressure into electric power via a Pelton wheel, which turns an electrical generator. The low pressure return-water passes back to the device in a closed loop via a second pipeline (Ackerman, 2011). Figure 25 shows the overall concept. The actual Oyster is shown in Figure 26.



Aquamarine Power's Oyster device is a wave-powered pump which pushes high pressure water to drive an onshore hydro-electric turbine.

Figure 25: Overview of Oyster Wave Energy Generator (Alves, 2011)

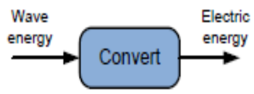
Figure 26: Offshore Oyster Device (Ackerman, 2011)

Operation

The design of the Oyster is based on the principle of capturing wave energy and converting it into grid quality electrical power. In order to achieve this there are four conversion systems. Each of these systems comprises of its own piece of equipment requiring optimisation of design (Collier, Whittaker, & Crowley, undated). The four systems are:

1. Hydrodynamic to Mechanical – which is the WEC Flap
2. Mechanical to Hydraulic – which are the Pistons
3. Hydraulic to Mechanical – which is the Pelton Wheel
4. Mechanical to Electrical – which is the turbine or Generator

The design uses a hinged flap which is completely submerged in the water and an onshore hydroelectric power take-off (PTO). The power take-off cylinders are mounted at the quarter points of the flap and the non-return valves are contained in the sub-frame. Directionally drilled pipelines transmit hydraulic power to the shore and convert it to electrical power. The power is then exported to the grid by a 315kW rated hydroelectric plant.



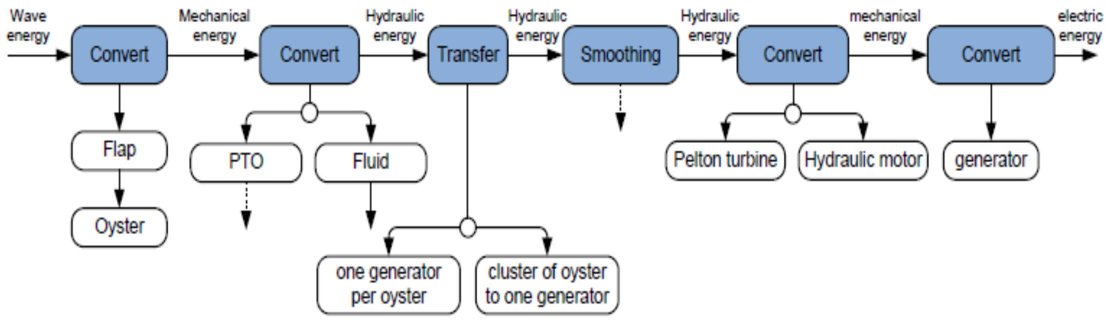


Figure 24: Flow Chart Showing Process

Source: http://www.eeng.nuim.ie/coer/doc/EV003_vantHoff_251011.pdf

According to Folley and Whittaker (2009) the resource could be measured using the "average exploitable wave power". "The average exploitable wave power is the average wave power propagating in a fixed direction for a single sea state and limited to a multiple of four times the annual average wave power".

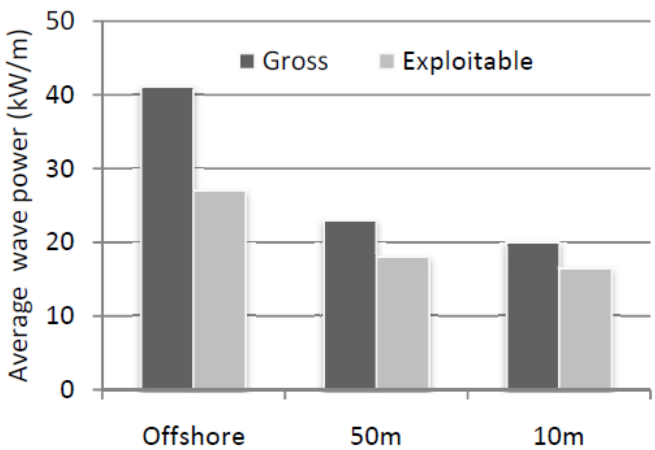


Figure 27: Average gross and exploitable wave power at three water depths (50m and 10m correspond to 'deep-water' and 'near shore' respectively) at EMEC (Henry, Doherty, Cameron, Whittaker, & Doherty, 2010).

Folley, Elsaesser, and Whittaker (2009) calculated both gross omnidirectional and exploitable wave powers for EMEC and showed that the gross power offshore is two times that in the near shore, but the difference between exploitable power between the two locations is only 10 per cent, see also Figure 27.

Figure 28 shows the graph of the average power capture plotted against the flap width. It is observed that power capture increases with flap width. The power captured by the 18m wide flap is six times more than the 6m wide flap, however the width of the flap is only thrice that. The graphical results are based on generic test cases and are not directly connected to Oyster 1 or Oyster 2 flaps (Cameron et al., 2010).

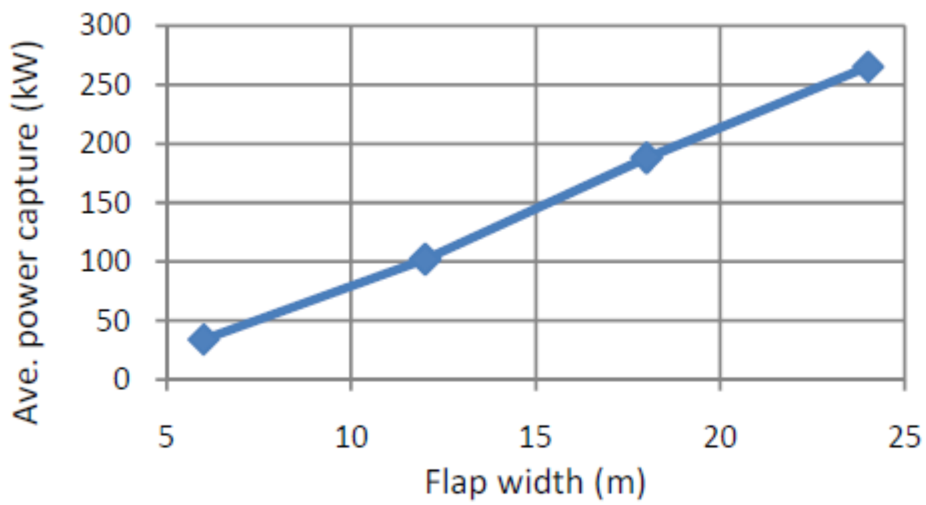


Figure 28: Average power capture against flap width.

In order to measure wave energy absorption efficiency, capture factor is the commonly used measure. Capture factor is defined as the ratio of power captured by the device to that incident across its width. Figure 29 shows the graph of the average capture factor plotted against the flap width (Cameron et al., 2010).

From Figure 29, it is observed that an increase in the width of the flap leads to increased efficiency. However the shape of the curve indicates that there could be a limit in improving capture factor merely by increasing the width of the flap.

Some of the factors which have to be taken into account in the design in order ensure that the costs of installation and operation are not affected are: the location of the offshore site, the condition of the seabed, the method of attaching the structure to the seabed, the method of installation and removal of the WEC, the method of converting the wave energy, the location and maintenance of the power take off system (Collier et al., undated).

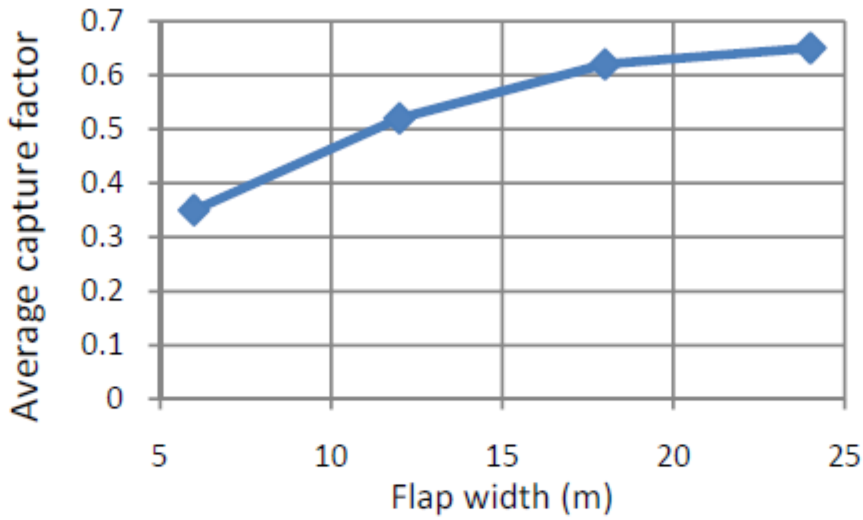


Figure 29: Average capture factor against flap width.

Benefits

Some of the benefits associated with the Oyster technology are (Collier et al., undated):

1. Surging WEC's can benefit from the wave formation in the near shore region. Storms of an extreme nature are avoidable.
2. The levels of exploitable wave energy in the near shore region are comparable with those of the deeper water regions.
3. It becomes easier for maintenance of the device as it is installed near the shore.
4. It is possible to achieve maximum power capture by optimizing the installation depth and flap width, utilising the full height of the water column and a low hinge point owing to the design of the Oyster. This leads to an increase in wave force, thereby enabling greater power capture.
5. The Oyster 800 design would follow a modular maintenance by replacement concept for its offshore components and uses an onshore hydroelectric PTO for accessibility.
6. As the hydrodynamics of the oscillating flap has been modified the output of the Oyster 800 has been enhanced. This is 2.5 times that of Oyster 1 with only a 50 per cent increase in the width of the flap.
7. The device is not restricted to certain sites and mass production is possible (Trevor Whittaker & Folley, undated).

The project in its entirety would have three 800kW wave generators attached side by side, which would pump out 2.4MW of wave energy. Seven of these devices would possibly supply power to 15,000 homes. Notably the energy generated in this manner is zero carbon. Some of the main benefits associated with the device are "high capture efficiency, high power to weight ratio, design for extreme seas and high reliability" (Collier et al., undated).

Figure 8 shows the levellised cost of electricity. It is estimated that the Oyster's cost of power is between 70 -90 pounds per MWh (McAdam, undated).

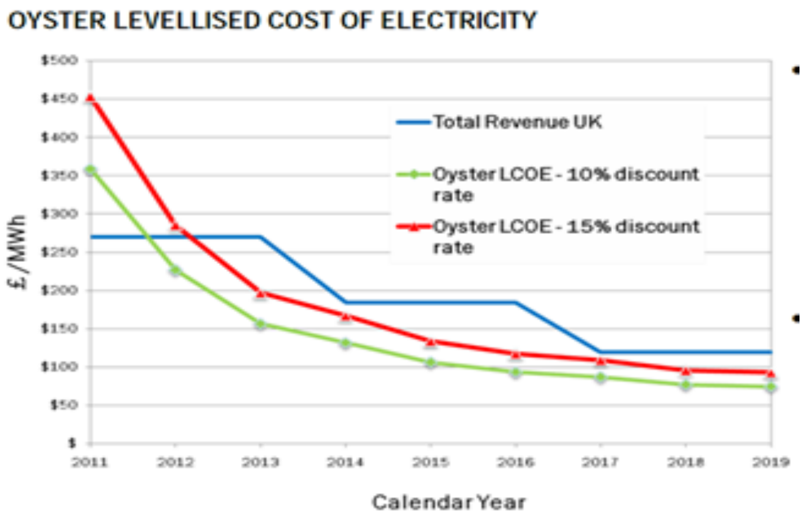


Figure 30: Cost of Power (McAdam, undated).

A statement of feasibility has been awarded to the design of Oyster 800 on the basis of a twenty year life span by one of the world's leading provider of services for managing risk, Det Norske Veritas (DNV) (Thetys, 2012).

Using the Oyster for Dover

According to the 2013 report of the DECC UK there is a fall in the primary energy production by 10.7 per cent, an increase in energy consumption by 1.7 per cent and an increase in electricity produced from renewable energy sources in the UK by 19 per cent. The UK continental shelf experienced long term decline and maintenance activity. On account of this there was a reduced production of oil and gas. The average yearly rate of decline is 7.1 per cent, see Figure 31 (Department of Energy and Climate Change, 2013a).

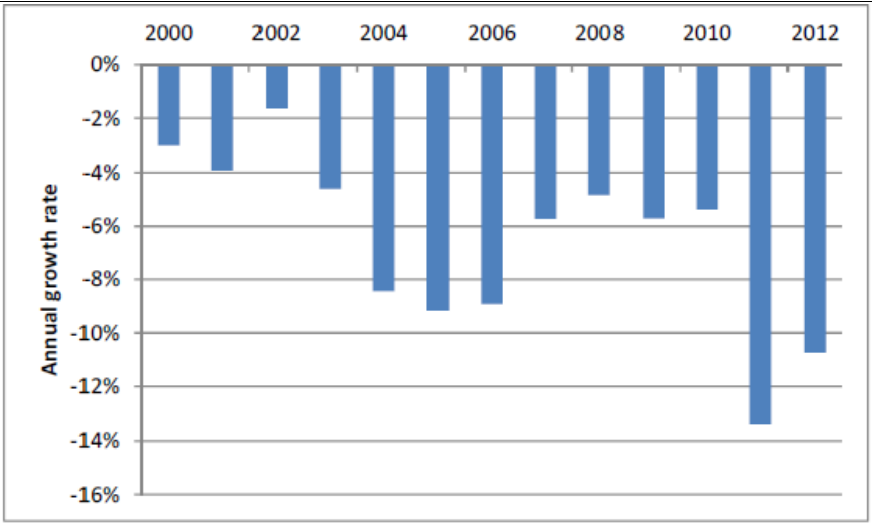


Figure 31: UK production annual growth rate 2000 – 2012 (Department of Energy and Climate Change, 2013a).

There was a substantial increase in energy imports which were 6.9 per cent higher than those in 2011, as shown in Figure 32 (Department of Energy and Climate Change, 2013a).

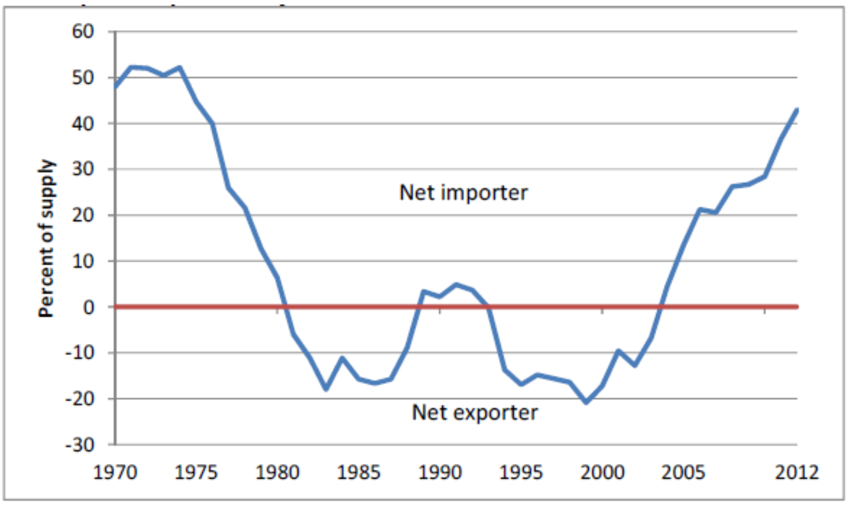


Figure 32: UK import dependency from 1970 – 2012 (Department of Energy and Climate Change, 2013a).

Gas as a means to produce electricity was no longer considered lucrative due to rising gas prices in 2012. This led to a shift to increased use of coal, whose usage increased by nine per cent (Department of Energy and Climate Change, 2013a). Figure 33 shows the percentage distribution of the generation of electricity using various sources.

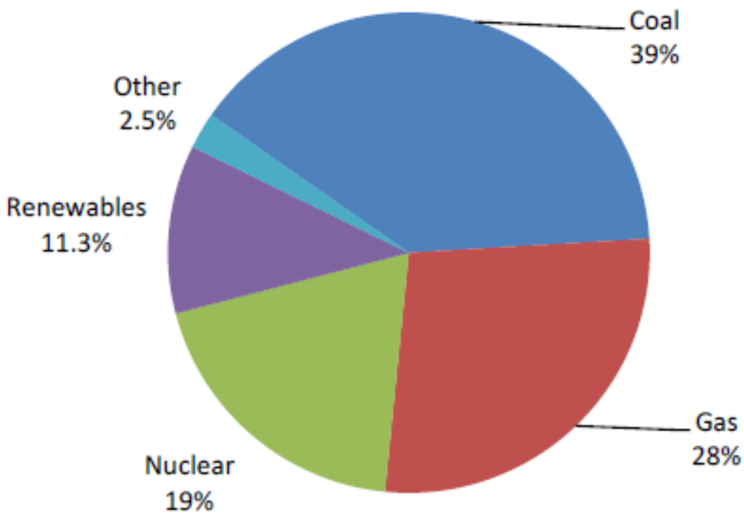


Figure 33: Generation of Electricity by fuel (Department of Energy and Climate Change, 2013a).

The contribution of the Energy industry to the economy of the UK also needed to be taken into account. Statistics suggest that the industry contributes to 3.5 per cent of the GDP and was responsible for 7 per cent of the industrial employment (Department of Energy and Climate Change, 2013b).

The above discussion shows that there is a strong case for looking at alternative methods to increase generation of electricity especially making use of renewable energy sources.

As described in Chapter 4, Section 4.4, there are numerous environmental and legislative constraints which characterize the Dover strait. Hence it was a challenging task to decide upon the exact deployment of the Oyster in terms of the location. Currently the energy requirement of the port of Dover is 140 GW per year. The deployment of a single one of these devices can produce 2.4MW of energy. Hence providing 5 % of the total energy required by the port. The calculation is based on the following :

The normal capacity factor at a wave energy power plant is 35%.

Capacity Factor = Actual output per year /(365 X 24 X nominal output)

0.35 = Actual output per year /(8760 X 2400)

Hence actual output per year = 0.35 X 8760 X 2400 = 7358400 = 7358MW ≈ 7.5 GW

Since the port of Dover requires 140GW of electricity, the Oyster technology is able to meet 5% of the total requirement.

5.3.2 Project Description

- Project name: Oyster 800 WEC For Dover
- Project Developer: XXX Power Company
- Regional Stakeholder Group (RSG)

The final recommendations for rMCZs are decided by the RSG. These are done on the basis of the aims of the project and the Ecological Network Guidance (ENG). The members represent the key sectors with an interest in the Balanced Seas project area. These are individuals from organizations and sectors which could provide a strategic and regional perspective. The important stakeholders for this region were identified as those related to: Recreation – water sports, Recreational Seas Angling, Charter Boats, Commercial fisheries, Port, Renewable energy industry, Environment NGO's, Archaeology and heritage NGO's, Coastal partnerships, Government agencies, local government and others like The Crown Estate and Ministry of Defence, as key national stakeholders besides the residents of Dover (BalancedSeas, 2011).

- Technology type: Oscillating Wave Surge Converter
- Resource: Wave
- Project scale (test site, prototype, array, commercial): 3 Oyster wave energy converters
- Installed capacity (MW): 2.4 MW
- Location: Device to be installed in the vicinity of Dover harbour eastern walls outside the rMCZ 11.1 (at a distance of 0.6 nautical mile from the coastline)
- Coordinates: The Coordinates for Oyster 800 are longitude 1.347^{o} latitude 51.122^{o}, see Figure 34.
- Project Schedule: Two years.

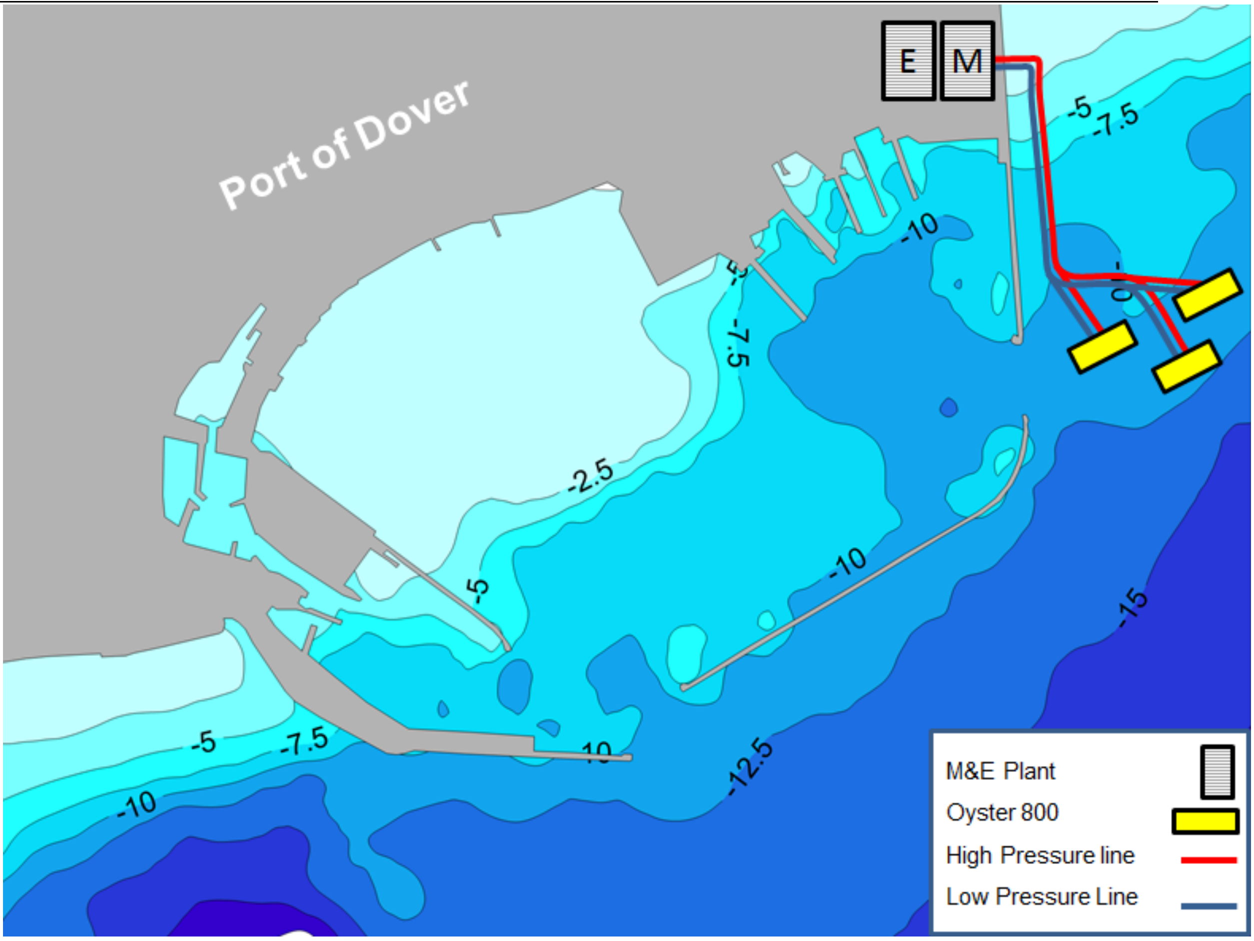


Figure 34: Schematic sketch of proposed site for Oyster800a, Oyster 800b and Oyster 800c and pipe lines near the Dover eastern harbour wall. Courtesy: Julio Salcedo Castro.

5.3.3 Rationalization of the Proposed Project

UK has become a net importer of energy in 2004 after almost 3 decades of being a net exporter, due to closure of coal-fired power stations which cannot meet the future emission standards and the shutdown of aging nuclear power stations. Figure 1 Figure 35 shows the UK energy import and export of energy. The gap between the import and export is expected to increase in the future. In addition, increasing fuel prices and concerns over the security of energy supply has become a great challenge in the UK energy market (Bolton, 2013).

DECC's report on UK energy trend in 2013, as illustrated in Figure 36, shows that in first quarter of year 2013, compared with the same period in 2012, imports of electricity rose by 5.8 per cent, whilst exports fell by 80.5 per cent. For every quarter from 2010 Q2, the UK has been a net importer after two quarters of being a net exporter (2009 Q4 and 2010 Q1). Net imports of electricity rose by 57.2 per cent from 2.0 in 2012 Q1 to 3.1 TWh in 2013, due mainly to increased imports from the Netherlands via the interconnector which came into full operation in April 2011. Net imports represented 3.2 per cent of electricity supplied in 2013 Q1.

"In 2013 Q1, the UK was a net importer from France and the Netherlands (whom the UK started trading with in February 2011) with net imports of 1.5 TWh and 1.6 TWh respectively. The UK was also a net importer from Ireland with net imports of 20 GWh, after three quarters of being a net exporter".

(Department of Energy and Climate Change, 2013b)

These figures emphasise the importance of proposals for generating energy form the existing sources in the UK namely, tidal and wave energy.

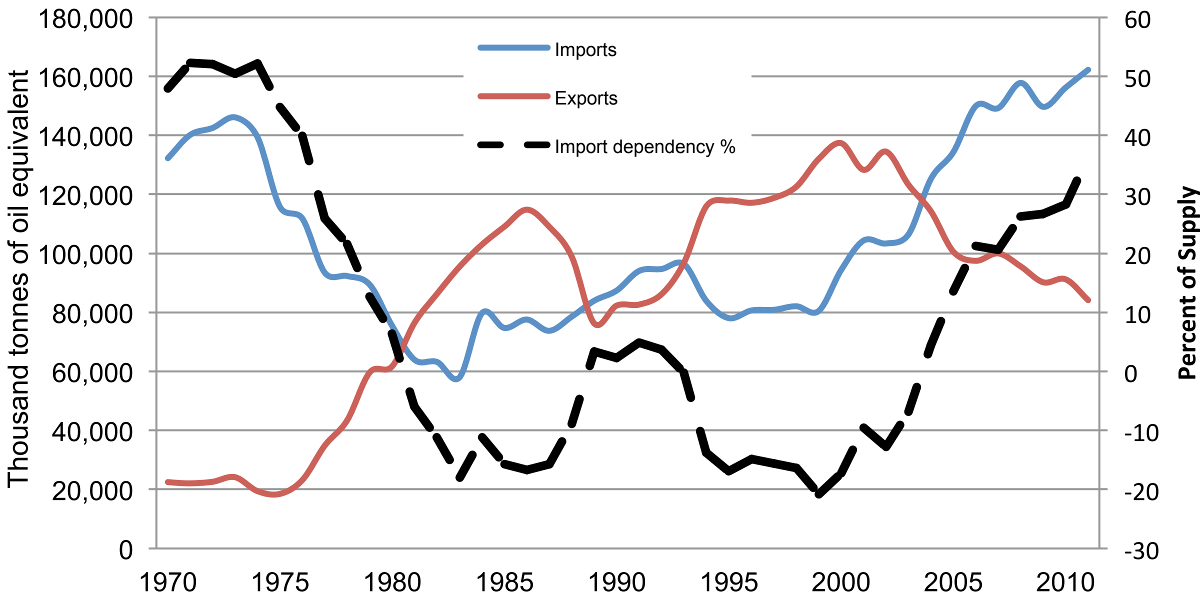


Figure 35: UK imports and exports of energy during the past four decades (Department of Energy and Climate Change, 2013b).

Coastal Erosion and Flood Defence

From the legal perspective, Department of The Environmental, Food and Rural Affairs in the UK (DEFRA) is in charge of coastline protection from flooding and erosion. Costal defence in general includes both costal protection (erosion of the coast) and flood defence. In the UK different authorities are responsible for coastline protection. Under the Coast Protection Act 1949, Dover District Council is

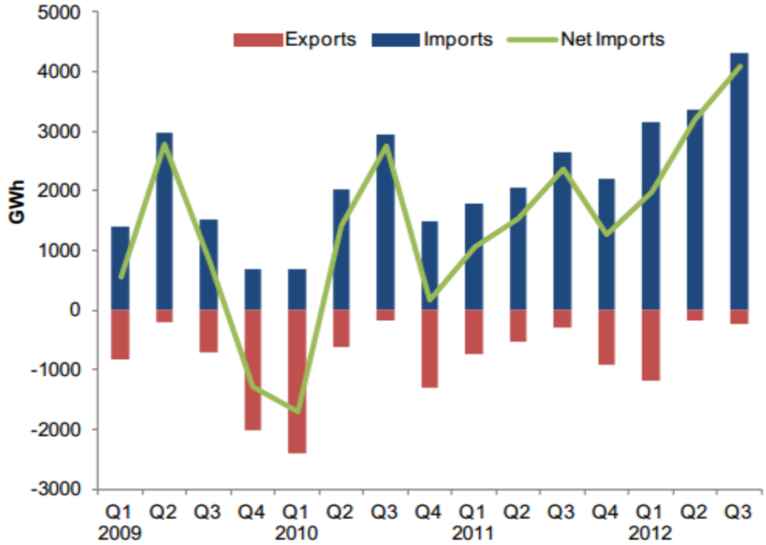


Figure 36: UK trade in Electricity (Department of Energy and Climate Change, 2012).

responsible for the management of coast defences, in District of Dover, to protect the coast from the effects of erosion. Whilst, Environmental Agency, under the Water Resources Act 1991 is responsible for construction and maintenance of resist coastal flooding in the region (Dover District Council, undated-a). Managing erosion is very critical in coastal areas, because changes in natural defence can lead to an increased risk of flooding or land loss, which can become an issue for urban and industrial areas, and nature reserves. Figure 37 shows the effect of erosion on coastal areas at Happisburgh, Norfolk, where more than 40 meters of land was lost between 1998 and 2007 and Oldstairs Bay, Kingsdown between 1949 and 1999.

There are many factors and drivers that affect coastal erosion. Nevertheless, the main controlling factor is argued to be the wave approach which set up onshore and alongshore currents (Dover District Council, undated-b). There are also other aspects which are required to be considered studying the coastal erosion in Dover region for example, Goodwin Sands which many ships are believed to have been wrecked upon the sands. Besides, inshore currents and wind direction together with the orientation of the shore influencing the angle with which waves approaching the shore and consequently moving the sediment along the coast.

It is clear that high-energy waves are able to transport larger amounts of sediment. With the Kent Coast predominantly made up of shingle, high wave energy is required and is provided by the long fetch from the South-west and North-east and beaches are believed to provide the best defence against wave attack, as they disintegrate wave energy. Therefore, if the beach is removed due to coastal erosion, as shown in Figure 37, the cliffs will start eroding and destabilising.

Figure 37: Effect of Coastal Erosion on Land Loss (Dover District Council, undated-b; National Oceanography Centre, 2013)

To protect the coastline in District of Dover, specially the cliffs, it is necessary to change the angle with which the waves approach the coast or reduce their energy before reaching the cliffs. Hence, developing a wave array in front of the cliffs not only contribute electricity generation from a renewable source, but also reduces the energy of wave in the area and therefore will have a great impact on moderating the coastal erosion. Figure 38 shows a schematic sketch of wave array development which has the capacity to provide 40 Megawatts (MW), enough energy to power up to 38,000 homes, according to a report by Lewis Wave Power Ltd. in 2012, a project which is planned to be developed in inshore waters off the north-west coast of the Isle of Lewis near the village of Siadar (Lewis Wave Power Ltd., 2012). The wave array will consist of between 40 and 50 Oyster devices.

As mentioned before the direction of wind will affect the wave direction approaching the shore and consequently the installed Oysters; hence, it must be borne in mind that the direction of the Oysters has to be decided based on wind and wave direction over the year, to detect the best angle for their installation.

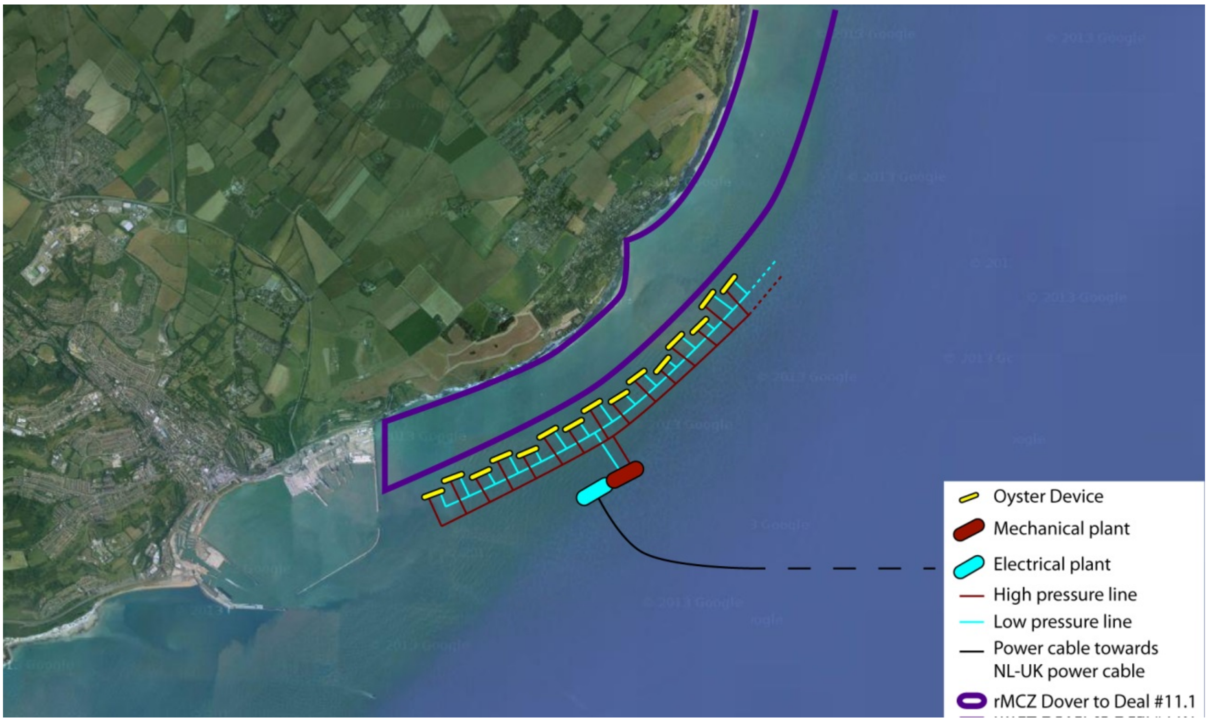


Figure 38: The development site location and layout of 40mW power plant (Google Maps).

The technical and operational consideration and environmental impact assessment for this site will be similar to those explained in 2.4 MW proposed Oyster project for port of Dover. Although, in this case the M&E plants are going to be offshore, due to constraints imposed by existence of cliffs. In this regard much can be learned from offshore wind farms. Figure 39 shows an offshore substation platform connected to high voltage export cable. Submarine export (transmission) cable (offshore substation to shore) has to be capable of continuous operation of 40MW at 90 to 100 kV. For example ABB's HVDC Light cable is qualified up to 150kV. HVDC cable has an advantage, due to its bi-polar construction, of eliminating magnetic radiation generated from the conductors. This feature is critical for obtaining required environmental permissions (ABB, 2004). Figure 40 shows the HVDC Light cross sectional diagram.

Figure 39: Offshore High Voltage Substation Platform for a Wind Farm (Knodel, 2010).

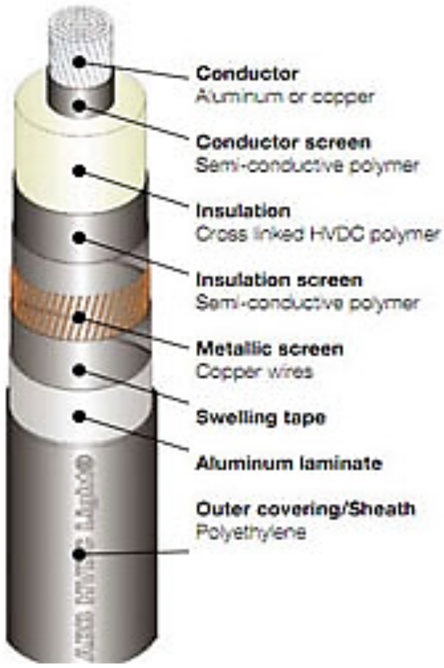


Figure 40: HVDC Light cross sectional diagram (ABB, 2004)

It is worth mentioning that using submarine power cables and constructing an offshore substation requires consideration of further international treaties. For example, under United Nations Convention on the Law of the Sea (UNCLOS) permission from a coastal state is not required to lay and maintain a submarine power transmission cable outside territorial seas; however, such permission is required if the power cable will be used for energy harvesting from waves, currents and winds (Snyder & Rondorf, 2011). Figure 41 shows the Legal boundaries related to offshore installation and operation.

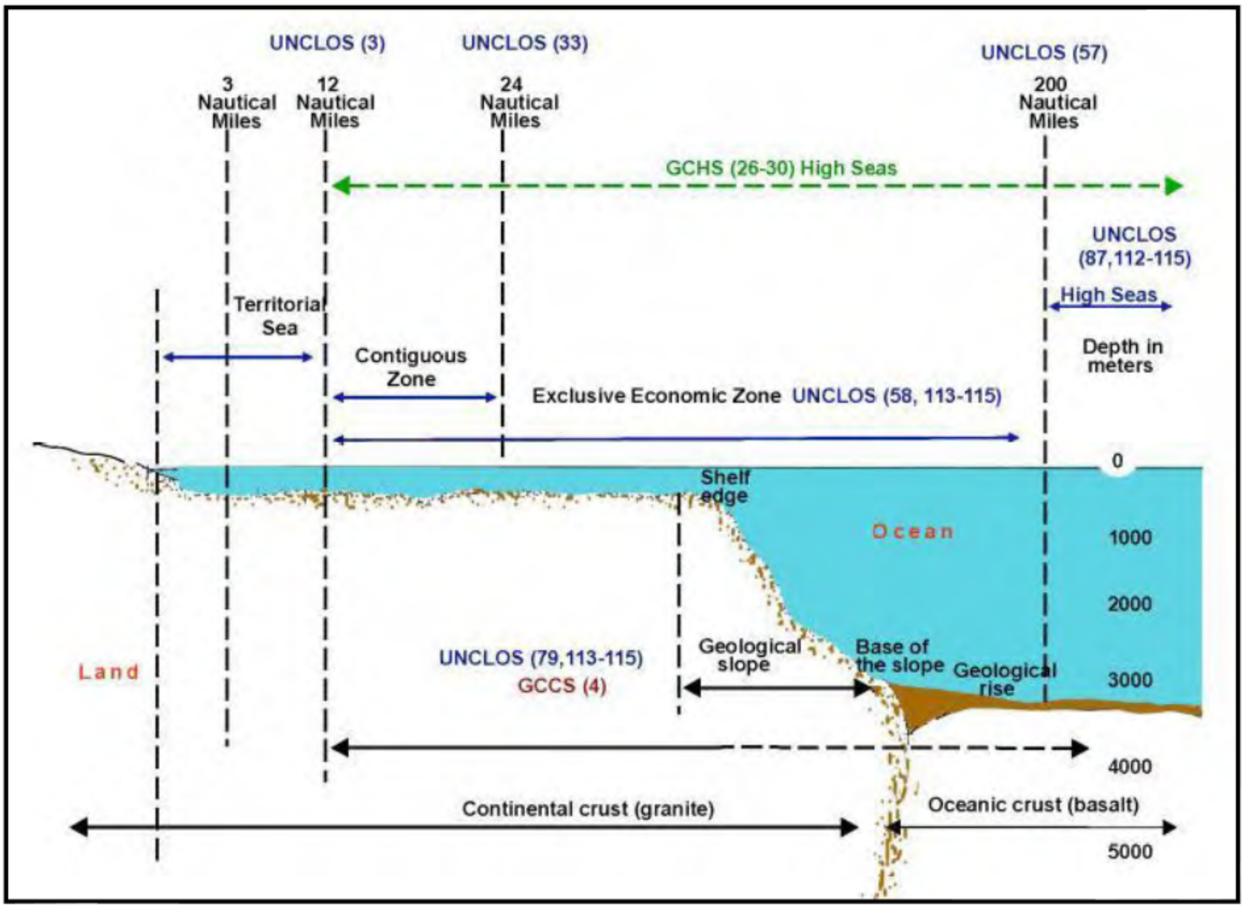


Figure 41: Legal boundaries of the ocean from Territorial Seas to Exclusive Economic Zone and onto the High Seas (note: The numbers in (brackets) refer to treaty articles) (Snyder & Rondorf, 2011)

5.3.4 The Project Constraints

The development of the final site layouts will take into account the following constraints (Aquamarine Power, 2011):

- Marine Protected Areas
- Existing Cables Across the Site
- Shipping and Navigation

- Archaeological Features
- Geology
- Fisheries interests
- Ecology
- Aggregates extraction areas

5.3.5 Components and Installation

Prior to developing any installation on the seabed, a seabed lease has to be obtained from The Crown Estate. The next step then is the preparation of the seabed. The WEC's are positioned by rock anchors during the installation. There are also interconnecting pipelines and associated stabilisation anchors. The Oyster 800 requires only two tugs for positioning. The WEC is then ballasted into position. The installation could be affected by delays related to suppliers and the weather and any other unexpected issues. The time duration is shown in Table 2.

Table 2: Proposed Installation Programme.

Operation	2014				
	M	J	J	A	S
Seabed preparation	■				
Installation of latching anchors	■				
Installation vessel mobilised	■				
Oyster 800 installation		■	■		
Installation of stabilising rock anchor supports		■			
Pipeline hook up			■		
Commissioning				■	
Oyster 800 operational					■

Onshore infrastructure

The onshore infrastructure consists of the following:

- 2 drive trains, each comprising of 2 Pelton wheel turbines within a common enclosure, driving a shaft with 1 flywheel per drive train and 1 generator per drive train.

- 2 banks of power electronic inverters to convert generator output to grid frequency and voltage.
- A Header water tank vented to the environment at ambient pressure.
- Filtration system.
- 2 step up transformers (1 per drive train) between the generator output and grid connection point.
- Electrical system protection to protect itself and the grid.
- Additional transformer to convert grid voltage to ‘step down’ to provide mains voltage to the site.
- Onshore accumulators connected to the directionally drilled pipelines which are used for smoothing the flow of pressurised water.
- Dump resistors which are used in any sort of emergency to shed power quickly
- Operator’s rest/office area, workshop and switch room
- Directionally drilled pipelines from the onshore facility to an exit point on the seabed near to the location of the Oyster devices.

Offshore infrastructure

The material options will be using steel as the main material of construction alternatively a combination of steel, composites, elastomers, marine grade rubber and steel also can be used. Either of these would not make a very great impact on the environment.

Specifications (per WEC):

- Flap – 30m wide (parallel to shore), 6m thickness (perpendicular to shore), 13m high (vertically – top of flap to hinge point), hinge axis depth approximately 9m below MSL (mean sea level)
- Baseframe – 1 unit is 30m wide, 10m thick, 6m high (this is the envelope within which the baseframe would be located). The top of the baseframe is upto 8m high above seabed depending on seabed slope.
- Hydraulic modules – These will be contained within the envelope of the base frame and flap.
- Mono pile foundation – Preinstalled and subject of a previous FEPA Licence application (Ref 03987/10/0-4849 and 03987/11/4849).

The design of the supporting seabed infrastructure could be done in the following ways:

- Hydraulic pipelines (1 Glass Reinforced Epoxy (GRE) plastic low pressure pipeline and 1 steel high pressure pipeline); Carbon steel spool support/protection frames including glass flake epoxy protection paint; Aluminium alloy sacrificial anodes; A number of mattresses will be used as localised protection around pipeline exit points and tie-ins.
- Four sets of anchors to be installed on both/either sides of each Oyster device. Each set comprising of 3 anchors which are 52mm in diameter and 1.5m in length. These will assist the Oyster WEC onto its foundation monopole and also will be used for maintenance operations throughout the life of the project.

5.3.6 Commissioning, Operation and Maintenance

The Oyster will be commissioned in as per a written commission plan. The main features of this plan will be the commissioning of sub-systems followed by the commissioning of the entire system. The steps in the commissioning will be: pressure testing, electrical component testing, visual examinations and functional testing of the mechanical, electrical and instrumentation components, offshore commissioning, post installation seabed survey and technical survey of the Oyster 800 WEC. Upon successful commissioning a document detailing the readiness of the system for operation will be submitted by the commissioning contractor which will then be followed by commencement of operations.

The time frame for starting operations is within five months of starting the installation process. The maintenance can be without divers on account of the design of the Oyster 800. Divers may be required for specific inspections. Maintenance activities are perceived to be taking place every six months with a plan for extended maintenance every five years. Maintenance will comprise of removal of isolated hydraulic modules, leak testing of pipelines, power-washing biofouling, small areas of kelp removal or maintenance of any other component parts.

5.3.7 Decommissioning

The decommissioning of the Oyster 800 will take place at the end of its operating life and all the equipment will be removed from the deployment site according to a standard which is acceptable to industry best practice at that period of time. The Decommissioning Programme will be in accordance with Chapter 3 of the Energy Act 2004. In principle decommissioning of the device will effectively be a reverse of the installation process. The main phases will be: mobilisation of vessels to site, securing of the Oyster device, cutting the interconnecting pipelines and retrieval of these to the vessel deck, attachment of recovery rigging, cutting of piles at seabed and using buoyancy aids allowing the Oyster device to float to the surface (with piles attached), tow the Oyster device to the selected port for the purpose of disassembly, retrieval of all equipment and materials from the seabed onto the decommissioning vessels, a reinstatement of the seabed including cutting of piles down to seabed level wherever required, clearing up the seabed and finally a post decommissioning seabed survey.

Table 3: Estimated Costs in £m for both proposals (SQW Energy Consulting, 2009).

Project	Fabrication	Installation	Operation & Maintenance	Decommissioning	Total
2.4MW	2.448	4.752	1.296	3.576	11.892
40MW	40.8	129.2	21.6	59.6	251.2

5.3.8 Economic Analysis of Oyster Technology

Major cost components of Oyster wave energy convertor are foundations/mooring, structure, mechanical and electrical (M&E) plant, and finally operation and maintenance (O&M) (T. Whittaker & Folley, 2005). Figure 42 demonstrates indicative contributions of components to the cost of generated electricity. The figure illustrates the significance of O&M costs, which includes maintenance tasks, insurance, unscheduled repairs and periodic refits. A study carried out by the Royal Academy of Engineering in 2004 suggested that the O&M costs could be approximately £56/kW. The same study states that with future advancement in wave and tidal technology, the industry should expect a cost reduction mainly in capital expenditure and to some extent in O&M costs over the period to 2020 (The Royal Academy of Engineering, 2004). Figure 43 indicates the cost reductions assumed to apply to the technologies by 2020.

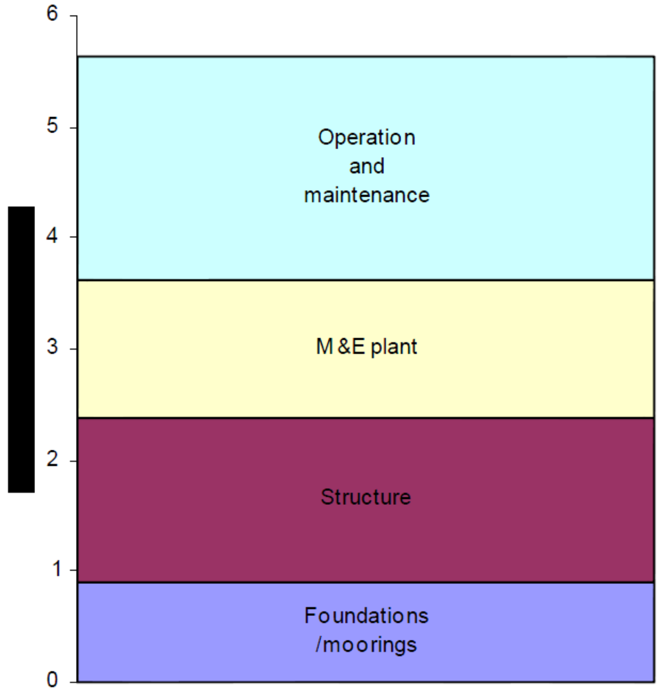


Figure 42: Typical cost breakdown for a wave energy converter (T. Whittaker & Folley, 2005).

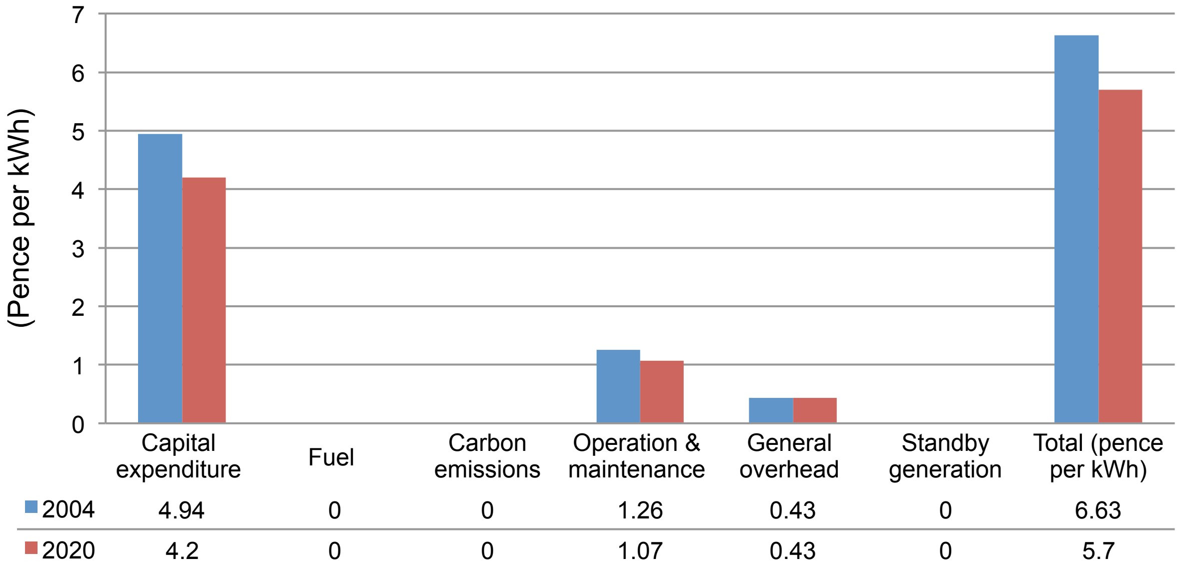


Figure 43: Cost reduction scenario for a marine wave technology (The Royal Academy of Engineering, 2004).

The cost of Mechanical and Electrical containers is largely subjected to the plant capacity. T. Whittaker and Folley (2005) reported that this cost is around £400/kW. Suppose that the capacity factor of the power plant is 35 per cent, which is a typical output estimation for a wave energy plant, the cost of generating electricity using this type of plant is approximately 1.25p/kWh. Perhaps it is worth mentioning that the capacity factor of a power plant is basically an indicator of its efficiency and defined as the ratio of the plant's actual output over a period of time, to its potential output. Expected capacity factor for number of renewable energy technologies are shown in Table 4.

Table 4: Expected Capacity Factor for Renewable energies (Baringa Partners Ltd., 2013).

	Wave	Tidal	Onshore Wind
Expected capacity Factor	30-35%	26-35%	35-50%

Estimating the costs of structure and foundation is mainly governed by the quality of material being used and the level of structural strength required during operation and survival, the ease of manufacture, assembly and installation on site (T. Whittaker & Folley, 2005). Finally the productivity of the plant will be influenced by variety of factors such as, deployment, availability, wave to wire conversion efficiency and reliability of the plant, which itself is linked to operation and maintenance.

Decarbonising the Energy System

Marine energy resources namely wave and tidal can potentially have a significant influence on carbon emission reduction 2050 targets in the UK. The total amount of wave energy in UK and Irish waters is reported to be 840TWh/year which holds approximately 50 per cent of the total European wave energy resources (RenewableUK, 2013b); Whilst the tidal energy (including tidal range and tidal stream) is estimated to be 216 TWh/year, which counts for almost 25 per cent of the European tidal energy resource. With today's technology it is evaluated that only 50TWh/year of wave energy resource and some 48TWh/year of tidal energy can be economically convertible (RenewableUK, 2013a). Considering current UK annual electricity demand of 350 TWh/year, with renewable energy industry's existing technology approximately 27 per cent of the UK electricity could be recovered from marine energy resources.

Table 5: CO_2 and GHG replaced by Oyster technology (Defra/DECC, 2013).

Scenario	Capacity Deployed (kW)	CO_2 reduction (tonnes/year)	CO_2e (GHG) reduction (tonnes/year)
Plant capacity factor 30%	2400	2700 Conversion factor 0.43kg of CO_2 per kWh replacing a combined cycle gas turbine (CCGT) power station	3100 Conversion factor 0.49kg of CO_2e (Including Transmission /Distribution Losses)
Plant capacity factor 35%	2400	3200	3600

Exploiting a 2.4 MW Oyster wave converter plant in port of Dover, which will displace conventional fossil-fuel power plant in the region, could reduce CO_2 from the energy system approximately by 3200 tonnes/year. Table 5 shows two different scenarios in carbon reduction in port of Dover based on the energy conversion factors reported by Department of Energy and Climate Change (Defra/DECC, 2013). It must be born in mind that the greenhouse gas conversion factor comprises the effect of the CO_2, CH_4 and N_2O combined and is quoted as $kgCO_2e$.

5.3.9 Oyster 800 Project Risk Assessment

This part provides an environmental statement (ES), considering Marine Wildlife Impact Assessment during installation, operation and decommissioning, Seabed Interactions Impact Assessment, Navigational Safety risk Assessment (NSRA) and Accidental Discharge Assessment, prepared by the site developer under section 36 of the Electrical Act (1989) for development of the 2.4 MW Oyster 800 array wave energy.

Environmental Impact Assessment (Underwater Noise Impact on Marine Wildlife)

Impacts of drilling, installation and maintenance vessels, besides operation of hydraulic system on marine mammal, seabird and fish species is required to be assessed. Much has been written on the effect of human activities on marine mammals. Some of the known impacts are, navigational interference, masking, mating, communication problems, behavioral effects and etc.

Seabed Interactions Impact Assessment

An assessment of the potential impacts on the seabed environment has to be provided by the site developer or another company. The seabed in the vicinity of the project, especially in front of the cliffs, is a conventional seabed unlike the other parts of English Channel were the seabed is rock and the transition slope from coast to sea is smooth, which has to be considered during the installation of the Oyster components,

Navigational Risk Assessment (Offshore Renewable Energy Installations: impact on shipping)

An NSRA has to be conducted by developer or a consultancy company for Oyster 800 and foundations (monopole). The NSRA has to be undertaken in accordance with Marine General Guidance Notice MGN 371 (M + F) – Offshore Renewable Energy Installations (OREI): Guidance on UK Navigational Safety and Emergency Response Issues. The main navigational feature in the vicinity of the Project is the Traffic Separation Scheme (TSS) in the eastern English Channel adjacent to the Dover Strait.

Undertaking a navigational Preliminary Hazard Analysis (PHA), using existing information on the navigational interests of the project area (East Coast of Dover Harbour) and details of the proposed project to scope the requirements of the full NRA is a common practice in developing renewable energy sites (Aquamarine Power, 2011).

Accidental Discharge

Whilst there is no specific legislation or published guidance regarding accidental or non-routine pollution events associated with marine renewable energy developments the following applies (Aquamarine Power, 2011):

- The International Convention for the Prevention of Pollution from Ships (MARPOL) covers pollution of the marine environment by ships from operational or accidental causes.
- Regulation 37 of Annex I of MARPOL requires that all ships of 400 gross tonnage (GT) or more carry an approved Shipboard Oil Pollution Emergency Plan (SOPEP).

6 Carbon Management in Dover

6.1 Introduction

The UK Climate Change Act 2008 sets the framework for how the UK will manage and respond to the threat of climate change. According to Chapter 27 of the Climate Change Act 2008 (House of Lords, 2008), it is the “duty of the Secretary of State to ensure that the net UK carbon account for the year 2050 is at least 80% lower than the 1990 baseline” (p. 1). The 1990 baseline means the “aggregate amount of net UK emissions of carbon dioxide for that year, and net UK emissions of each of the other targeted greenhouse gases for the year that is the base year for that gas” (p. 2). Moving to a more energy efficient, low-carbon economy is the way to go in order to meet the Climate Change Act target.

There is much room for improvement in Dover District, where transportation at the busy port results in significant carbon emissions. In the 2005 sustainability evaluation report of Dover by Scott Wilson Business Consultancy (Smith, 2005), it was found that among 14 strategic sustainability objectives, the two most significant problems to be addressed in Dover District were air pollution and lack of public transport. The latter has a direct impact on air pollution as well. Therefore, the book focuses on ways to reduce air pollution by targeting carbon emissions, so as to work towards a high level of air quality.

This chapter presents the carbon emissions levels in Dover, along with the current efforts in carbon management. Thereafter, solutions using biomimicry are proposed to capture and reduce the carbon content in the atmosphere to alleviate the effects of global warming. Finally, the feasibility of the solutions in terms of their application to Dover is reviewed and discussed.

6.2 Carbon Emissions in Dover District

Information pertaining to carbon emissions in Dover was drawn from the Department of Energy and Climate Change (DECC) reports (Kent County Council, 2011). Figures on CO_2 emissions for Dover District from the most recent 5-year report for Kent County are presented in Table 6 and Table 7. The data is presented for both total and per capita carbon emissions, and each is categorised into 3 sectors, namely Domestic, Industrial/Commercial, and Road Transport. Graphs illustrating the trend from 2005 to 2009 are shown in Figure 44 and Figure 45.

Table 6: Total CO_2 emission for Dover district in kilotonnes (Kent County Council, 2011).

Sector	2005	2006	2007	2008	2009
Industrial/Commercial	356.35	288.83	292.66	383.93	184.83
Domestic	245.98	244.68	238.22	236.53	212.35
Road transport	187.99	184.94	193.64	180.91	174.10
Total CO_2 emissions (kt)	790.32	718.45	724.52	801.37	571.28

Table 7: Total CO_2 emission per capita in Dover district in kilotonnes (Kent County Council, 2011).

Sector	2005	2006	2007	2008	2009
Industrial/Commercial	3.36	2.74	2.76	3.62	1.74
Domestic	2.32	2.32	2.25	2.23	2.00
Road transport	1.77	1.75	1.83	1.70	1.64
Per capita CO_2 emissions (kt)	7.45	6.81	6.84	7.55	5.38

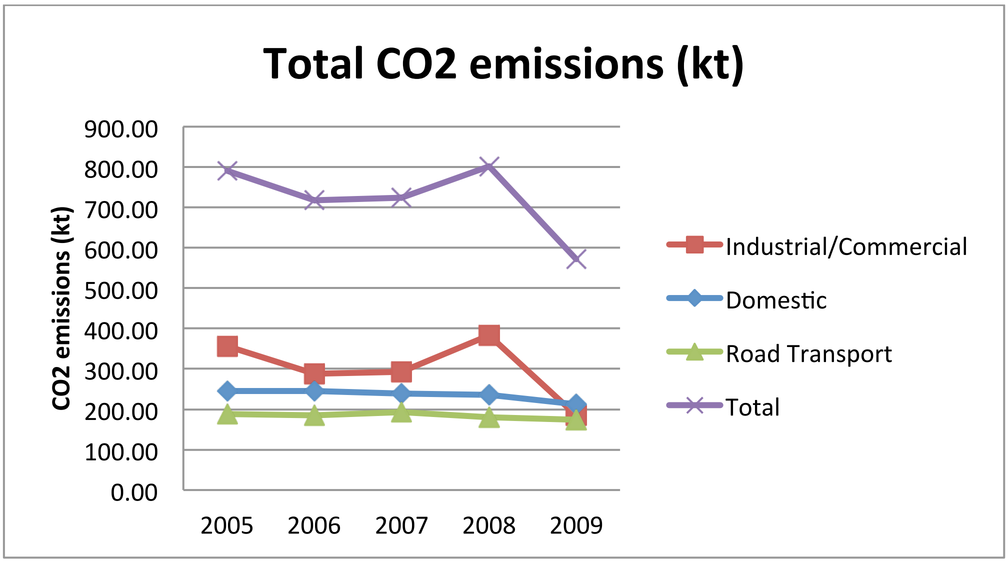


Figure 44: Total CO_2 emissions in Dover district in kilotonnes.

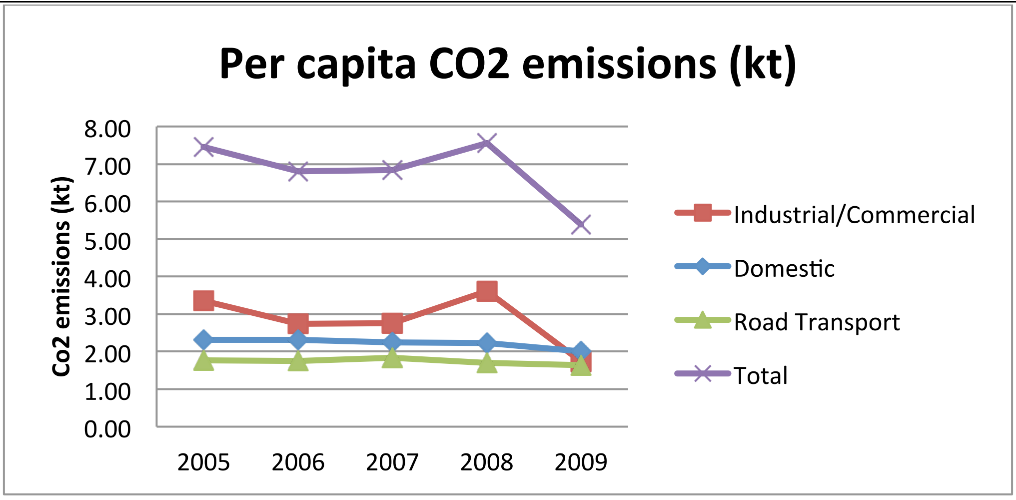


Figure 45: CO_2 emissions in Dover district per capita in kilotonnes.

For both total and per capita carbon emissions, most of the changes were accounted for by the industrial/commercial sector, while the other two remained relatively constant. Additionally, the former was the major contributor of carbon emissions from 2005 to 2008, but ceased to be so in 2009. This suggests that local authorities have effective measures in place to reduce carbon emissions in that sector. Hence in 2009, the major contributor to carbon emissions is in fact the domestic sector. As such, efforts need to be focused on this sector in order to continue the trend of carbon emissions reduction. In view of this, the carbon emissions for the domestic sector is further analysed, as shown in Table 8 and Table 9. Similarly, graphs illustrating the trend from 2005 to 2009 are shown in Figure 46 and Figure 47.

Table 8: Estimates of local level domestic CO_2 emissions in Dover district (Kent County Council, 2011).

Sector	2005	2006	2007	2008	2009
Domestic Electricity	105.10	109.90	110.90	107.40	95.50
Domestic Gas	135.90	129.80	122.50	124.10	111.90
Domestic Other fuels	5.00	5.00	4.90	5.00	5.00
Domestic Total	246.00	244.70	238.30	236.50	212.40

Table 9: Estimates of local level domestic CO_2 emissions per capita in Dover district (Kent County Council, 2011).

Sector	2005	2006	2007	2008	2009
Domestic Electricity	0.99	1.04	1.05	1.01	0.90
Domestic Gas	1.28	1.23	1.16	1.17	1.05
Domestic Other fuels	0.05	0.05	0.05	0.05	0.05
Domestic Total	2.32	2.32	2.26	2.23	2.00

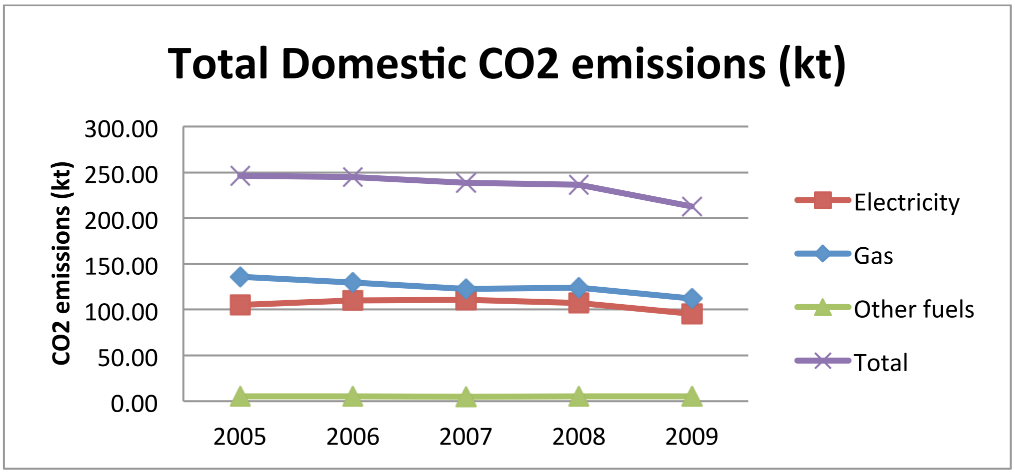


Figure 46: Total domestic CO_2 emissions in Dover district in kilotonnes.

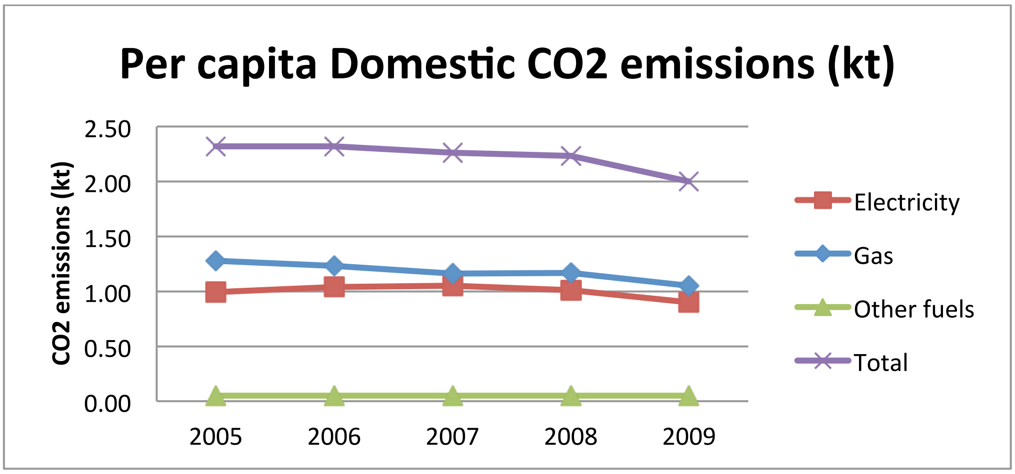


Figure 47: Per capita domestic CO_2 emissions in Dover district in kilotonnes.

It is noted that electricity and gas are the main contributors of carbon emissions in the domestic sector in Dover. Hence to achieve carbon reduction, energy efficiency in buildings and infrastructure could be looked into, on top of tapping on renewable energy sources.

The above reported carbon emissions levels are for the whole of Dover District. On the ground level, organizations are also required to report their respective greenhouse gas emissions as part of the Low Carbon Transition Plan (Department of Energy and Climate Change, 2008) and the Low Carbon Industrial Strategy (Department for Business Innovation and Skills & Change, 2009). The six main greenhouse gases (GHG) defined in the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). GHG emissions are known to cause positive radiative forcing of the Earth's atmosphere, which drives up the surface temperature of the Earth. In other words, they are the cause of global warming and climate change. Therefore, reduction in GHG emissions is imperative to alleviate the effects of global warming and climate change.

The first step to reducing GHG emissions is to understand how to measure them. The widely accepted approach to reporting GHG emissions (Department for Environment Food and Rural Affairs, 2009) is to identify and categorize the emissions-releasing activities into three scopes. Scope 1 refers to direct emissions, which are "activities owned or controlled by the organisation that release emissions straight into the atmosphere". Scope 2 refers to energy indirect, which are "emissions being released into the atmosphere associated with the organisation's consumption of purchased electricity, heat, steam and cooling". Scope 3 refers to other indirect, which are "emissions that are a consequence of the organisation's actions, which occur at sources the organisation does not own or control and which are not classed as scope 2 emissions". Figure 48 provides a guide as to how the activities are classified in the respective scopes.

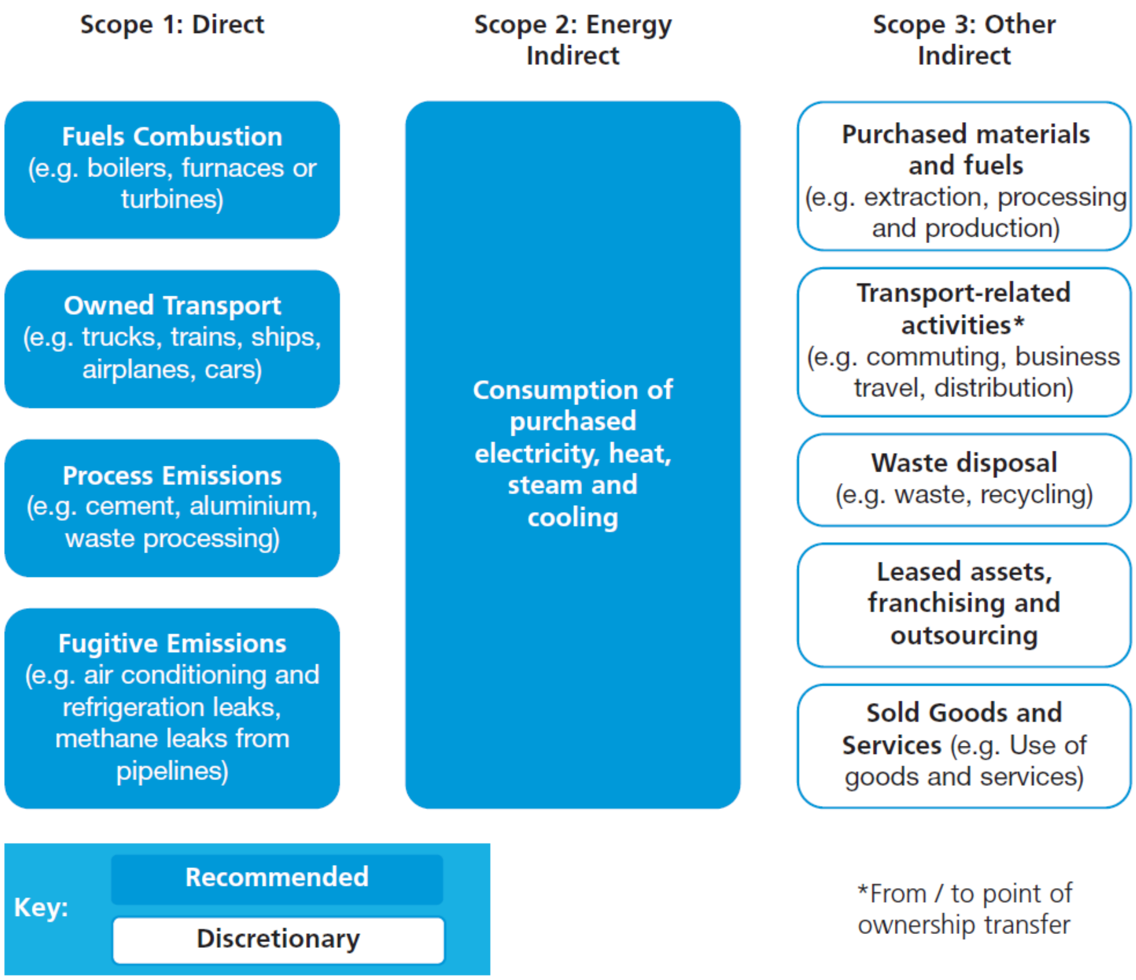


Figure 48: Guide on the classification of emissions-releasing activities (Department for Environment Food and Rural Affairs, 2009)

The greenhouse gas emissions from Dover District Council (Dover District Council, 2012) as an organisation are provided as an example. Table reports its GHG emissions for year 2011/2012, and Table 10 and Table 11 give a more detailed report on emissions under each individual scope. The base year is set as 2008/09, and the recorded baseline data complies with the Government's NI185 National Performance Indicator data set. The collected data is converted to the carbon equivalent using the GHG conversion factors on the DECC website. The metric of tonnes of CO_2e per square meter of corporate building space is chosen as it is a valuable comparator. The Intensity measurement in 2011/12 is 4136.56/25148 which gives a measurement of 0.1645 tonnes CO_2e per m^2.

Table 10: Greenhouse Gas Emissions Data 2008-2012 (Dover District Council, 2012)

	Global Tonnes of CO_2e			
	2011/12	2010/11	2009/10	Base year 2008/09
Scope 1	1221.01	1212.43	1169.30	1130.40
Scope 2	2085.13	2130.20	2163.60	2199.40
Scope 3	832.65	680.75	702.30	552.04
Total Gross Emissions	4138.79	4023.38	4035.20	3881.84
Carbon Offsets	2.23	2.80	2.00	2.82
Total annual net emissions	4136.56	4020.58	4033.20	3879.02

Table 11: Greenhouse Gas Emissions Data 2011/12 by Scope (Dover District Council, 2012)

	GHG emissions 2011 in tonnes of CO_2e	Specific exclusions and where known % this represents
Scope 1		
Gas consumption	1202.70	
Owned transport	18.32	
Fugitive emissions	---	Emissions from AHU's in office buildings are excluded due to the cost of data collection. Losses are expected to be <1% of scope 1.
Total Scope 1	1221.02	
Scope 2		
Purchased electricity	2085.13	
Wind turbine	-2.23	
Total Scope 2	2082.90	
Scope 3		
Business travel	122.39	Excludes employee commuting
Freight	710.26	Includes waste disposal
Total significant scope 3	832.65	

In 2009, the emission reduction target of Dover District Council is to reduce global CO_2e by 15% from 2008/09 to 2015/16 for scopes 1, 2 & 3 (Scope 3 reductions are for business miles only). (Dover District Council, 2012). In the base year 2008/09, the total annual net greenhouse gas emissions is 3879 tonnes CO_2e. This translates to GHG emissions of 3297 tonnes CO_2e in 2015/16. However, scrutiny of the figures in Table reveals that the GHG emissions have in fact been showing an ascending trend over the years instead of going downwards. This is illustrated in Figure 49. Although there is a slight drop from 2009/10 to 2010/11, the overall trend is still positive, indicating that there is more work to be done. Just to maintain GHG emissions at the base year level, approximately 500 tonnes of CO_2e has to be removed from the atmosphere by 2015/16. In order to meet the target, 1100 tonnes of CO_2 has to be removed. It is apparent that human practices of reducing GHG emissions are not yet effective, hence the notion of looking to nature for help ensues.

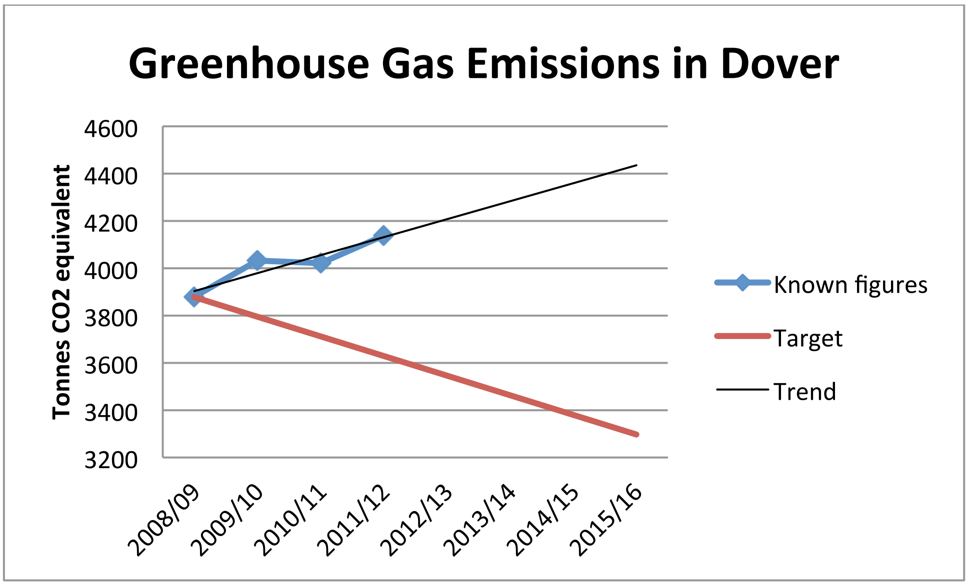


Figure 49: Greenhouse gas emissions in Dover.

In addition, Dover is known for being a commercial port for passenger and freight ferries, as well as cruise ships. As such, the carbon footprint of the port of Dover is significant. Carbon footprint, as described by the Carbon Trust, is "the total set of greenhouse gas (GHG) emissions caused by an organisation, event, production or person." It can be expressed in terms of the amount of CO_2, or the equivalent effect caused by all the GHG's emitted. Carbon footprints are used to measure the environmental impact of energy consumption.

Figure 50 shows the carbon footprint of Dover Harbour Board (DHB) in 2010 and 2011 (Dover Harbour Board, 2012). In 2011, the carbon footprint for the Port of Dover was 12,878 tonnes CO_2e, a reduction of 14% from the previous year. This translates to the savings of over 2,080 tonnes of CO_2. Reductions were achieved in all emission sources in comparison with 2010:

- Electricity consumption reduced by 12%,
- Gas consumption reduced by 30%,
- Owned transport emissions reduced by 9%,
- Gas oil purchases reduced by 10%,
- Refrigerant gas losses reduced by 49%.

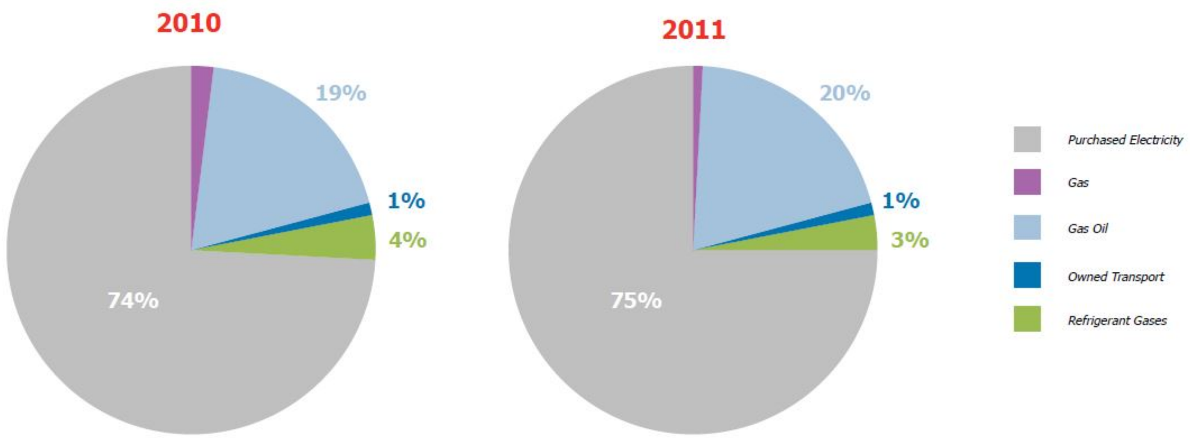


Figure 50: The carbon footprint of the Port of Dover in 2010 and 2011 (Dover Harbour Board, 2012)

It is evident from Figure 50 that electricity consumption is a major source of carbon emissions. Electricity is used to heat and power the operations of the port every day, resulting in significant impact on the port's carbon footprint. In view of this, the main focus of the DHB's carbon reduction programme is to reduce the carbon footprint arising from this sector, as can be seen from the yearly 5% reduction target made since 2009 (Dover Harbour Board, 2013b). In fact, the savings achieved in this area in 2011 are the most significant, contributing to 67% of the overall savings made (Dover Harbour Board, 2012). Additionally, Figure 51 shows that electricity consumption in kilowatt hours of Dover port has decreased steadily over the years from 2006 to 2011.

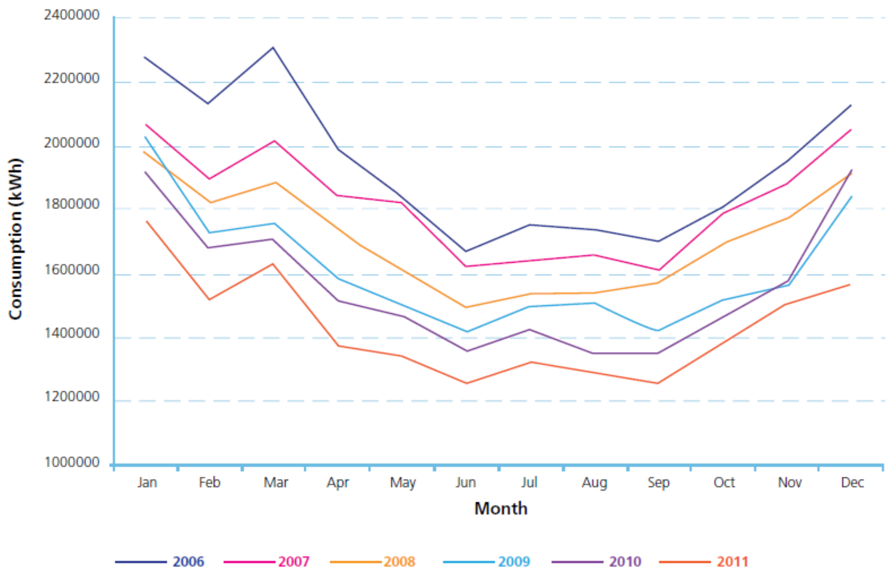


Figure 51: Monthly electricity use by the Port of Dover 2006 – 2011 (Dover Harbour Board, 2012)

Similarly, Figure 52 shows the carbon footprint of Dover Harbour Board in 2011 and 2012 (Dover Harbour Board, 2013b). In 2012, carbon emissions have been reduced by 2.2% from 12,878 tonnes CO_2e in 2011, translating to a saving of over 294 tonnes of CO_2. This demonstrates DHB's commitment to implement and maintain its carbon reduction strategies.

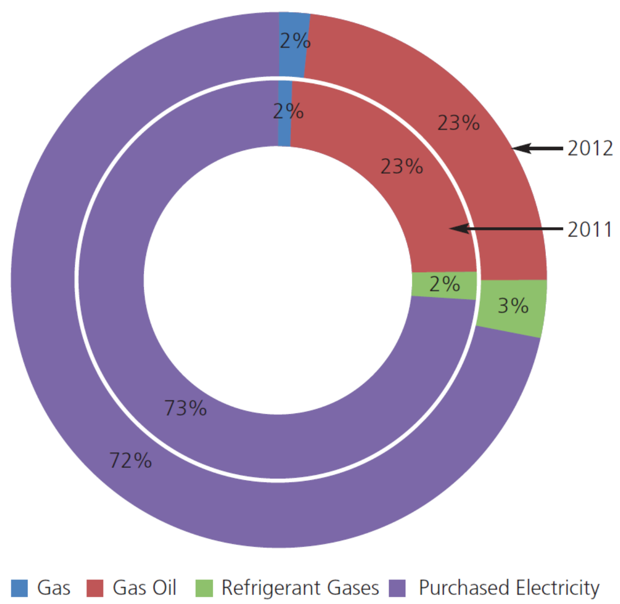


Figure 52: Per category contribution to the carbon footprint of the Port of Dover (Dover Harbour Board, 2013b)

An important point to note, however, is the fact that Dover is a port city, which means that there are high levels of transportation activity in and out of the port, on land and at sea. The carbon emissions arising from the transportation of goods, which are not meant for the people of Dover, from the port to the town and vice versa, is probably not included in the emissions figures reported above. The complexity of the problem is increased by the fact that ships stop at port of Dover for refueling as well. Hence, Dover's carbon emissions are ostensibly higher than the reported figures, due to the fact that Dover is not held accountable for these emissions.

6.3 Current efforts to manage carbon in Dover

This section presents Dover's emission reduction targets as well as ongoing efforts to achieve the target.

A report by Dover District Council on Dover District Sustainable Construction and Renewable Energy Strategy (Ebbs, 2009) presents concrete plans for carbon reduction in the near future. Table 12 shows the targets for carbon reduction in the construction industry by 2026, 13 years from now. The regulatory standard requires new residential development from 2009 to meet a certain level of the Code for Sustainable Homes before it can be approved. Should the policy be effective, carbon reduction in Dover may reach up to more than 86 kilotonnes in 2026.

Table 12: Targets for Carbon Reduction in construction industry by 2026 (Ebbs, 2009)

Carbon Reduction (tonnes) 2026 Compared with 2006 Baseline		
	Trend	Policy
Saving – Existing Stock	75,166	140,703
Addition – New Build	54,127	54,127
Net Saving	21,039	86,576

There are also ongoing efforts by Dover to reduce carbon emissions in the domestic sector (Kent County Council, 2012). For example, as part of the Kent Retrofitting Programme in 2011, high carbon or socially deprived areas in Dover were identified, and independent energy consultants provided easy-to-fit energy and water-saving devices to residents in these areas. They also provided information on grants towards loft and cavity wall insulation, heating controls and A-rated condensing boilers. This strategy enabled the residents to reduce energy consumption as well as cut utility bills.

To offset carbon emissions in Scope 1, the Dover District Council has also installed a 20kW wind turbine at the Whitfield Office site in November 2007. The turbine is "grid connected and has provided Feed in Tariff payments under the Government's renewable energy programme" (Dover District Council, 2012). The use of wind energy as a source of renewable energy helped to offset carbon emissions by approximately 2.23 tonnes per annum, as reported in Table.

The Dover ferry port is also doing its part to reduce its carbon emissions. In 2012, it was awarded the Carbon Trust Standard for the second time, which entails continued carbon reductions for four consecutive years (Dover News, 2013). The Carbon Trust Standards, which is awarded every two years, verifies the carbon footprint and emission reduction of organisations. To achieve the Carbon Trust Standard, organisations must fulfill three main criteria (Dover Harbour Board, 2013b). First, the carbon footprint has to be measured accurately. Second, absolute or relative carbon emissions have to be reduced by 2.5% per annum over the two year period. Third, evidence must be produced to show that carbon is managed appropriately through effective governance procedures and accurate carbon accounting. Thorough analysis of the port's carbon footprint revealed a 4.4% reduction in emissions each year from 1 April 2010 to 31 March 2012. This figure contributes to the 25% reduction made since the port's carbon management programme started in 2006 (Dover News, 2013).

Furthermore, the Dover ferry port is part of the first mandatory UK government's Carbon Reduction Commitment (CRC) Energy Efficiency Scheme (Environment Agency, 2012) aimed at improving energy efficiency and cutting emissions in large organisations in the UK. It applies to all public and private organisations that have "half-hourly metered electricity and consumption greater than 6000 MWh per year" (Dover Harbour Board, 2013b). In 2012, the Port of Dover "outperformed all other UK Ports in the CRC league table with a weighted score of 1484.28 within a range of 1900.25-162.85" (Dover Harbour Board, 2013b). This score helped to place DHB in the top 10% among over 2000 participating organisations.

The success of Dover ferry port in reducing its carbon emissions is made possible through several energy initiatives. First, the high mast lighting in the Eastern Docks was reconfigured to incorporate the latest lamp technology, which resulted in a saving of 500,000 kWh per year (Dover News, 2010). Similarly, lighting was refitted at Dover's cruise terminal at the Western Docks, which saved approximately 218 tonnes of CO_2 (Dover News, 2013). Second, a marina electricity metering system was implemented to monitor energy consumption and identify where energy can be saved.

Third, campaigns were introduced to improve working habits, such as turning off computer screens and shutting windows in air-conditioned offices.

Even after its achievements in carbon reduction, the Dover ferry port shows no signs of slowing down. In 2013, Chief Executive Tim Waggott signed an environmental policy to demonstrate DHB’s commitment to continue its efforts in carbon management (Dover Harbour Board, 2013a). The main targets are to accurately calculate DHB's carbon footprint for 2013, to reduce the CO2 produced from the electricity and heating oil consumption by 5% from a 2012 baseline and to develop a range of renewable energies at the Port of Dover (Dover Harbour Board, 2013b).

In addition, Kent County Council also has its own carbon management action plan (Kent County Council, 2013). Four key areas are identified on which sustained efforts will be focused, namely buildings & infrastructure (including ICT), streetlighting, business travel and staff behavior. The target for CO_2 emissions reduction for Kent County Council is 2.6% per annum reduction up to 2015/16 from the baseline year of 2010/11.

6.4 Biomimicry as a solution

This section presents several solutions using Biomimicry to reduce carbon emission levels in Dover, in order to work towards a carbon neutral Dover. Two methods of carbon capture are proposed: the use of artificial trees to capture carbon from the atmosphere, and the use of ‘industrial lungs’ to capture carbon from concentrated sources. The concept of eco-cement is then proposed to complete the carbon cycle.

The concept of carbon cycle arises from the observation that nature works in a cycle. There is no waste, that is, what are unused by one species becomes nutrients for another species, as illustrated in Figure 53. In contrast, the human industrial system functions primarily in a linear manner, as seen in Figure 54. In order to achieve sustainability, it is imperative for society to understand that the human system is but part of nature’s larger system, and that the cycle for the human industrial system needs to be completed as well, as shown in Figure 55.

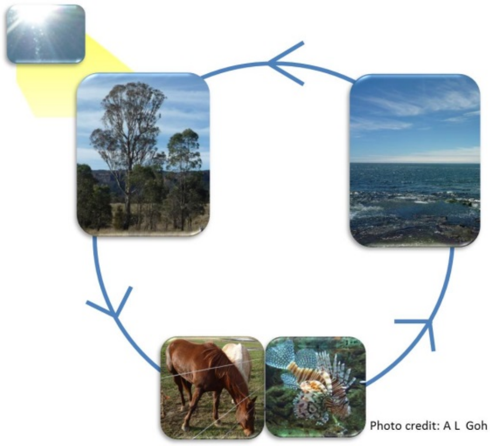


Figure 53: Cycle in nature's eco-system.

Figure 54: Linear human industrial system.

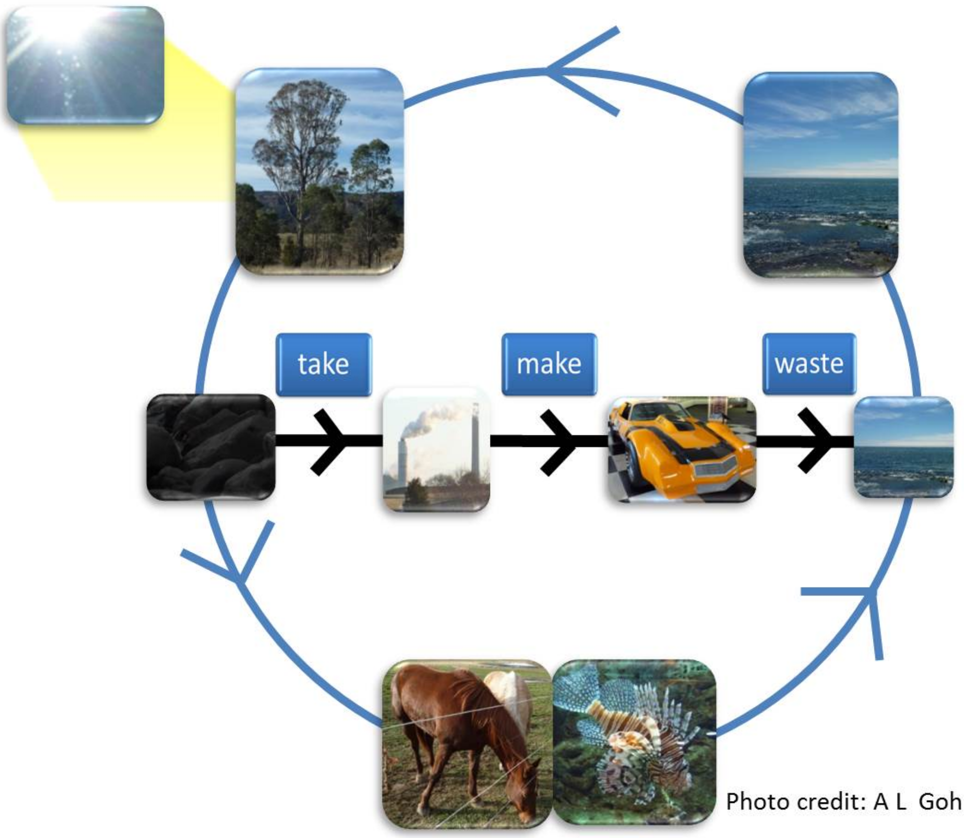


Figure 55: Human industrial system as part of nature's eco-system.

Since the start of the Industrial Revolution some 300 years ago, human activity has produced an ever increasing amount of carbon emissions, of which the effects are becoming increasingly evident and possibly disastrous if the current trend continues. Hence, to mitigate the effects of global warming and climate change, society needs to find ways to complete the carbon cycle, by putting back to nature what it takes. This essentially means to capture and store carbon such that it can be used by subsequent generations.

6.4.1 Carbon Capture

Artificial trees

Trees are known to be great absorbers of CO_2 from the atmosphere and good inhibitors of climate change. However, recent research on Seattle's urban forest found that the current forest sequesters nearly the same amount of CO_2 that the predevelopment old growth forest sequestered (Ramsden & Barnes, 2013). Although older trees store significant amounts of carbon, they do not continue to sequester at the same rates as when they were younger. Older trees grow slower and hence sequester less, and CO_2 is emitted by dying trees as well. This means that the current urban forest creates more of a CO_2 balance than a CO_2 sponge, as illustrated in Figure. Thus, in the case when carbon emissions are increasing at an exponential rate, the sequestration capability of urban forests is insufficient.

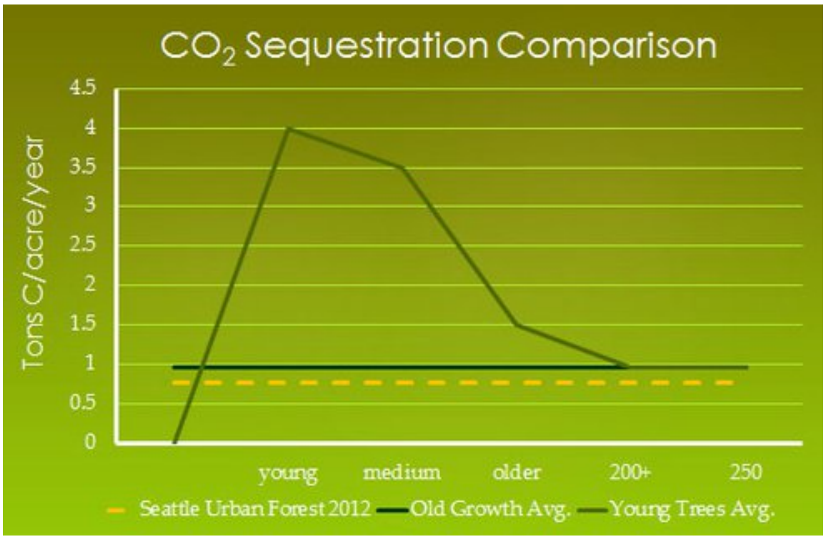


Figure 56: CO_2 sequestration comparison (Ramsden & Barnes, 2013).

This gives rise to the proposition of using artificial trees to sequester CO_2 from the atmosphere. With respect to this, (Goeppert et al., 2011) at the University of Southern California's (USC) Loker Hydrocarbon Research Institute investigated the use of polyethylenimine (PEI), a cheap polymer which has CO_2 absorbing properties, to carry out the function of natural trees. To increase absorption rates, the PEI is dissolved in a methanol solvent and spread on fumed silica, generating a PEI-silica combo. Upon evaporation of the solvent, solid PEI with a high surface area is formed. It is reported that under humid conditions similar to ambient conditions, each gram of the solid PEI absorbed an average of 1.72 nanomoles of CO_2 (Goeppert et al., 2011). This figure is among the highest levels of CO_2 absorption possible from air by current technological standards.

After the PEI is saturated with CO_2, it is heated to 85°C. CO_2 is then harvested, regenerating the PEI-silica combo. In contrast, other commonly used solid CO_2 absorbers have to be heated to over 800°C to release the absorbed CO_2 (Service, 2012). The fact that this polymer works at low temperatures means that it can possibly be used to build massive farms of artificial trees to mitigate the effects of climate change. However, a downside to this polymer is that it degrades at high temperatures. Hence it is not applicable for use in industrial smokestacks or automobile tailpipes, where the CO_2 is often highly concentrated but emitted at high temperatures. In view of this, the USC team is currently working to develop PEIs which can function at high temperatures as well.

Similarly, the Lenfest Center for Sustainable Energy at Columbia University designed an artificial tree that absorbs CO_2 from the air using plastic leaves that are "1,000 times more efficient than the real thing" (Brandon, 2009). The synthetic trees use plastic leaves that capture CO_2 in a chamber, which is then compressed into liquid form. The fact that the trees do not require direct exposure to sunlight means that they can be stored in enclosed places, used anywhere, and transported from one location to another regardless of lighting conditions. In an interview with CNN (Whiteman, 2009), Klaus Lackner, a professor at Columbia University who is developing the tree, said that the synthetic tree is "several hundred times better at collecting CO_2" than windmill generators, and that "for every 1,000 kilograms of carbon dioxide collected, the tree emits just 200 kilograms". This ratio sufficiently justifies the relatively high cost of building the trees or retrofitting coal plants. Each synthetic tree is expected to collect about 90,000 tonnes of carbon per year (Brandon, 2009).

Industrial Lungs

The use of artificial trees is more applicable to CO_2 absorption from the atmosphere. For CO_2 absorption from emission sources like flue stacks, there is another form of biomimicry to be studied – the human lungs (Biomimicry Institute, 2013). There are three major adaptations of the human lungs which accounts for their high CO_2 removal effectiveness. First, the ultra-thin membrane allows CO_2 to travel across and out at an extraordinary rate. Second, there is an enormous surface area for gas exchange, which is about the size of a volley ball court. Third, and more significantly, the human lungs have specialised chemical translators, in particular carbonic anhydrase, which allow CO_2 to be removed thousands of times faster than otherwise possible.

In view of this, CO_2Solutions Inc. was founded in 1997 (CO2 Solutions, 2013a) to develop an 'industrial lung' to efficiently remove CO_2 using the enzyme carbonic anhydrase. Carbonic anhydrase is the most powerful catalyst known for the hydration of CO_2, which is the conversion of CO_2 to bicarbonate and protons. The main focus of the company is on large-scale carbon capture at coal-fired power plants and other major industrial applications. In 2011, the company, together with Codexis, Inc., entered into a pilot collaboration with Alcoa, Inc. to capture CO_2 from aluminium production factories and combine it with bauxite residue, a major aluminium industry waste product, to create a new commercial product useable for environmental reclamation projects. This effectively means that waste from one industry is used as a resource for another, thereby completing the industrial cycle.

Figure 57 illustrates the post-combustion carbon capture process using available industrial low-energy solvents such as methyldiethanolamine (MDEA). Addition of the CA enzyme increases the rate of CO_2 absorption in MDEA by approximately 50 fold, as shown in Figure 58. This reduces the height of the CO_2 absorption column by 90%, allowing for smaller equipment to be used. In addition, the low-energy properties of MDEA reduce solvent regeneration and process energy consumption by at least 30%, as compared to the current industry standard monethanolamine (MEA) process. These translate into an estimated cost savings of 50-70 million USD (approximately 32-45 million GBP) per year (CO2 Solutions, 2013b) for a typical coal-fired power plant. Since the CO_2 capture portion accounts for about 80% (Intergovernmental Panel on Climate Change, 2005) of the total cost of Carbon Capture and Storage (CCS) at present, the amount of cost savings through the use of the CA enzyme makes CCS economically viable for large-scale applications.

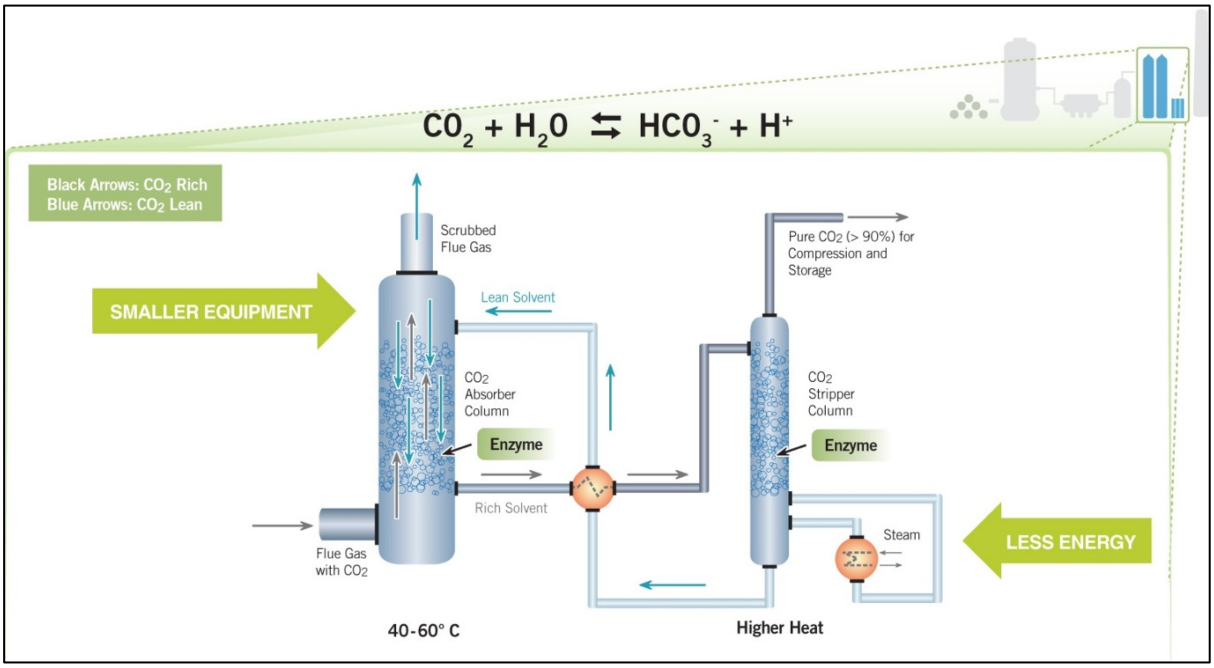


Figure 57: Post-combustion carbon capture process using available industrial low-energy solvents (CO2 Solutions, 2013b).

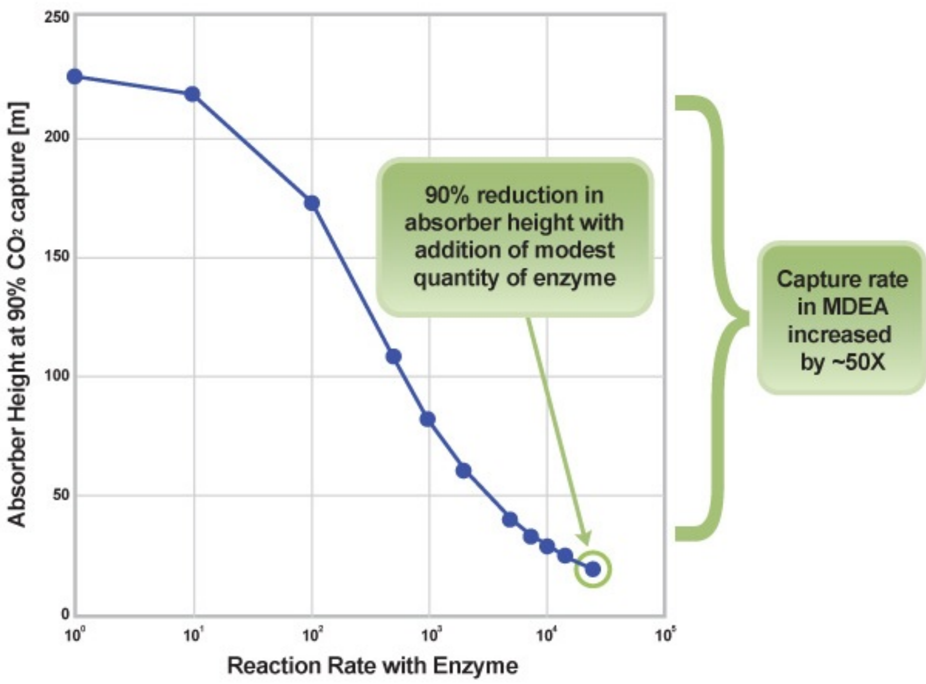


Figure 58: Effects of adding the CA enzyme (CO2 Solutions, 2013b).

On top of the cost benefits, there are several motivations to use CA enzyme. For one, it is the fastest known solvent accelerator for CO_2 capture. It also works with existing readily available solvents and fits in well with the gas scrubbing process already familiar to the industry. Last but not least, it is environmentally friendly.

6.4.2 Completing the carbon cycle

Eco-cement

In nature, marine organisms make reefs and shells by using dissolved CO_2 and calcium ions in seawater to form carbonates at normal temperatures and pressures. The long term stability of carbonate minerals is well known, as can be seen from the White Cliffs in Dover. Published literature (Folk, 1974; Gattuso, Frankignoulle, Bourge, Romaine, & Buddemeier, 1998; Zeebe, 2012) suggests that storage of captured CO_2 as carbonate minerals provides a secure storage over geological timeframes, even in acidic environments. Similarly, human industrial practices can produce calcium carbonate from carbon emissions and seawater. The calcium carbonate can then be heated and processed to form calcium silicate, which is a main ingredient in Ordinary Portland Cement (OPC), the most common cement currently used worldwide.

Cement production is one of the dirtiest industrial processes on Earth, and it produces nearly 9% of global carbon emissions (Mathews, 2012). CO_2 is produced in two ways, directly when calcium carbonate is heated to form calcium oxide, and indirectly from burning fossil fuels to generate the energy for heating. The simplified chemical equation is given in Equation:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

About 50% of the cement carbon footprint comes from the CO_2 produced during the chemical transformation of limestone ($CaCO_3$) into lime (CaO). An additional 40% of the carbon footprint is from the thermal process energy, and 10% is from the electricity to operate the plant and for raw material transportation (Andersen, Zaelke, & Young, 2011).

By sequestering CO_2 into calcium carbonate and using it to produce cement, the industry can not only directly reduce the atmospheric carbon content through carbon capture, but also to reduce carbon emissions by scaling down on conventional cement production methods. The carbon cycle can then be successfully completed to achieve sustainability, as illustrated in Figure 59.

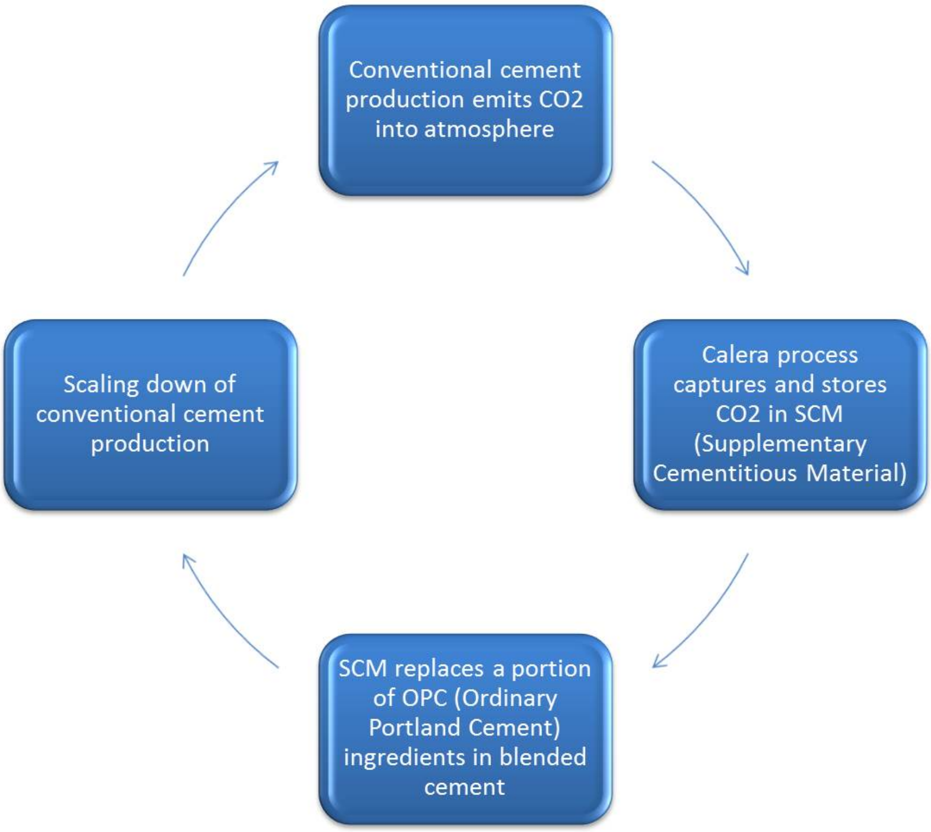


Figure 59: The eco-cement carbon cycle.

In 2011, a scientific synthesis team of 12 influential experts came together to assess the technical and economic feasibility of the Calera carbon capture and sequestration technology from a multidisciplinary viewpoint for technical experts and climate policy makers. The consensus is that the core process chemistry is valid and plausible, and the profitability depends on availability of ample supplies of low cost inputs and on sufficient revenue from carbon sequestration (Andersen et al., 2011).

There are two stages in the patented Calera process, which is known as Carbonate Mineralization via Aqueous Precipitation (CMAP), as illustrated in Figure 60. The first carbon capture stage can capture "up to 90% of CO_2" (Andersen et al., 2011) from power plants using brines extracted from geological deposits and manufactured alkalinity, and can convert the CO_2 into stable calcareous material with "an energy penalty ranging from about 10% to 40%, depending on power plant characteristics and availability of brines” (p. 5). The second stage is to further process and dry the calcareous material, and use the material as Supplementary Cementitious Material (SCM) to replace a portion of OPC. This reduces OPC ingredients in blended cement, thus reducing the carbon emissions from the original cement manufacturing process.

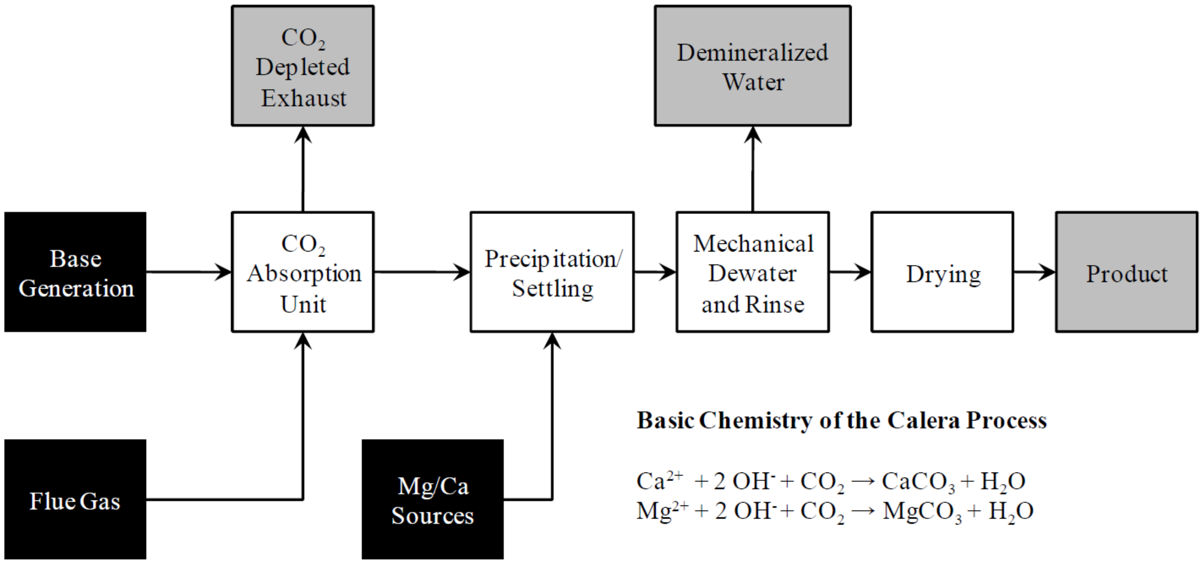


Figure 60: Calera ‘Carbonate Mineralization via Aqueous Precipitation’ Process (Andersen et al., 2011).

There are 3 main advantages of the Calera process relative to other proposed CCS. Firstly, it is available near-term at a lower estimated cost. Secondly, it is modular retrofit to existing power plants, making it scalable. Thirdly, it has the potential to capture carbon while producing a useful product, whereas other long-term CCS, such as geological and terrestrial sequestration, is largely an added cost. In addition, the potential of the Calera process to simultaneously capture SO2 and other acid gases, as well as certain heavy metals enhances its cost effectiveness. Figure 61 shows that the total cost of capturing carbon dioxide, sulphur oxides (SOx), nitrogen oxides (NOx), and mercury (Hg) using traditional single pollutant technologies is 1807 USD (approximately 1160 GBP) per kilowatt. The Calera process is able to capture these pollutants at competitive rates and simultaneously create marketable building materials for around half of that cost (Calera, 2013).

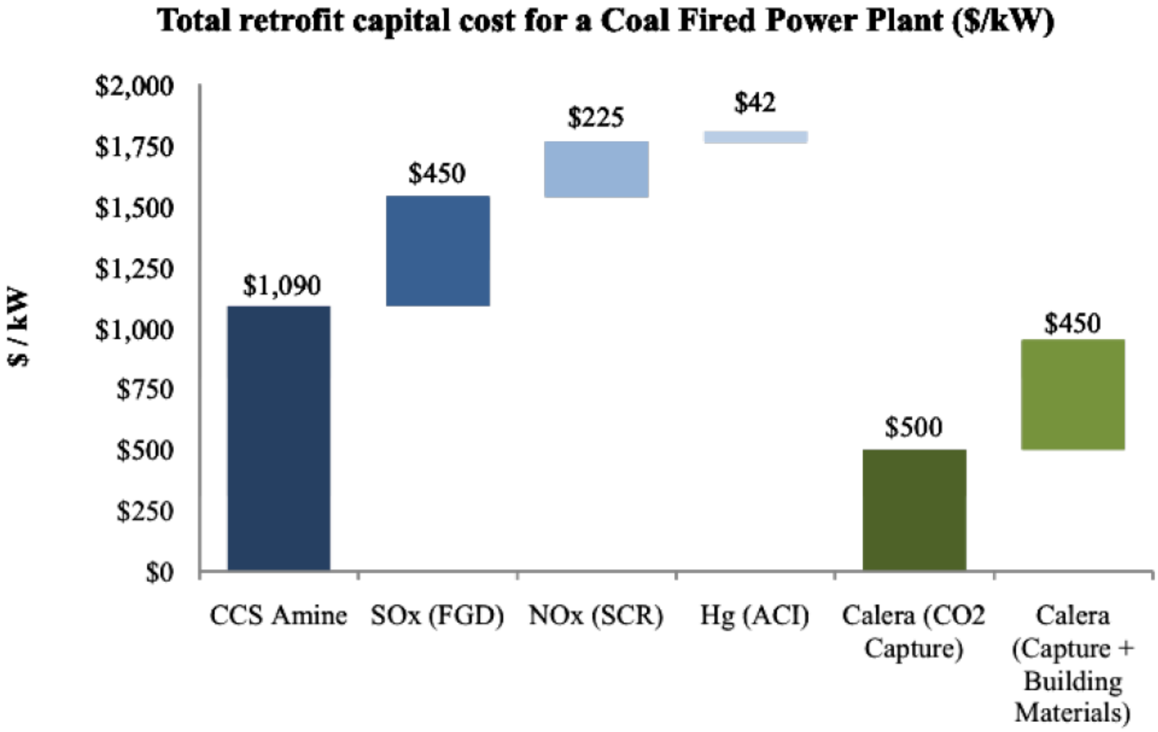


Figure 61: Total retrofit capital cost for a coal fired power plant (Calera, 2013).

From the legislative standpoint, the Calera process eliminates the need to transport gaseous CO_2, locate feasible storage sites, and address the ownership and liability issues associated with injection operations and long-term storage. Due to the stability and usefulness of the carbonate mineral in the built environment, "ownership is clear and liability is limited to the normal liability for any building material" (Calera, 2013). In terms of environmental risks, the Calera process eliminates the risk of CO_2 leaking from pipeline or geologic storage sites. Environmental issues associated with building the pipelines to transport CO_2 to geologic storage sites become irrelevant as well.

In summary, mineralogical sequestration locks the carbon dioxide gas in a stable solid mineral that will reliably store the carbon in an inert and harmless form for millions of years. This calcareous material can be used as building materials in the construction industry; and even when the building is demolished and crumbled into sand, the carbon is still safely stored and does not escape into the atmosphere in the form of greenhouse gas. Even if the material is not suitable for use as building materials, the solid minerals are still a better option to be stored underground, as compared to gaseous carbon dioxide which has the potential risk of gas leakage.

6.5 Applications in Dover

There are practical reasons why the concept of eco-cement is considered to be applicable in Dover. First, Dover has the three main inputs which are required to produce eco-cement, namely calcium ions, alkalinity and carbon dioxide. The White Cliffs of Dover, which mainly comprise calcium carbonate, indicate the abundance of calcium ions and the alkalinity of the seawater in the Strait of Dover. The carbon input can be obtained using the artificial trees concept to capture CO_2 from the atmosphere, since Dover is a port city and majority of carbon emissions arises from transportation at the port. Additionally, Dover has a concrete factory near the coast, operated by CEMEX UK, shown in Figure 62. The factory's carbon footprint can also be used as a carbon input. Therefore, there is huge potential and motivation to tap on the natural and man-made resources already existing in Dover to work towards producing carbon neutral, if not carbon negative, eco-cement.

Figure 62: Map of the port of Dover and the Dover concrete plant (Google Maps, clker.com).

6.5.1 Carbon Impact

Detailed analysis and calculations were carried out to demonstrate the feasibility of this eco-cement concept in Dover. Figure 63 and Figure 64 show the surface and seabed salinities of the seawater surrounding the United Kingdom and Ireland (United Kingdom Marine Monitoring and Assessment Strategy, 2011). It is noted that at the Strait of Dover, the salinity ranges from 34.5 to 35.5 all year around. Table 13 shows the major ions and their respective concentrations in seawater of salinity 35 (Libes, 2009). By definition, salinity is roughly the number of grams of dissolved matter per kilogram of seawater.

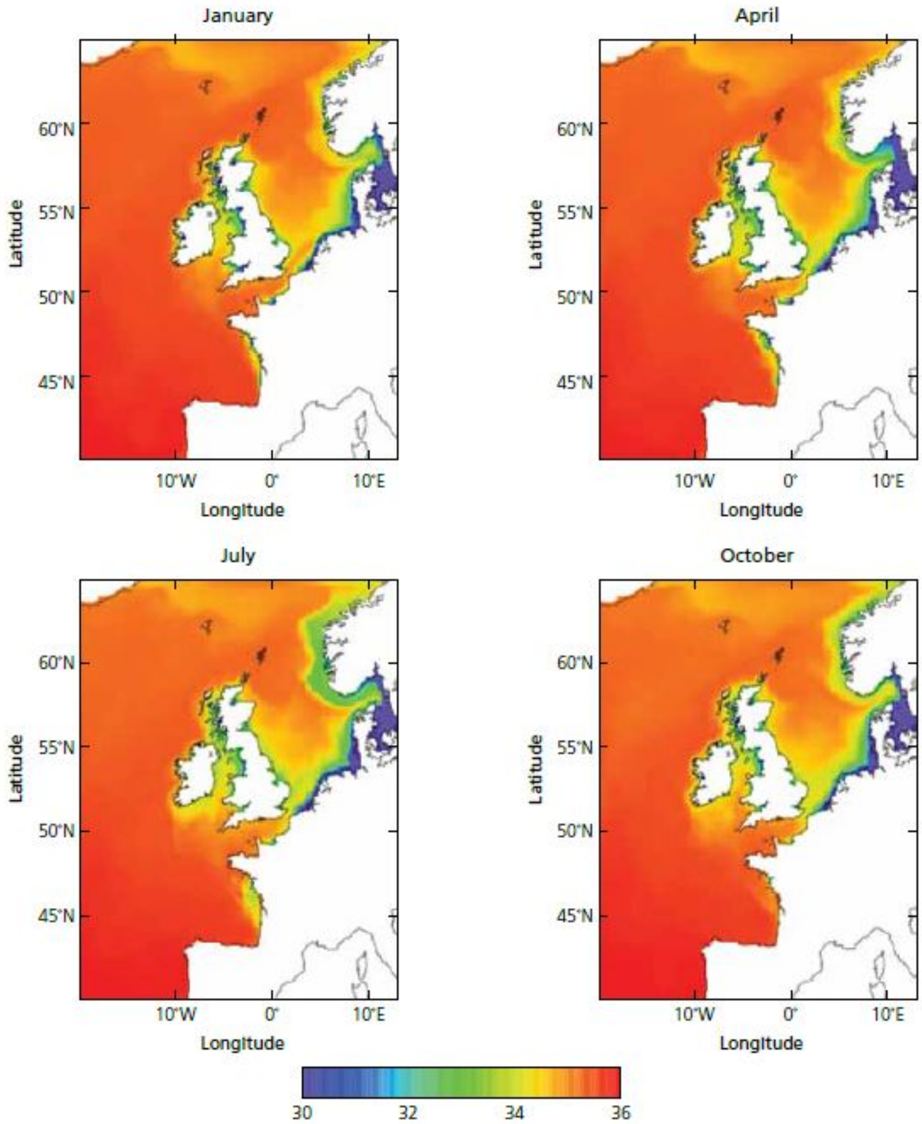


Figure 63: Surface salinities for January, April, July and October. A mean is shown for the month and the five years 2003 to 2007 (United Kingdom Marine Monitoring and Assessment Strategy, 2011).

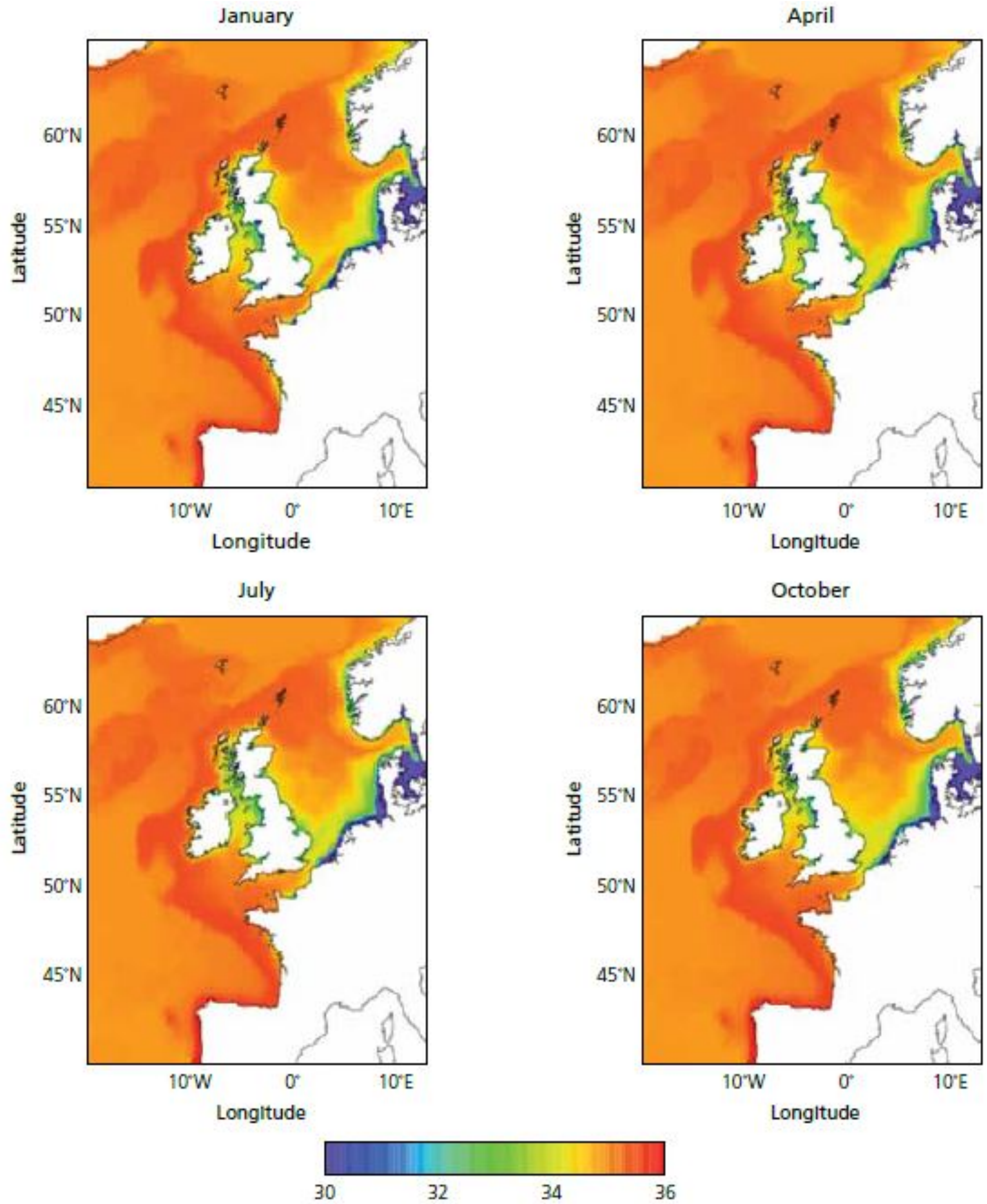


Figure 64: Seabed salinities for January, April, July and October. A mean is shown for the month and the five years 2003 to 2007 (United Kingdom Marine Monitoring and Assessment Strategy, 2011).

Table 13: Major ions in seawater of salinity 35 (Libes, 2009).

Symbol	Name	% of total	mmoles	gms/kg
Cl-	Chloride	55.29	546	19.353
Na+	Sodium	30.74	469	10.76
SO42-	Sulphate	7.75	28	2.712
Mg2+	Magnesium	3.69	53	**1.292**
Ca2+	Calcium	1.18	10.3	**0.412**
K+	Potassium	1.14	10.2	0.399

The basic chemistry of the Calera process comprises of two chemical equations, which are shown in Equations and respectively. Calculations were carried out to determine the amount of seawater required and amount of carbonates produced in order to sequester one tonne of CO_2.

$$Ca^{2+} + 2OH^- + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

$$Mg^{2+} + 2OH^- + CO_2 \rightarrow MgCO_3 + H_2O \quad (2)$$

Molar mass of CO_2 is 44.00964 ± 0.00003 g/mol

In 1 tonne of CO_2, there are

$$= 1{,}000{,}000\ g \div 44\ g/mol$$
$$= 22727\ moles$$

From Equation (1), one mole of CO_2 and one mole of Ca^{2+} produce one mole of $CaCO_3$.

Therefore, 22727 moles of Ca^{2+} ions is required and 22727 moles of $CaCO_3$ is formed.

Molar mass of Ca is 40.0784 ± 0.0001 g/mol.

This means that the amount of Ca^{2+} ions required to react with 1 tonne of CO_2

$$= 22727\ moles \times 40\ g/mol$$
$$= 909091\ grams$$

From table, in seawater of salinity 35, there are 0.412 grams of Ca2+ ions dissolved in 1 kg of seawater.

This means that the amount of seawater required to react with 1 tonne of CO_2

$$= 909091\ grams \div 0.412\ \frac{g}{kg}$$
$$= 2206531\ kg$$
$$\underline{\approx 2207\ tonnes}$$

Molar mass of $CaCO_3$ is 100.0875 ± 0.0001 g/mol

This means that the amount of $CaCO_3$ formed from 1 tonne of CO_2

$$= 22727\ moles \times 100 \frac{g}{mol}$$
$$= 2272727\ grams$$
$$\underline{\approx 2.3\ tonnes}$$

Molar mass of Mg is 24.30506 ± 0.00001 g/mol

This means that the amount of Mg^{2+} ions required to react with 1 tonne of CO_2

$$= 22727\ moles \times 24.3\ g/mol$$
$$= 552273\ grams$$

From table, in seawater of salinity 35, there are 1.292 grams of Mg^{2+} ions dissolved in 1 kg of seawater.

This means that the amount of seawater required to react with 1 tonne of CO_2

$$= 552273\ grams \div 1.292 \frac{g}{kg}$$
$$= 427456\ kg$$
$$\underline{\approx 427\ tonnes}$$

Molar mass of MgCO3 is 84.31413 ± 0.00005 g/mol

This means that the amount of $MgCO_3$ formed from 1 tonne of CO_2

$$= 22727\ moles \times 84.3 \frac{g}{mol}$$
$$= 1915909\ grams$$
$$\underline{\approx 1.9\ tonnes}$$

In summary, to sequester 1 tonne of CO_2 in calcium carbonate, 2200 tonnes of seawater are required and 2.3 tonnes of calcium carbonate are produced; to sequester 1 tonne of CO_2 in magnesium carbonate, 430 tonnes of seawater are required and 1.9 tonnes of magnesium carbonate are produced. The carbonates produced can be utilized in the concrete plant in Dover. Any excess can conveniently be exported through the port of Dover.

The results of the calculation also imply that on average, when 1 tonne of cement is produced, about half a tonne of CO_2 is sequestered. This is indeed in line with what Brent Constantz, founder of Calera stated (Biello, 2008). Furthermore, CEMEX's Climate Change report states that in 2011, the specific net CO_2 emissions is 0.612

tonnes CO_2 per tonne of cementitious product (CEMEX, 2013). This means that if the eco-cement concept is applied to CEMEX cement production worldwide, the effective net CO_2 emissions will be significantly reduced to only 0.112 tonnes CO_2 per 1 tonne of cementitious product.

In order to make Dover carbon neutral, at least 570,000 tonnes of CO_2 have to be removed from the atmosphere as of 2009, as inferred from Table. It is currently unknown how the CO_2 emissions in Dover has changed since 2009, since the succeeding five year report has yet to be published. Assuming that all 570,000 tonnes of CO_2 is captured into calcium carbonate, this implies that 1,140,000 tonnes of cementitious product will be produced. The question then arises whether there is a market for cement in the long run. Currently, the answer is yes. The global population is predicted to grow from today's 6.9 billion to over 9 billion by 2050 (US Census Bureau, 2012), accompanied by an ever-increasing need for improved living standards, particularly in developing countries. Under the assumption of business as usual, CEMEX calculates that "by 2050, global annual concrete consumption will double from the estimated 7.5 billion cubic meters (approximately 10.5 billion tonnes) that were used in 2006" (CEMEX, 2012). Furthermore, studies indicate that strict constraints on carbon emissions might increase demand for concrete in the order of 10% to 15% by 2050 (Entreprises pour L´Environnent, 2008).

6.5.2 Environmental Impact

Nonetheless, there may be concerns about causing imbalance to the oceanic eco-system through extracting the ions from the seawater. The ions may not be as abundant as expected, and their extraction may change the composition of seawater, which has remained relatively constant and undisturbed over the years. With regards to this concern, the industry can possibly expand its options for ion and alkalinity input. On top of using natural brines such as seawater, industrial waste products like kiln dust, cement dust or fly ash from smokestacks could provide a source of ions and alkalinity (Kanellos, 2011). In general, an input can be obtained in three ways: from naturally available sources, industrial waste or directly manufactured products. The most sustainable means would be to obtain an input from industrial waste. This closes the loop for the currently linear human industrial system, and industrial ecology can then be achieved.

This chapter concludes that there is strong motivation to implement the eco-cement concept at the CEMEX plant in Dover, in view of the natural and man-made resources available there. By locking gaseous CO_2 from the atmosphere into a stable carbonic solid, this process completes the carbon cycle of the human industrial system, thereby making it sustainable. In addition, this option of carbon storage has advantages over compressing CO_2 in geological formations or oceans, due to inherent leakage and environmental hazards associated with the latter. Zeebe (2012) also states that, on a million-year timescale, the burial of $CaCO_3$ in marine sediments is a major pathway to remove carbon from the ocean-atmosphere system. Therefore, implementation of the eco-cement concept is the way forward to work towards a carbon neutral Dover.

7 Conclusions and recommendations

7.1 Conclusions

In summary, this book defined coastal eco-city as a socially and economically significant urban area near the sea, which aims to reduce environmental impacts, improve human well-being and life, and stimulates growth through a harmonious relation between the land and the sea. There are several biomimetic options to reduce the carbon footprint of Dover. The two main areas looked into are renewable energy and carbon management.

In the area of renewable energy, the Oyster Wave Power technology mimics the movement of the oyster to harvest marine energy. The study concludes that development of a 2.4 MW near-shore Oyster farm at the Port of Dover leads to estimated savings of 3200 tonnes of CO_2e per year. This offsets the port's carbon emissions by about 25%. The scalability of the Oyster also allows for an array arrangement, which could be implemented in a 40 MW Oyster farm along the white cliffs. This development could serve to protect the cliffs from coastal erosion, on top of providing energy to the district.

In the area of carbon management, the eco-cement concept mimics the way marine organisms make reefs and shells in nature. The recommendation of the study is to produce cement from carbon emissions and seawater at the CEMEX plant in Dover. Calculations show that for every tonne of eco-cement produced, 0.5 tonnes CO_2 is sequestered. On the other hand, CEMEX, one of the world's largest cement producers, emits 0.612 tonnes CO_2 per tonne of conventional cement. These results imply that worldwide production of eco-cement could possibly reduce the industry's effective CO_2 emissions to 0.112 tonnes CO_2 per tonne of eco-cement. By locking atmospheric gaseous CO_2 into a stable carbonic solid, this sequestration method completes the carbon cycle of the human industrial system, thereby making it sustainable.

7.2 Recommendations

This book serves as a platform for further in-depth discussions on the recommended topics. Researchers, companies and institutions interested in these topics are strongly encouraged to look into and invest in the book's recommendations.

Due to research limitations, an environmental impact assessment of the solutions proposed in this book was not feasible. However, to fully grasp the effects on the environment, such an assessment is necessary.

Further research into biomimicry as a solution for coastal eco-cities includes how biomimicry can be used for other aspects of the city, such as transportation, waste management, urban planning, flood management and housing.

References

ABB. (2004). HVDC Light, the World's first HVDC Light offshore converter. Retrieved August 26, 2013, from http://www05.abb.com/global/scot/scot245.nsf/veritydisplay/f58913acc532cdb7c1256e36003f4879/$file/project%20troll%20a%2080%20kv%20hvdc%20light%20subm-.pdf

Ackerman, E. (2011). Gigantic wave energy generator destined for Scottish coast. Retrieved August 6, 2013, from http://www.dvice.com/archives/2011/07/gigantic_wave_e.php

Alves, M. (2011). The dynamics of wave energy. Retrieved August 8, 2013, from http://powerelectronics.com/energy-harvesting/dynamics-wave-energy

Andersen, S. O., Zaelke, D., & Young, O. (2011). Scientific Synthesis of Calera Carbon Sequestration and Carbonaceous By-Product Applications.

Aquamarine Power. (2011). ENVIRONMENTAL STATEMENT Oyster 2 Wave Energy Project. Billia Croo, UK.

Aquamarine Power. (2013). Aquamarine Power. Retrieved August 10, 2013, from http://aquamarinepower.com/

Aquamarine Power. (undated). Projects. Retrieved August 5, 2013, from http://www.aquamarinepower.com/projects/

ARUP. (2006). Port of Dover Economic Impact Assessment. London.

AskNature.org. (2013). Moth eye antireflective coatings - Coatings for solar panels that are increase efficiency. Retrieved July 25, 2013, from http://www.asknature.org/product/a81b57057e84006083ad9062fa1ef921

BalancedSeas. (2011). Balanced Seas Marine Conservation Zone Project - Final Recommendations.

BalancedSeas. (2013). Final recommendation sites, Dover to Deal rMCZ no 11.1, Marine Conservation Zone: Selection Assessment Document, Draft final recommendations refined by the RSG and Local Groups in July 2011 and finalised by the RSG 2/3 August 2011, V1.07.09.11. Retrieved August 11, 2013, from http://jncc.defra.gov.uk/PDF/BS_FinalRecommendationsSites_Part2.pdf

Baringa Partners Ltd. (2013). Scottish Islands Renewable Project - Final Report.

Barton, H. (1998). Eco-neighbourhoods: A review of projects. *Local Environment, 3*(2), 159–177.

Benyus, J. M. (1997). *Biomimicry. Innovations Inspired by Nature*. New York: Perennial - HarperCollins.

Biello, D. (2008). Cement from CO2: A Concrete Cure for Global Warming? Retrieved August 25, 2013, from http://www.scientificamerican.com/article.cfm?id=cement-from-carbon-dioxide

Biomimicry 3.8. (2012). Biomimicry. Retrieved July 22, 2013, from http://biomimicry.net/about/biomimicry/

Biomimicry Institute. (2013, 2013). Learning from Human Lungs How to Sequester Carbon. from http://www.biomimicryinstitute.org/case-studies/case-studies/climate-change.html

Biomimicry Institute. (undated). Recent Case Studies. Retrieved July 23, 2013, from http://www.biomimicryinstitute.org/case-studies/case-studies/

BioPower Systems. (2013). BioPower Systems. Retrieved August 10, 2013, from http://www.biopowersystems.com/

Bolton, P. (2013). Energy Import Export, Starndard Note: SN/SG/4046, Social and General Statistics.

Brandon, J. (2009, 24 June 2009). Synthetic Tree Soaks Up Carbon 1000x Faster Than the Real Thing. from http://www.popsci.com/environment/article/2009-06/installing-plastic-trees-help-environment

Bridge, G., & Watson, S. (Eds.). (2000). *A Companion to the City*. Malden, MA: Blackwell Publishing.

Buczek, B. (2012). Managing the Port of Dover - Operating and Developing one of the World's busiest Ferry Ports.

Calera. (2013). Basics of Calera Process. from http://www.arb.ca.gov/cc/etaac/meetings/102909pubmeet/mtgmaterials102909/basicsofcaleraprocess.pdf

Cameron, L., Doherty, R., Henry, A., Doherty, K., Hoff, J., Kaye, D., . . . Whittaker, T. (2010). *Design of the next generation of the Oyster wave energy converter.* Paper presented at the 3rd international conference on ocean energy.

Carbon Trust. (2012). UK wave energy resource: AMEC Environment & Infrastructure UK Limited.

CEMEX. (2012). Climate Change - CEMEX´S POSITION. Retrieved August 26, 2013, from http://www.cemex.com/MediaCenter/Files/CEMEX_POSITION_on_Climate_Change.pdf

CEMEX. (2013). Building the Cities of the Future: 2012 Sustainable Development Report. San Pedro Garza García, Mexico.

Checkmate Sea Energy. (undated). Anaconda. Retrieved July 27, 2013, from http://www.checkmateukseaenergy.com/

Chino, M. (2011). Housing Complex in Slovenia is a Series of Honeycomb Modular Apartments. Retrieved July 28, 2013, from http://inhabitat.com/slovenias-gorgeous-honeycomb-housing-complex/

CO2 Solutions. (2013a). Company History. Retrieved August 21, 2013, from http://www.co2solutions.com/en/history

CO2 Solutions. (2013b). Technology: the Process. from http://www.co2solutions.com/en/the-process

Collier, D., Whittaker, T., & Crowley, M. (undated). The Construction of Oyster – A Nearshore Surging Wave Energy Converter. Retrieved August 23, 2013, from http://www.aquamarinepower.com/sites/resources/Published%20papers/2473/The%20construction%20of%20Oyster%20-%20a%20nearshore%20surging%20wave%20energy%20converter.pdf

Creel, L. (2003). Ripple Effects: Population and Coastal Regions. Washington, D.C.

Defra. (2013). Marine protected areas. Retrieved August 12, 2013, from https://www.gov.uk/marine-protected-areas

Defra/DECC. (2013). 2013 Government GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors.

Department for Business Innovation and Skills, & Change, D. o. E. a. C. (2009). The UK Low Carbon Industrial Strategy. Norwich.
Department for Environment Food and Rural Affairs. (2009). *Guidance on how to measure and report your greenhouse gas emissions*.
Department of Energy and Climate Change. (2008). The UK Low Carbon Transition Plan: National strategy for climate and energy. Norwich.
Department of Energy and Climate Change. (2012). Energy Trends, December 2012.
Department of Energy and Climate Change. (2013a). Digest of UK Energy Statistics 2013.
Department of Energy and Climate Change. (2013b). UK Energy in Brief 2013.
Devuyst, D., Hens, L., & Lannoy, W. D. (Eds.). (2001). *How Green is the City? Sustainability Assessment and the Management of Urban Environments*. New York: Columbia University Press.
Doan, A. (2012). BIOMIMETIC ARCHITECTURE: Green Building in Zimbabwe Modeled After Termite Mounds. Retrieved July 27, 2013, from http://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/
Dover District Council. (2007a). Strategic Flood Risk Assessment. Atherstone, UK.
Dover District Council. (2007b). STRATEGIC FLOOD RISK ASSESSMENT CURRENT FLOOD ZONES. Atherstone, UK.
Dover District Council. (2009). Dover Core Strategy Evidence Base - Sustainable Construction and Renewable Energy.
Dover District Council. (2012). Greenhouse Gas Report 2012.
Dover District Council. (undated-a). Coast Protection. Retrieved August 26, 2013, from http://www.dover.gov.uk/Environment/Coast-Protection/Home.aspx
Dover District Council. (undated-b). Coastal Erosion. Retrieved August 26, 2013, from http://www.dover.gov.uk/Environment/Coast-Protection/Coastal-Erosion.aspx
Dover District Council. (undated-c). Natural England.
Dover Harbour Board. (2012). Port of Dover Environmental Bulletin 2011. Dover, UK: The Port of Dover Environmental Office.
Dover Harbour Board. (2013a). Environmental Policy. Retrieved August 22, 2013, from http://www.doverport.co.uk/?page=DoverPortEnvironmentManagementManual
Dover Harbour Board. (2013b). Port of Dover Environmental Bulletin 2012. Dover, UK: The Port of Dover Environmental Office.
Dover News. (2010). Port Of Dover Receives Carbon Award. Retrieved August 27, 2013, from http://www.dover.uk.com/news/2010/port-of-dover-receives-carbon-award
Dover News. (2013). Port of Dover retains Carbon Trust Standard. Retrieved August 27, 2013, from http://www.dover.uk.com/news/2013/port-of-dover-retains-carbon-trust-standard
Ebbs, M. (2009). Dover District Sustainable Construction and Renewable Energy Strategy.
Ecocity Builders. (undated). Ecocity Builders. Retrieved August 12, 2013, from http://www.ecocitybuilders.org/why-ecocities/

Energy Harvesting Journal. (2011). Biomimicry for wind and solar energy harvesting. Retrieved July 25, 2013, from http://www.energyharvestingjournal.com/articles/biomimicry-for-wind-and-solar-energy-harvesting-00003073.asp

Entreprises pour L´Environnent. (2008). Scenarios for transition towards a low-carbon world in 2050 : What's at stake for heavy industries ? Retrieved August 26, 2013, from http://www.iddri.org/Evenements/Conferences-internationales/08_Fonddri_summary-for-industiral-decision-makers.pdf

Environment Agency. (2012). CRC Energy Efficiency Scheme guidance for participants in Phase 1 (2010-2011 to 2013-2014).

European Straits Initiative. (2013). Retrieved August 20, 2013, from http://www.europeanstraits.eu/Partners/Strait-of-Dover

Fazi, S., & Flewwelling, P. (undated). Coastal Resources Management, Ulugan Bay, Palawan Island, The Philippines. Volumes I, ecology, culture and socioeconomics. Retrieved August, 2013, from http://www.unesco.org/sci/act/ulugan/ulugan3.htm

Folk, R. L. (1974). The natural history of crystalline calcium carbonate: Effect of magnesium content and salinity. *Journal of Sedimentary Petrology, 44*, 40-53.

Folley, Elsaesser, B., & Whittaker, T. (2009). Analysis of the wave energy resource at the European Marine Energy Centre. Retrieved August 24, 2013, from http://www.aquamarinepower.com/sites/resources/Published%20papers/2472/Analysis%20of%20the%20wave%20energy%20resource%20at%20the%20European%20Marine%20Energy%20Centre.pdf

Folley, & Whittaker, T. J. T. (2009). Analysis of the Nearshore Wave Energy resource. *Renewable Energy, 34*(7), 1709-1715.

Gattuso, J. P., Frankignoulle, M., Bourge, I., Romaine, S., & Buddemeier, R. W. (1998). Effect of calcium carbonate saturation of seawater on coral calcification. *Global and Planetary Change, 18*, 37-46.

Goeppert, A., Czaun, M., May, R. B., Prakash, G. K. S., Olah, G. A., & Narayanan, S. R. (2011). Carbon Dioxide Capture from the Air Using a Polyamine Based Regenerable Solid Adsorbent. *Journal of the American Chemical Society, 133*, 20164−20167.

Gunawansa, A. (2011). Contractual and policy challenges to developing ecocities. *Sustainable Development, 19*, 382-390.

Henry, A., Doherty, K., Cameron, L., Whittaker, T., & Doherty, R. (2010). *Advances in the design of the Oyster wave energy converter.* Paper presented at the Royal Institution of Naval Architect's Marine and Offshore Renewable Energy Conference.

Climate Change Act 2008 (2008).

Hunt, A., & Watkiss, P. (2011). Climate change impacts and adaptions in cities: a review of literature. *Climatic Change, 104*, 13-49.

Intergovernmental Panel on Climate Change. (2005). Carbon Dioxide Capture and Storage.

Jha, A. (2009a). Anaconda wave-power generator snakes into next stage of production. Retrieved July 28, 2013, from http://www.theguardian.com/environment/2009/may/06/anaconda-wave-power

Jha, A. (2009b). Anaconda wave-power generator snakes into next stage of production. Retrieved July 29, 2013, from http://www.businessgreen.com/bg/news/1804602/anaconda-wave-power-generator-snakes-stage-production
Joss, S. (2010). Eco-cities: a global survey 2009. *WIT Transactions on Ecology and The Environment, 129*, 239–250.
Kanellos, M. (2011). Calera expands options for capturing carbon. http://www.greentechmedia.com/articles/read/calera-expands-options-for-capturing-carbon
Kent County Council. (2011). Carbon dioxide (CO2) emissions in Kent, Year ending October 2009.
Kent County Council. (2012). Kent County Council Environment Report.
Kent County Council. (2013). Carbon Management Action Plan 2013.
Kline, E. (2000). Planning and Creating Eco-cities: Indicators as a tool for shaping development and measuring progress. *Local Environment, 5*(3), 343–350.
Knodel, B. (2010). *A high-level overview of offshore wind project development identifying current technologies, challenges, risks and costs*. Paper presented at the IEEE Power and Energy Society (PES), Boston.
Lewis Wave Power Ltd. (2012). 40MW Oyster Wave Array North West Coast, Isle of Lewis Environmental Statement, Volume 1: Non-Technical Summary.
Libes, S. (2009). *Introduction to Marine Biogeochemistry* (2 ed.). Burlington: Academic Press.
MarineTraffic.com. (2013). Live Map. Retrieved August 14, 2013, from http://marinetraffic.com/ais/
Mathews, J. (2012, 18 December 2012). Eco-cement, the cheapest carbon sequestration on the planet. from https://theconversation.com/eco-cement-the-cheapest-carbon-sequestration-on-the-planet-10978
McAdam, M. P. (undated). The Development of Marine Aquamarine Power.
Merriam-Webster. (2013a). Definition of City. Retrieved August, 2013, from http://www.merriam-webster.com/dictionary/city
Merriam-Webster. (2013b). Definition of Coast. Retrieved August, 2013, from http://www.merriam-webster.com/dictionary/coast
MTMC. (2007). Atlas of the Tidal Energy Resource on the South East Coast of England, Prepared for the South East England Development Agency (SEEDA). Cowes, UK.
Mumford, L. (1937). What is a city? *Architectural record, 82*, 59-62.
National Oceanography Centre. (2013). Coastal Erosion. Retrieved August 25, 2013, from http://noc.ac.uk/science-technology/marine-hazards/coastal-erosion
O'Kane, P. (2011). Why nearshore? Retrieved August 15, 2013, from http://www.aquamarinepower.com/blog/why-nearshore/
Oxford Dictionary. (2013a). Definition of City in English. Retrieved August, 2013, from http://oxforddictionaries.com/definition/english/city?q=city
Oxford Dictionary. (2013b). Definition of Coast in English. Retrieved August, 2013, from http://oxforddictionaries.com/definition/english/coast?q=coast
Oxford Economics. (2013). The economic impact of the UK Maritime Service Sector: Ports.

Paul, R. (2013). Design Inspiration from Nature - Biomimicry for a Better Planet. Retrieved July 25, 2013, from http://inhabitat.com/finding-design-inspiration-in-nature-biomimicry-for-a-better-planet/
Pelamis Wave Power. (2013). Pelamis Waver Power. Retrieved August 4, 2013, from http://www.pelamiswave.com/
Pelamis Wave Power. (undated). Wave Power. Retrieved August 5, 2013, from http://www.pelamiswave.com/wave-power
Ramsden, A., & Barnes, J. (2013). The urban greenprint: biomimicry applied to a city. from http://www.treehugger.com/urban-design/urban-greenprint-biomimicry-applied-city.html
Rees, W. E. (2001). The Conundrum of Urban Sustainability. In D. Devuyst, L. Hens & W. D. Lannoy (Eds.), *How Green is the City? Sustainability Assessment and the Management of Urban Environments* (pp. 37-42). New York: Columbia University Press.
RenewableUK. (2013a). Wave and Tidal Energy in the UK, Conquering Challenges, Generating Growth.
RenewableUK. (2013b). Wave Energy - Industry Response to the National Grid CfD for Strike Prices V5.
Roseland, M. (1997). Dimensions of the eco-city. *Cities, 14*(4), 197–202.
Roseland, M. (2001). The Eco-City Approach to Sustainable Development in Urban Areas. In D. Devuyst, L. Hens & W. D. Lannoy (Eds.), *How Green Is the City? Sustainability Assessment and the Management of Urban Environments* (pp. 85–104). New York: Columbia University.
Sawada, Y., Murata, B., & Fujii, Y. (2004). *The proposal to the 21st century coastal eco-city development.* Paper presented at the OCEANS '04. MTTS/IEEE TECHNO-OCEAN '04.
ScienceDaily.com. (2011). Is the Hornet Our Key to Renewable Energy? Physicist Discovers That Hornet's Outer Shell Can Harvest Solar Power. Retrieved July 24, 2013, from http://www.sciencedaily.com/releases/2011/01/110105102725.htm
Scott Wilson Business Consultancy. (2005). Sustainability Appraisal (SA) of Dover Local Development Framework, DOVER STRATEGIC OPTIONS – INTERIM SA REPORT. London.
Service, R. F. (2012, 9 Jan 2012). New CO2 Sucker Could Help Clear the Air. from http://news.sciencemag.org/2012/01/new-co2-sucker-could-help-clear-air
Smith, S. (2005). SEA / SA of Tonbridge and Malling Local Development Framework – Tonbridge Central Area Action Plan: Final Sustainability Appraisal Report. London.
Snyder, J., & Rondorf, N. (2011). About Submarine Power Cables.
SQW Energy Consulting. (2009). Socio-economic impact assessment of Aquamarine Power's Oyster Projects.
Swiegers, G. F. (Ed.). (2012). *Bioinspiration and Biomimicry in Chemistry: Reverse-engineering Nature*. Hoboken, New Jersey: John Wiley & Sons.
The National Archives. (2013). BalancedSeas. Retrieved August 14, 2013, from http://webarchive.nationalarchives.gov.uk/20120502155440/http:/www.balancedseas.org/

The Royal Academy of Engineering. (2004). The costs of generating electricity. London.
Thetys. (2012). Oyster 800. Retrieved August 27, 2013, from http://mhk.pnnl.gov/wiki/index.php/Oyster_800
Timmerman, P., & White, R. (1997). Megahydropolis : coastal cities in the context of global environmental change. *Global Environmental Change, 7*(3), 205-234.
United Kingdom Marine Monitoring and Assessment Strategy. (2011). Charting Progress 2; Feeder Report: Ocean Processes
University of Auckland. (2012). Marsden grant success for ABI researchers. Retrieved July 27, 2013, from http://www.des.auckland.ac.nz/uoa/home/about/newseventsandnotices/news/news/template/news_item.jsp?cid=526456
US Census Bureau. (2012). World Population 1950 - 2050. Retrieved August 25, 2013, from http://www.census.gov/population/international/data/idb/worldpopgraph.php
Whiteman, H. (2009). 'Synthetic tree' claims to catch carbon in the air. http://edition.cnn.com/2009/TECH/science/06/22/synthetic.tree.climate.change.ccs/
Whittaker, T., & Folley, M. (2005). *Optimisation of Wave power devices towards economic wave power systems.* Paper presented at the World Renewable Energy Conference, Aberdeen, UK.
Whittaker, T., & Folley, M. (undated). Optimisation of Wave Power Devices Towards Economic Wave Power Systems. Retrieved August 12, 2013, from http://www.aquamarinepower.com/sites/resources/published%20papers/2476/optimisation%20of%20wave%20power%20devices%20towards%20economic%20wave%20power%20systems.pdf
Wordpress.com. (2012). Kingfisher biomimicry. from http://envirocomm.files.wordpress.com/2012/04/kingfisher-biomimicry3.jpg
Yao, R. (2013). Sustainability in the Built Environment. In R. Yao (Ed.), *Design and Management of Sustainable Built Environments* (pp. 1-23). London: Springer-Verlag.
Zeebe, R. E. (2012). History of Seawater Carbonate Chemistry, Atmospheric CO2, and Ocean Acidification. *Annual Review of Earth and Planetary Sciences, 40*(1), 141-165. doi: 10.1146/annurev-earth-042711-105521
Zimmer, L. (2011). TREEPODS: Carbon-Scrubbing Artificial Trees for Boston City Streets. Retrieved July 25, 2013, from http://inhabitat.com/treepods-carbon-scrubbing-artificial-trees-for-boston-city-streets/