14 Socio-economic Impacts—Offshore Activities/Energy

Kirsten Halsnæs, Martin Drews and Niels-Erik Clausen

Abstract

The energy sector has a strong presence in the North Sea and in the surrounding coastal areas. Commercial extraction of offshore oil and gas and related activities (exploration, transportation and distribution; pipelines; oil refining and processing) constitutes the single most important economic sector and renewable electricity generation—mainly from offshore wind—is increasing. Energy and offshore activities in the North Sea are critically vulnerable to climate change along the full supply chain. The major vulnerabilities for offshore installations like rigs, offshore wind energy and pipelines concern wind storms and extreme wave heights, whereas on land coastal installations and transportation may also be adversely affected by flooding. Future renewable energy potentials in the North Sea are also susceptible to climate change. Whereas the hydropower potential is expected to increase, it is highly uncertain how much the future potential of other renewable energy sources such as wind, solar, terrestrial biomass, or emerging technologies like wave, tidal or marine biomass could be positively or negatively affected. Due to the different national energy supply mixes the vulnerability to climate-related impacts will vary among North Sea countries. To ensure safe and reliable future operations comprehensive and systematic risk assessments are therefore needed which account for, for example, the high integration of power systems in the region.

14.1 Introduction

Reliability and security of the energy supply are of critical socio-economic importance and safety at sea is one of the main concerns for offshore industries in general. The offshore energy sector is particularly vulnerable to future changes in climate. This includes changes in metocean conditions (the combined wind, wave and climate conditions as found at a certain location), in relation to the full energy supply chain from resource extraction, to pipelines, refineries, conversion, and transmission (e.g. Ebinger and Vergara 2011). Maintenance and operation as well as energy demand are also likely to be influenced by climate change. This chapter reviews some of the main risks and potential for offshore and energy activities in maritime and coastal areas; with a focus on energy supply and on selected economic sub-sectors within the North Sea region that are considered particularly climate sensitive, including offshore oil rigs and wind farms.

K. Halsnæs (✉) · M. Drews (✉)
Systems Analysis, DTU Management Engineering, Lyngby, Denmark
e-mail: khal@dtu.dk

M. Drews
e-mail: mard@dtu.dk

N.-E. Clausen
DTU Wind Energy, Roskilde, Denmark
e-mail: necl@dtu.dk

14.2 Climate Vulnerabilities in the North Sea Region

The major climate vulnerabilities in terms of resource extraction in the North Sea region are associated with the operation and maintenance of offshore oil and gas

M. Quante and F. Colijn (eds.), *North Sea Region Climate Change Assessment*,
Regional Climate Studies, DOI 10.1007/978-3-319-39745-0_14

Table 14.1 Overview of climate change risks on energy conversion

Conversion technology	Gradual climate change	Extreme weather events
Thermal power plant	Rising temperature implies decreased thermal efficiency and cooling efficiency	Damage to plant from storms Lower efficiency of cooling
Oil refinery and gas treatment	Sea-level rise and flooding	Flooding emergency Water scarcity disturbs production
Nuclear power plant	Cooling water scarcity	Damage to plant from flooding or storms
Wind power	Less frequent icing Dust from precipitation Flooding at coastal sites	Structural damage from storms Operation and maintenance
Solar energy	Lower efficiency of photovoltaic systems with higher temperature Higher efficiency of solar thermal heating systems with higher temperatures	Structural damage from storms, hail and heavy precipitation
Hydropower	Decreased potential in some areas and increased potential in others	Damage to dams

Adapted from Troccoli et al. (2014)

infrastructure, principally rigs and pipelines, due to their susceptibilities to wind storms and extreme wave heights (Vanem and Bitner-Gregersen 2012; Bitner-Gregersen et al. 2013; IEA 2013).

Climate change effects are also expected to have a significant impact on renewable energy sources (e.g. EEA 2012; Weisse et al. 2012). Some of the projected impacts include: changes in wind and wave energy potential; changes in hydropower potential (i.e. related to precipitation and temperature); changes in solar energy production (i.e. dependent on solar radiation and temperature); and variations in biomass for energy (i.e. related to the climate-related productivity of dedicated crops, and indirectly influenced by agricultural productivity and food security).

In addition to effects on resource extraction, the energy system is also influenced by vulnerabilities related to energy conversion. Table 14.1 provides an overview of major risks and shows that energy conversion is sensitive both to gradual changes in the mean and variance of climate parameters such as temperature and precipitation and to the projected intensification of extreme weather events in the North Sea region. The efficiency of many existing plants is expected to decline with higher temperatures, for example cooling will be more difficult, and damage from storms and flooding can disrupt energy supply with significant consequences for the economy and for disaster management in the case of extreme weather events. The International Energy Agency (IEA) estimates that for a 1 °C rise in temperature by 2040, 20 % of coal-fired power plants in Europe would need additional cooling capacity, whereas the electricity production capacity could be reduced by up to 19 % during summer (IEA 2013: their Table 3.2). In contrast, Thorsteinsson and Björnsson (2012) concluded that the projected increase in precipitation implied a potential increase in hydropower-based electricity production in the Nordic countries of about 10 % by 2050.

14.3 National Energy Supply Mixes

The vulnerability of energy systems around the North Sea to climate change must be seen in relation to the supply structure of individual countries. Figures 14.1 and 14.2 provide an overview of the present sources of electricity generation in the North Sea region and may be used to highlight some of the key risks.

In 2013, coal and peat accounted for about 32 % of the total electricity generation in the North Sea region, gas for

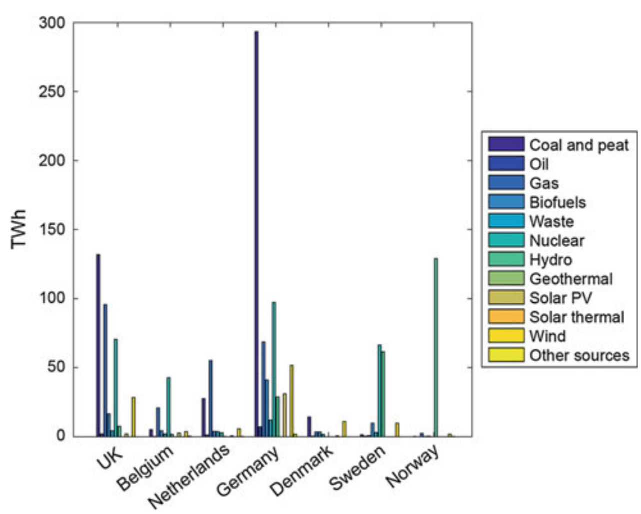

Fig. 14.1 Total electricity generation by source in 2013 (TWh) for North Sea countries (www.iea.org/statistics)

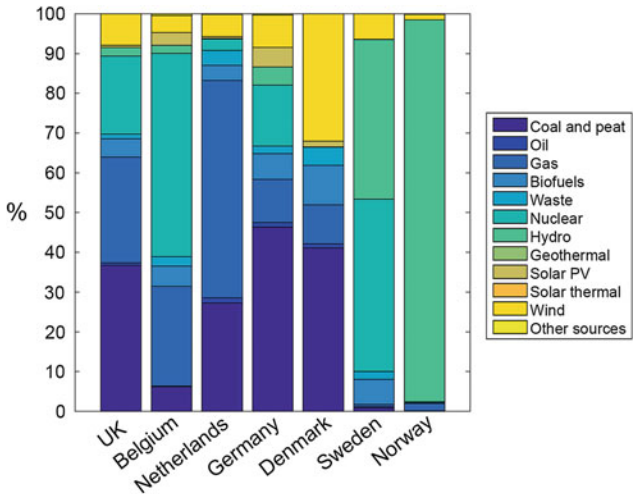

Fig. 14.2 Percentage composition of electricity generation by source in 2013 for North Sea countries (www.iea.org/statistics)

about 16 %, and nuclear for about 19 % (Fig. 4.1). In terms of renewable energy sources, hydropower accounts for about 15 % of total electricity generation and wind for 7 %. Several countries bordering the North Sea depend largely on coal and gas plants (the UK, Netherlands, Germany and Denmark), while nuclear power is important in others (Belgium and Sweden). Sweden, and especially Norway are highly dependent on hydropower. The different national energy supply mixes (Fig. 4.2) show that the projected climate-related impacts on electricity generation will vary on a country-by-country basis. The combined impacts of climate change on the energy system, whether related to gradual changes in mean climate parameters and their variations or to extreme weather events will also depend on the highly interconnected nature of the electricity markets, which is particularly strong in northern Europe and the possible correlation (e.g. in time) of climate and non-climate related stressors affecting the different fuel sources. Countries like Denmark that aim to base electricity generation on very large shares of fluctuating energy sources (e.g. wind energy), could thus become even more dependent than today on electricity trade with the Scandinavian market, such as for another climate-impacted energy source like hydropower (Halsnæs and Karlsson 2011).

Energy demand is also likely to be affected by climate change. Higher temperatures are likely to lead to decreased demand for space heating during winter, but to an increased demand for cooling in summer, especially in cities (e.g. Aebischer et al. 2007). The IEA has estimated that the energy demand for space heating could decrease by about 12 % by 2050 (IEA 2013) and that this decline could be particularly strong in northern Europe due to the current relatively high demand for space heating.

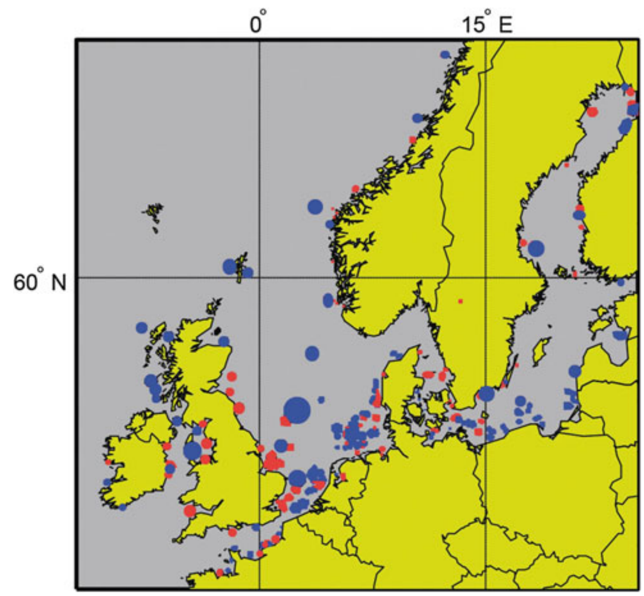

Fig. 14.3 Future offshore wind power development in Northern Europe aligned with the wind energy targets for 2020 (41 GW, *red*) and 2030 (107 GW, *blue*) from the European Wind Energy Association (2014) (Hvidtfeldt Larsen and Sønderberg Petersen 2015)

14.4 Renewable Energy Sources

Energy supply by means of renewable energy sources is expected to increase dramatically as the European Union aims to increase its share of energy consumption from renewable resources to 20 % by 2020. Options include offshore wind, hydropower, bioenergy, solar, wave energy and tidal power. They are all electricity-generating renewable technologies. Two of these technologies—offshore wind energy and hydropower—are well developed and already fully integrated into the energy system, while solar photovoltaics (PV) are in the commercial phase for land-based applications only. Likewise, the production of bioenergy/biofuels, such as from energy crops, has been extensively explored for land-based applications (see Chap. 13), whereas large-scale energy generation from marine biomass is still at an experimental stage.

Wind power is by far the most exploited renewable offshore technology in the North Sea area. Several recent initiatives, including three research and development projects funded by the European Union's Seventh Framework Programme *The Ocean of Tomorrow,*[1] explore the synergies of different renewable technologies in designing new floating offshore platforms powered by a combination of several renewable energy sources. The platforms also include aquaculture, leisure and transport options.

[1]http://ec.europa.eu/research/bioeconomy/fish/research/ocean/index_en.htm.

14.4.1 Offshore Wind Energy

More than 80 % of all offshore wind farms are installed in four countries bordering the North Sea: the UK, Denmark, Germany and Sweden, future development plans are shown in Fig. 14.3. A recent report by the European Wind Energy Association described the current status of the European offshore wind farms (EWEA 2014; Navigant Research 2014):

- 2080 turbines are installed and grid-connected offshore, accounting for a cumulative capacity of 6.5 GW divided onto 69 wind farms in eleven European countries.
- The offshore wind farms generate 24 TWh in an average year. Including land-based wind farms this corresponds to about 204 TWh generated in an average year or about 7.3 % of Europe's total electricity consumption.
- Twelve offshore projects are currently (2014) under construction corresponding to about 3 GW, which will bring the cumulative capacity in Europe to 9.4 GW.
- The average water depth of all wind farms in operation in 2013 is about 16 m and the average distance to shore 29 km.

Offshore wind energy technology is sensitive to changes in average wind speed, extreme wind speed, sea level, atmospheric icing and the extent and duration of sea ice.

The local wind climate represented by the average wind speed is the single most important factor in determining annual electricity generation by a wind farm and thereby the economy of single wind farms and of European offshore wind farms in general. Current climate projections (see Chap. 5) suggest largely unchanged average wind speeds in the North Sea area but as these projections have large uncertainties, considerable changes in generation potential cannot be ruled out.

'Extreme wind', defined as winds with a return period of 50 years (U_{50}) is an important design parameter for offshore wind turbines and used to define the durability of turbines. In general, strong winds are more important than extreme winds for the operation of an offshore wind farm as they occur much more frequently, for example strong winds with wind speeds exceeding 17 m s^{-1} occur as often as for 3–4 days per year at 10 m height in the Fehmarn Belt between Denmark and Germany. Strong winds are commonly described as winds above the 99th percentile (Thorsteinsson and Björnsson 2012) and are important for several reasons. First, during the planning period, the developer must compare potential wind farm sites and different operation and maintenance strategies. Second, in the daily planning of maintenance, strong winds and wind-induced waves have a large influence upon the ability to deploy vessels for installation and maintenance activities and thus on decision-making regarding such operations. Very strong winds (above 25 m s^{-1}) can result in periodic shutdowns due to structural safety. While this leads to a minimal loss of energy generation overall, such events are a challenge for the transmission systems operators who may need to cope with losing a large part of the electricity generating capacity within a few hours and with loads cycling on and off the grid potentially many times within a relatively short period.

Future climate projections for the North Sea (see Chap. 5) indicate that the number of storms towards the end of the century could remain at the same level as in the present-day reference period. The extreme wind speed U_{50} on the other hand could increase by as much as 10 % above present-day extremes in some areas, with the uncertainty of the same order as the estimated increases in extreme wind speed. This is likely to influence slightly the design of the wind turbines and possibly have a (minor) influence on the price of a wind turbine (Tarp-Johansen and Clausen 2006). Changes in strong winds may have a larger impact as they influence the time schedule during construction in general and in particular for crane work during erection of the wind farm. Maintenance activities are also affected by strong winds and boat transport of service crew and spare parts may be periodically difficult or impossible (Fig. 14.4).

Atmospheric icing and sea ice are rare in the North Sea (even though the Baltic Sea partly freezes every year) due to warming from the Gulf Stream. Thus higher temperatures are expected to have only minor influence on offshore wind energy generation.

14.4.2 Hydropower

Hydropower is the most important renewable energy source in Norway, where it currently covers about 99 % of Norway's electricity demand (Chernet et al. 2013). Hydropower also plays an important role in Sweden and makes a significant contribution to energy systems in the UK, Germany and Belgium. Small-scale hydropower plants (<10 MW) generate electricity by converting power from flowing water in rivers, canals or streams, while larger-scale plants often include dams and storage reservoirs to retain water.

Hydropower systems in the North Sea region will be strongly affected by the projected climate change (Thorsteinsson and Björnsson 2012; Chernet et al. 2013). The potential for hydropower is projected to rise by up to 20 % in northern and eastern Europe towards the end of the century. This is due to increased inflow to the hydropower systems from precipitation and snow melt and contrasts with the future decrease in hydropower potential projected for southern Europe.

Fig. 14.4 Installation of wind turbine at Horns Rev II wind farm (Picture provided by DONG Energy)

Hydropower production is sensitive to changes in both total runoff and its timing, and so any increase in climatic variability, even with no change in annual runoff, is likely to affect hydropower performance. Performance also depends on several other factors that are all inherently vulnerable to climate change, including reservoir design, operation strategies, dam safety, and distributions of floods and droughts. Thorsteinsson and Björnsson (2012) showed that climate change may have critical significance for dam safety and flood risk and so is likely to influence the future design and operation of hydropower plants.

14.4.3 Solar Energy

Solar energy is playing an increasingly important role in Europe. Currently, the two main technologies for generating energy from the sun are photovoltaics and solar thermal heating and most applications are land-based. In the North Sea region the largest contributions are found in Belgium and in particular in Germany, where about 7.6 GW of newly connected photovoltaic systems were installed in 2012 alone—the most in the world.

The adverse effects of climate change on solar energy primarily concern damage due to extreme weather events such as storms and heavy precipitation. In addition, some types of photovoltaic systems are sensitive to temperature, that is, their performance declines at higher temperatures (Troccoli et al. 2014). In contrast, solar thermal heating systems generally gain from increasing temperatures. Current climate projections for northern Europe (see Chap. 5) indicate small increases in sun hours (reduced cloud cover) during summer and small decreases in sun hours (increased cloud cover) during winter, but are generally associated with large uncertainties. The performance of both solar thermal heating and photovoltaic systems would thus be expected to improve during summer and decline during winter. Given the dominant uncertainties, however, future technological developments are likely to far outweigh the impacts of climate change.

14.4.4 Wave and Tidal Energy

Wave energy is an emerging technology, which is expected to see future use in the North Sea both in the coastal zone and offshore. Several conceptual designs are being tested or are at a prototype or demonstration stage worldwide. Devices still need to prove their integrity and reliability both during normal operations as well as extreme conditions. If successful some designs, in particular shoreline and near-shoreline devices, could reach commercial status within a decade. Wave energy devices are expected to be highly susceptible to the projected changes in metocean conditions and especially to extreme weather events (see Chap. 5).

The potential of tidal energy generated from either tidal impoundment or tidal streams is very low in the North Sea except near the UK coast, where it is slightly higher (Carbon Trust 2005). Currently, a range of demonstration projects are being implemented, and two commercial-scale power plants are in operation—one in Brittany, France. To date, no studies have highlighted specifically the climate change

Table 14.2 Vulnerability of the oil and gas sector to climate change

Climate change	Oil and gas activities	Potential impacts
Higher temperatures	Extraction and transportation	Arctic sea-ice decline could lead to increased exploration and increased access for shipping
	(Oil) refining	Reductions in steam turbine effectiveness might lead to higher energy costs; higher temperatures could affect plant design and operational requirements, materials, and process efficiency
	Delivery and distribution	Low impacts (e.g. extreme temperatures have the potential to cause maintenance problems)
Heavy rain, river floods, sea-level rise	Extraction and transportation	Low impacts however onshore transportation could be affected
	(Oil) refining	Flooding of critical infrastructure may cause serious damage and shutdown of operations
	Delivery and distribution	Soil erosion may expose buried pipelines; exposed pipeline sections may suffer damage; transportation by vessel, pipeline, road and rail may suffer flood-induced disruption and damage
Storms and storm surges, extreme wave heights	Extraction and transportation	Significant damage to offshore and onshore installations and equipment will disrupt and possibly shut down operations entirely; possible environmental consequences; increased focus on safety; new design standards
	(Oil) refining	
	Delivery and distribution	Transportation by vessel, pipeline, road and rail may suffer storm or flood-induced disruption and damage
Lightning	Extraction and transportation	Oil and gas pipelines may be damaged by lightning strikes, which may lead to increased corrosion, ignition, and operational disruption
	(Oil) refining	Risk of explosions or fires due to hazardous materials
	Delivery and distribution	–

Based on Cruz and Krausmann (2013 and references therein)

impacts on tidal technologies, but it is clear that tidal turbines like wave energy devices are highly vulnerable to the projected changes in extreme wind and wave conditions in the North Sea and this could influence the operation of such installations and increase the risk of damage.

14.4.5 Marine Biomass

The production of marine biomass like microalgae for bioenergy and/or biofuel has emerged as a promising renewable energy source (e.g. Roberts and Uphamb 2012; Jard et al. 2013). Extensive research and development activities are ongoing; a demonstration case for offshore applications has also been successfully developed by the National University of Ireland, Galway (Edwards and Watson 2011). Results suggest that use of marine biomass if commercially realised could potentially be as large and comparable to existing land-based forestry and agricultural energy crops. The potential of marine biomass as a future energy source would be affected by climate-related changes in the marine ecosystem (see Chap. 8). Likewise, offshore installations would be subject to changes in the frequency and/or intensity of wind and wave extremes.

14.5 Fuel Extraction

Commercial extraction of offshore oil and gas along with related activities such as exploration, transportation and distribution; pipelines; and oil refining and processing at present constitutes the single most important economic sector in the North Sea. Five countries are involved in oil and gas extraction in the North Sea: Norway, Denmark, Germany, Netherlands, and the UK. While oil and gas reserves in the North Sea and thus revenues are expected to decline over the course of the century, industry continues to push the boundaries of oil and gas exploration technology. Even with the expansion in renewable energy sources it is highly likely that the oil and gas sector will continue to be critically important in the North Sea.

A warming climate with stronger and more frequent extreme weather events will pose serious challenges to the oil and gas sector (Bitner-Gregersen et al. 2013; Cruz and Krausmann 2013). Structural failure of offshore structures may result in a loss of lives, severe environmental damage, and large economic consequences. Climate change impacts are likely to affect the entire value-chain of the sector, particularly activities in low-lying areas or areas exposed to extreme weather events. Table 14.2 summarises some of the main vulnerabilities related to oil and gas extraction in the North Sea.

Several researchers, including Cruz and Krausmann (2013) and Bitner-Gregersen et al. (2013), have argued that comprehensive and systematic risk assessment frameworks are needed to manage emerging risks to the offshore oil and gas sector from climate change. This is to ensure that present and future design standards for offshore and onshore infrastructure, maintenance and operations reflect the actual physical threats posed by climate change while remaining acceptable from an economic, societal and environmental perspective. Adaptation options could in some cases require significant investment to upgrade facilities, protect critical infrastructure and build redundancy and robustness into systems.

14.6 Conclusion

Energy systems and offshore activities in the North Sea region of which offshore wind, oil and gas dominate are virtually certain to be affected by climate change. While most studies show that hydropower potential is expected to increase, climate projections are highly uncertain regarding how much the future potential of other renewable energy sources such as wind, solar, terrestrial biomass, or emerging technologies like wave, tidal or marine biomass could be positively or negatively affected. Offshore and onshore activities in the North Sea region are very vulnerable to extreme weather events like extreme wave heights, storms and storm surges. To ensure safe and reliable operations and to mitigate the possible loss of lives and economic assets it is necessary to take action to prevent the potentially negative effects of climate change and to develop comprehensive and systematic risk assessment frameworks, which incorporate climate projections and environmental data.

References

Aebischer B, Henderson G, Jakob M, Catenazzi G (2007) Impact of Climate Change on Thermal Comfort, Heating and Cooling Energy Demand in Europe. In: ECEEE 2007 Summer Study Proceedings: Saving Energy – Just do it! Panel 5 Energy Efficient Buildings: 859-870.

Bitner-Gregersen EM, Eide LI, Hørte T, Skjong R (2013) Ship and Offshore Structure Design in Climate Change Perspective. Springer Briefs in Climate Studies. Springer Verlag.

Carbon Trust (2005). Phase II: UK Tidal Stream Energy Resource Assessment. Report prepared by Black & Veatch Ltd.

Chernet HH, Alfredsen K, Killingtveit Å (2013) The impacts of climate change on a Norwegian high-head hydropower system. J Water Clim Change 4:17–37

Cruz AM, Krausmann E (2013) Vulnerability of the oil and gas sector to climate change and extreme weather events. Clim Change 121:41–53

Ebinger J, Vergara W (2011) Climate Impacts on Energy Systems: Key Issues for Energy Sector Adaptation. Energy Sector Management Assistance Program (ESMAP) and The World Bank

Edwards M, Watson L (2011) Cultivating *Laminaria digitata*. Aquaculture Explained No. 26, National University of Ireland

EEA (2012) Climate Change, Impacts and Vulnerability in Europe 2012 - An Indicator Based Report. European Environment Agency (EEA) Report no. 12/2012

EWEA (2014) The European offshore wind industry – key trends and statistics 2013. European Wind Energy Association (EWEA)

Halsnæs K, Karlsson K (2011) The costs of renewable – past and future. In: Gallaraga I, González-Eguino M, Markandya A (eds), Handbook of Sustainable Energy. Edward Elgar

Hvidtfeldt Larsen H, Sønderberg Petersen L (eds) (2015) DTU International Energy Report 2015. Energy systems integration for the transition to non-fossil energy systems. Technical University of Denmark

IEA (2013) Redrawing the Energy-Climate Map. World Energy Outlook Special Report, International Energy Agency (IEA)

Jard G, Marfaing H, Carrère H, Delgenes JP, Steyer JP, Dumas C (2013) French Brittany macroalgae screening: Composition and methane potential for potential alternative sources of energy and products. Biores Tech 144:492–498

Navigant Research (2014) World Market Update 2013: International Wind Energy Development Forecast 2014-2018.

Roberts T, Uphamb P (2012) Prospects for the use of macro-algae for fuel in Ireland and the UK: An overview of marine management issues. Mar Pol 36:1047–1053

Tarp-Johansen NJ, Clausen NE (2006) Design of Wind Turbines in Typhoon area: A first study of structural safety of wind turbines in typhoon prone areas. EC-ASEAN Energy Facility

Thorsteinsson T, Björnsson H (eds) (2012) Climate Change and Energy Systems. Impacts Risks and Adaptation in the Nordic and Baltic Countries. TemaNord 2011:502, Nordic Council of Ministers

Troccoli A, Dubus L, Haupt SE (eds) (2014) Weather Matters for Energy, Springer-Verlag

Vanem E, Bitner-Gregersen EM (2012) Stochastic modelling of long-term trends in the wave climate and its potential impact on ship structural loads. Appl Ocean Res 37:235–248

Weisse R, von Storch H, Niemeyer HD, Knaack H (2012) Changing North Sea storm surge climate: An increasing Hazard? Ocean Coast Man 68:58–68