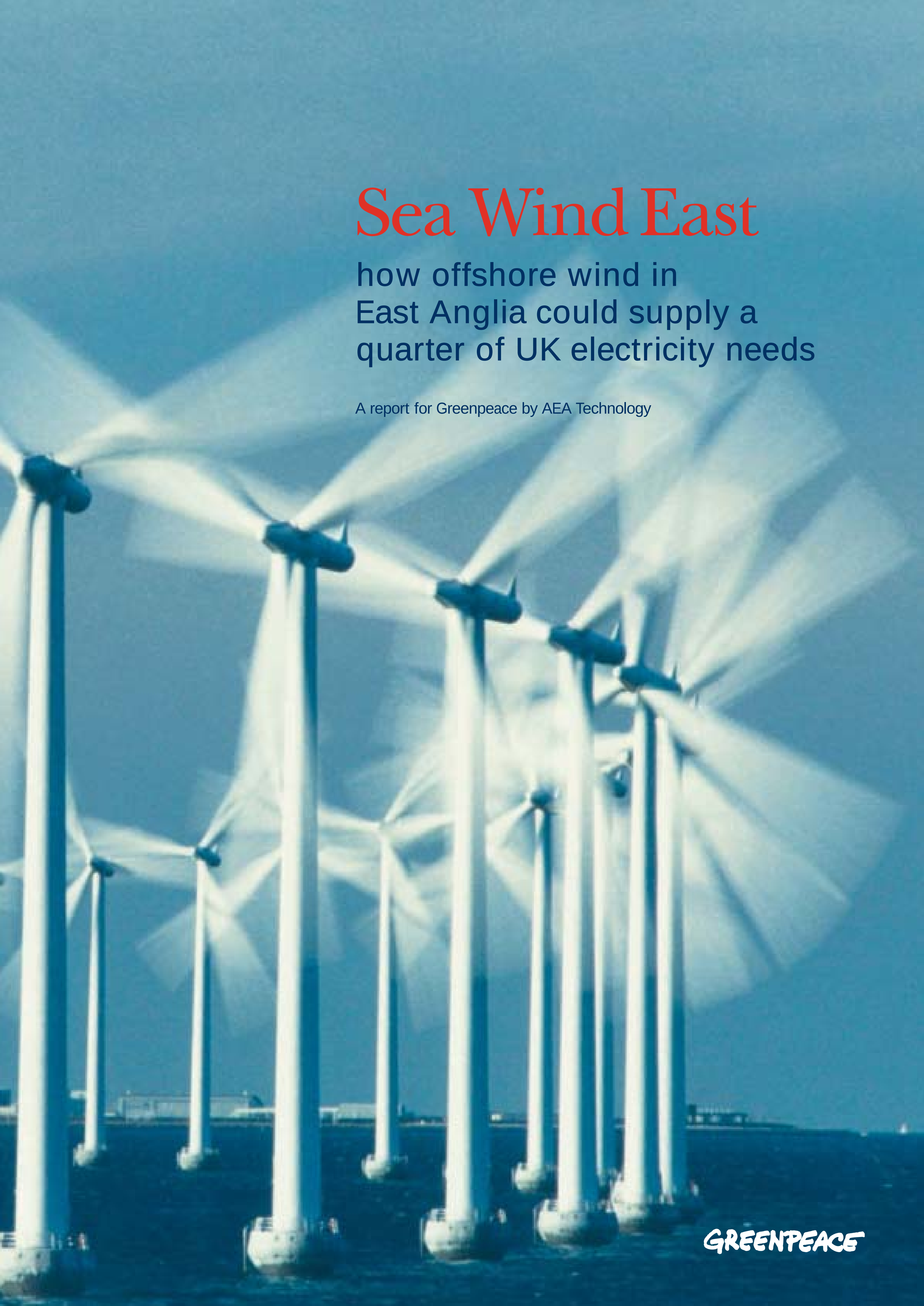
Sea Wind East

how offshore wind in East Anglia could supply a quarter of UK electricity needs

A report for Greenpeace by AEA Technology



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Foreword by Greenpeace

Renewable energy is already delivering electricity to millions of people worldwide, providing and sustaining hundreds of thousands of jobs, and offering the opportunities of a growing multibillion-pound market. The resources for wind, wave and solar generation are vast – easily enough to provide for the world's energy needs many times over. The UK is no exception, having the best assets for developing wind, offshore wind and wave in Europe. There is also great potential in the UK for tidal and solar power.

Yet, despite the enormity of the resources and the existing successes of the technologies, there are still those who say that renewables cannot deliver on a large scale. Critics hold that the UK cannot rely on renewable energy, that it cannot replace nuclear power and fossil fuels, that it cannot develop fast enough or be big enough to play a significant role in meeting the country's electricity demand. This study by AEA Technology puts paid to that argument.

Focusing on East Anglia, the study shows that using just one renewable technology – offshore wind – we could generate enough clean electricity to meet a quarter of current UK demand and still leave much of the resource untapped. There is enough offshore wind energy in this one region alone to completely replace all of the UK's outdated and dangerous nuclear power stations. The study shows that it can be done realistically and economically by 2020 if the Government takes the necessary steps to truly back renewables and see a clean, sustainable, carbon-free energy future become a reality.

In short, across the UK renewable energy can replace conventional power generation, including nuclear, and deliver on carbon reduction targets to help avert the climate catastrophe towards which fossil fuels are driving us.

East Anglia could be the epicentre of a Europe-wide boom in offshore wind. The region has the skills, the capacity and the massive offshore wind resources to dominate the European market in marine renewable energy. East Anglia stands to gain huge economic and employment rewards and the prestige of showcasing to the world exactly what cutting edge renewable technology development can do for the region and for the country.

This will only happen if the region speaks up and demands it. At the same time, Central Government must take decisive action before the huge potential for East Anglia, and the UK, can be realised and its benefits delivered.

There is now an opportunity for the Government to signal that it really does want a renewable future. The first step for the Government is to set its sights much higher for renewables. The naysayers and sceptics have kept the Government's ambitions small. By setting a high renewable energy target for 2020 and then working to deliver it, the Government would set the UK on the road to being a world leader in renewables. Only this would open the way for East Anglia to act on this plan. If the Government is bold enough to set in place the necessary framework as part of its new energy policy, then the plan laid out in this report could well become reality.

Matthew Spencer
Climate and Energy Campaign Director, Greenpeace UK


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Executive Summary

AEA Technology Environment has produced a 'visionary plan' highlighting the potential for offshore wind power that could be accessed off the East Anglian coast. This approach was deliberately chosen to expose the actions that need to be taken now to realise this potential. The plan identifies that at least 30GW of wind farms could be installed offshore, generating some 89TWh of electricity annually by 2020.[1] This represents around 25% of current UK electricity consumption. This is a challenging figure, but the results show it to be possible using today's technology.

The plan

An outline 'project plan' shows how the 30GW could be installed offshore with realistic installation rates. The rate of wind farm development is based on practical constraints on the rate of manufacture of turbines, connection to the grid and construction offshore. Installation rates ramp up from a low start in 2005 to reach a peak of 6GW/year in 2020.

Economic benefits arise from this plan. AEA Technology Environment estimates that 60,000 direct jobs could be won by 2020, mostly in the region itself, if such a plan was implemented. This would begin in 2005–2010 with a more modest ~4000 jobs. After achieving the 30GW, many jobs could be transferred to operation and maintenance and to replacing the oldest turbines as they reach the end of their working lives. Alternatively, a higher capacity could be installed if hydrogen production from surplus renewable electricity from the wind farms were to provide an additional market for the power.

Changes would be needed to the design, operation and management of the UK electricity system to achieve the target of 30GW installed capacity. By a combination of more intelligent networks, increased use of load-following generation plant[2] (for example using biomass) and advances in weather prediction for wind farms, this should not prove such a challenge as many opponents of wind power claim. In addition, by 2020 encouragement of the hydrogen economy could also result in hydrogen production being used in fuel cells to generate electricity during periods of low output from the wind farms.

Actions needed

To achieve this vision and gain the substantial benefits offered by this offshore wind resource, a number of barriers need to be overcome and several key actions need to be taken soon. These are especially related to strategic planning for the wind farms and include the following:

- A government plan would be required that sets out how much renewable capacity needs to be installed. A framework is also essential to enable development to take place in a predictable and integrated manner.

- A strategic plan for the national electricity grid should be developed which encourages the connection of all forms of electricity generation that reduce environmental impact – such as renewable energy – and improve security of supply.

- Licensing and permitting for offshore wind farms should be made more strategic and should encourage significant players to come forward to 'explore' potential sites within defined areas and in compliance with a published integrated development plan.

- Investment in grid extensions and upgrades would be needed around 2012. Planning for this must start now to ensure that the grid is in the right place and in step with the offshore developments and so unlock the renewable energy potential of the UK both for the domestic and

European markets. The cost of this grid will need to be met and passed on to the consumer.

- Strategic Environmental Assessment of the whole East Anglian coastal region will be needed to ensure that the selected 'site-search' areas are optimal.

- Economic development agencies responsible for attracting industry and encouraging development in their regions – such as the Government Offices – should begin planning their activities in support of offshore wind farms and in line with the Government strategic plan.

- Revisions should be identified for NETA that account for the environmental and economic advantages of offshore wind power.

With these actions taken soon, and the resulting strategic plan implemented, it should be possible to make significant progress necessary to gain the substantial economic, security of supply and environmental advantages that offshore wind power provides.

The study

The main objective of the study is to identify the key actions that need to be taken to realise the potential from offshore wind. Many actions need to be addressed now in order to prepare the way for the developments that are possible.

The work deliberately focuses on just one region of the UK and it illustrates just how large the potential for offshore wind power is. The benefit of the regional approach is clarity. It highlights the issues to be addressed and the actions that need to be taken to make the plan a reality. It should be noted that there is also significant opportunity for offshore wind power in other regions including the North West of England, the North East and Scotland, with similar economic, security of supply and environmental benefits.

The waters off East Anglia are well suited to offshore wind farms, having low tidal ranges, shallow water and good wind speeds, and so the region is generally suitable for this type of development. There is also a maritime tradition in East Anglia from which to launch the developments and maintain them in the long term.

Among the deliverables from the study, AEA Technology Environment has produced a series of charts indicating with some precision where the 30GW of wind farms might be built. Further work clearly needs to be done to confirm this, not least the SEAs required to ensure that the selected sites are the optimum ones.

Contents

1.	**Overview**	**1**
1.1	Introduction	**1**
1.2	Current situation	**1**
1.3	The region	**1**
2.	**Future plan**	**3**
2.1	Overview	**3**
2.2	Narrative	**3**
2.3	Strategic planning	**4**
2.4	Development over time	**5**
2.5	Key assumptions	**5**
3.	**What needs to happen for implementation**	**6**
4.	**Benefits**	**8**
4.1	Jobs and the economy	**8**
4.2	Investment	**8**
4.3	Security of supply	**8**
4.4	Emissions reductions	**8**
5.	**Additional information**	**9**
5.1	Use of international waters	**9**
5.2	Pipelines	**9**
5.3	Ministry of Defence	**9**
5.4	Grid issues	**9**
5.5	Supply fluctuation	**10**
5.6	Offshore grid	**11**
5.7	Dredging	**11**
5.8	Shipping routes	**11**
5.9	Environmental issues	**11**
5.10	Construction and maintenance support	**11**
5.11	Local manufacture	**11**
5.12	Hydrogen as an energy vector	**12**
6	**Appendx 1 – notes and references**	**13**
7.	**Appendix 2 – figures**	**14**
Figure 1	Turbine layout showing cable routing and exclusion zones around the turbines	**14**
Figure 2	Layout of each 750-800MW turbine block as shown on the charts	**14**
Figure 3	Installed capacity	**15**
Figure 4	Energy production	**15**
Figure 5	Job creation	**16**
Figure 6	Annual and total investments	**16**
Figure 7	Plan bar chart	**17**
8.	**Appendix 3 – charts**	**19**
Chart 1	East Anglia situational	**29**
Chart 2	Environmental considerations	**20**
Chart 3	Offshore obstacles	**21**
Chart 4	Electrical systems	**22**
Chart 5	Wind farm locations	**23**
Chart 6	Wind farm locations and offshore obstacles	**24**

1. Overview

1.1 Introduction

This report investigates the potential capacity for offshore wind power off the coast of East Anglia. An initial target to achieve an installed capacity of around 30GW by 2020, generating 89TWh/year, has been established as a working assumption underlying the study. The total potential resource is greater than this and more could be harnessed in the longer term.

The report deliberately concentrates on one region rather than the whole of the UK in order to ensure clarity of vision through the ability to focus on the practical issues relating to the development of a particular region. There are other opportunities for offshore wind developments around the UK and other issues emerging from a greater installed capacity.

The purpose of this work is to generate a plan for the future in which full advantage is taken of offshore wind in the area. The work highlights the technical innovation, infrastructure changes and political commitment that are necessary for the implementation of offshore wind power on this scale. It also highlights the economic benefits to the region as well as the potential for a significant contribution to the abatement of greenhouse gases.

The target installed capacity relates to the installation of around 30GW of turbines. The current generating capacity of the UK is approximately 80GW and the peak demand is 53GW. The target installed capacity is 38% of current generating capacity and 57% of current peak demand.[3] This compares to current installed wind (onshore and offshore) capacity of 500MW – 0.6% of current generating capacity.

Traditionally, resource studies of this type have used a GIS[4] sieve mapping approach where a series of constraints is applied consecutively to reduce a 'total' resource potential to a 'possible' level. This was considered inappropriate for this study for two reasons: firstly, the GIS approach does not allow for the ready inclusion of the effects of future changes to a region; secondly, it tends to produce a result based on 'what cannot be done' rather than seeking the opportunities that appear if some key changes could be made.

The plan produced here specifically highlights what could be possible if certain changes were made both in the region and nationally.

In so doing, it aims to guide thinking and inform policy makers so that the right decisions can be made now to encourage future development of offshore wind power.

1.2 Current situation

Following the announcement by The Crown Estate in April 2001 inviting developers to bid for sites, 18 offshore wind development consortia have 'pre-qualified' or been given permission to proceed to the next stages for site development. The pre-qualification applications were restricted to 30 turbines, 10km2 of seabed and a minimum installed capacity of 20MW. Five of the pre-qualified sites are located off the coast of East Anglia. These are Scroby Sands (76MW), Cromer (100MW), Inner Dowsing (60-90MW), Lynn (30 turbines) and Gunfleet Sands (100MW). The first out of the 18 expected to be installed – Scroby Sands – is anticipated to be operational in autumn 2003. The 18 sites were selected following a competitive application process to The Crown Estate in which the prospective developers identified the proposed sites and specified their planned number of turbines and area of coverage of the seabed.

1.3 The region

We have defined the geographical region of 'East Anglia' as the area south from the Humber to the Thames estuary. This marine environment lends itself well to offshore wind farms:

- The tidal range is low and water depths relatively shallow, allowing for practical foundation designs at a reasonable cost.

- Annual mean wind speeds are in the viable range of 7.5–9m/s.

- Seabed conditions are generally suitable for offshore wind farms.

In addition, much of the infrastructure necessary for the manufacture, installation and operation of offshore wind turbines either exists or could readily be sited in the region. East Anglia has historical and current maritime associations including the ports of Felixstowe, Harwich and Great Yarmouth.

Communications with the rest of the UK are good and the region's close proximity to the rest of Europe is also a benefit.

From an electricity industry perspective, there is a reasonably good grid infrastructure already in place serving a number of generating stations. As electricity demand in the UK is concentrated in the South East, offshore wind farms off East Anglia would also be well placed to deliver power southwards through existing and new connections.

Inland, employment centres including Lincoln, Peterborough, Norwich, Ipswich and Colchester offer potential for wind turbine component manufacture and supply.

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2. Future plan

2.1 Overview

The offshore wind plan developed here proposes a process to implement the installation of 89TWh/year (or 30GW) of offshore wind power off the coast of East Anglia over a practically achievable period. The plan sees the installation of full target capacity by the year 2020.

This deliberately bold target is technically achievable given appropriate policy support.

Offshore wind farm developments have a lead-time of the order of four years of planning leading to one year for construction. This lead-time encompasses the preparation of environmental statements, the obtaining of consents and the making of agreements with other parties with an interest in the area for development.

In addition, to allow the 30GW capacity to be connected to the UK grid, a number of important changes would be needed to grid connections, methods for balancing demand and supply within the intermittent output of the turbines, and electricity trading. None of these changes is unrealistic and we believe all would be needed in any case to move towards the 'low-carbon' economy that, for example, the Carbon Trust is aiming towards for 2050.

Taking the perspective of looking back in 2020 at the completed installation of 30GW capacity, the following plan shows how the offshore wind farms would be constructed and suggests where they could be situated. The plan identifies when key activities would need to take place, both in the wind farm design and in policy areas.

2.2 Narrative (written as if looking back from 2020)

The sites in planning in the East Anglian region in 2002 were completed by 2008, resulting in around 450MW installed capacity. The next round of offshore wind farm permitting went well and several applications were sufficiently advanced in their planning to allow further construction immediately after 2008.

From 2008 the annual rate of new installed capacity rose to 600MW. In order for the planning to start on new sites, prospective developers were identified and granted permission to investigate by 2004 with a view to installation in 2009. The DTI and The Crown Estate organised a strategic plan and consents process to initiate this long-term activity.

These early wind farms used technology available in the 2002–2005 period, typically 1.8–2.5MW turbines based very much on onshore designs because of their proven track record of good performance. Little needed to be done on the grid capacity or management at this stage.

Blocks of wind farm development areas were identified and agreed with the wind power industry in the period 2005–2010 and mechanisms put in place for permitting, connecting and selling power. This led to a long-term planning approach by various developers leading to the establishment of wind turbine manufacturing plant, foundation construction facilities and operation and maintenance bases in East Anglia. In 2010 there were nearly 8000 people employed directly in offshore wind businesses and plans for a further 10,000 jobs by 2015.

Part of the long-term planning included the development of the required electrical grid. From around 2012, substantial new grid capacity was required to connect the increasing capacity of offshore wind power. This was achieved in three main ways:

- *Connecting to existing, high-capacity onshore grids at locations including the Humber, Sizewell, Bradwell, and the Thames Gateway (a total of ~6GW).*

- *Reinforcing existing onshore grids to raise their capacity (an additional ~4GW).*

- *Establishing an Eastern UK offshore wind farm DC grid with a planned link to the Continent (~20GW).*

Managing the variable output from the wind farms also required a more proactive approach to managing the grid as the capacity passed 7.5GW in 2014. By this time, work on intelligent networks and weather prediction had reduced concerns about intermittent supply that existed at the turn of the century. Hence, it was possible to manage an output of up to 10GW by a mixture of improved demand-side management and the encouraging of a greater proportion of clean load-following generation plant (for example, biomass-fuelled electricity generation plant) to generate during short dips in wind farm output. In addition, by 2014 the hydrogen economy was beginning to emerge. The benefit of this was that during periods of high wind generation but low demand, wind power could be used to produce hydrogen through the electrolysis of water. By this means, power was stored for use during periods of low generation but high demand, when fuel cells generated electricity from the stored hydrogen in fuel cell power stations. By 2020, the introduction of a greater capacity hydrogen production also allowed for a growing volume of hydrogen to be used in fuel cell cars. Furthermore, by this time the DC grid link to the Continent enables increased electricity export capacity from the offshore wind farms.

The phased approach agreed in 2010 resulted in the following wind farms being operational by 2012:

- *A first tranche of 800MW off the Wash.*

- *A first tranche of 1.6GW off north Norfolk.*

- *A first tranche of 800MW off Harwich.*

By 2015, a second tranche of installations increased power dramatically:

- *A second tranche of 1.6GW off the Wash.*

- *A second tranche of 5.6GW off north Norfolk.*

- *A second tranche of 3.2GW off Harwich.*

By 2018, the final phases of the 30GW were being constructed. At this time there was strong growth in the job market as the installation rates increased.

By 2020, the Wash was at 9GW capacity with 12GW off North Norfolk and 9GW off Harwich.

Under a supportive electricity trading, permitting and licensing regime, by 2015 installation had increased to 2GW per year and in 2020 the installation peaked at 6GW. After 2020, annual installation is expected to level off at 1.5GW per year replacing the oldest turbines with new machines as they reach the end of their lives. Attention will henceforth shift elsewhere to adapt the knowledge that has been gained to other regions and countries with similar aspirations.

In 2020, the operation of wind farms is employing some 15,000 people, generally based in the coastal towns of Great Yarmouth, Ipswich and Felixstowe with smaller operations bases inland.

2.3 Strategic planning

The offshore wind farms were developed using a planned and integrated approach. This enabled the infrastructure around the wind farms to be put in place in the most efficient way – taking into account the planning of grid connections to shore, the strengthening of the onshore grid and the impacts on shipping routes. The areas were broken up and a competition launched for the *development and operation rights for each.*

A planned programme of installations provided the opportunity for a stable market for the manufacturing of offshore wind turbines in the UK. The output of UK industry continued to rise to 6GW of turbines and associated components per year, in line with the projected installations.

2.4 Development over time

A bar chart of the development over time appears in Appendix 3.

2.5 Key assumptions

In producing the above narrative description of the development of this plan for East Anglia, we have made a number of assumptions, representing 'what you need to believe' to understand these projections. These assumptions are as follows:

- No overriding engineering obstacles appear in the next ten years or thereafter.
- Offshore wind farms become cheaper because construction costs fall, operational costs fall, availability increases and output is as expected. All these gains arise as the industry becomes more experienced and makes full use of the strategically planned infrastructure.
- Better prediction of weather and output of wind farms becomes available to help to manage the wind farms and their interaction with the grid.
- Grid reinforcement is possible in the timescales allowed and broadly in the areas indicated, and sufficient investment is made to drive the plan through.
- Better management of demand-supply in the UK is implemented as required to allow for a greater capacity of intermittent renewables.
- Hydrogen production as an energy vector emerges by 2015 to supply fuel cells both for stationary uses generating electricity and for vehicles.
- A Euro-grid is under development by 2015 with a DC link to the Continent.

3. What needs to happen for implementation

To encourage developers and investors to play their part, a long term approach to renewable energy and especially offshore wind power would have to be developed in the next five years. This would be a clear, detailed plan of action identifying potential regions for selecting offshore wind farm sites, establishing a long-term power-purchase mechanism and developing means for integrating the capacity with UK electricity systems out to a 20-year horizon.

Key activities required over the next few years and then in the early years of implementation include the following:

- Revisions should be identified for New Electricity Trading Arrangements (NETA) that account for the environmental and economic advantages of offshore wind power. This should take account of security of supply issues, bearing in mind the likelihood that the UK will become a net importer of natural gas by 2011.

- A strategic plan for the national electricity grid should be developed which encourages the connection of all forms of electricity generation that reduce environmental impact and improve security of supply. It can be expected that this will also require changes to the way the Office of Gas and Electricity Markets (OFGEM) regulates the Distribution Network Operators who own, operate and manage local electricity networks. Much of this plan would cover offshore electricity grids establishing three types of connection:

– From offshore renewables to land-based demand centres supplying bulk green power to consumers.

– Between various land-based demand centres around the UK to help level out demand and cope with mismatches.

– From a range of renewables to potential sites for hydrogen production, as a means of energy storage and for supplying future fuel cell powered vehicles.

- Licensing and permitting for offshore wind farms should be made more strategic and should encourage significant players to come forward to 'explore' potential sites. This might be along similar lines to the systems used for oil and gas exploration and production.

- Strategic Environmental Assessment (SAE) of the whole coastal region should be conducted to ensure that the selected 'site-search' areas are optimal, taking account of all environmental impacts (positive and negative).

- Economic development agencies would need to begin planning for offshore wind farms. They would need to consider the manufacture of the turbines, towers and foundations, as well as supply of subsystems and components and operation and maintenance of the wind farms after commissioning. There may be roles for industrial areas with a history of energy supply (major mechanical and electrical components), disused airfields (larger structures such as towers and blades) and ports and harbours (foundations, construction and operations).

- In the long term (beyond 2020), planning should take account of the potential that would result from 'replanting' or replacing worn out turbines that have reached the end of their 20-year operational lives. This would create a long-term sustainable wind farm and turbine manufacturing business.

- Research, development and demonstration of technologies and methods required to support the 'hydrogen economy' should begin.

- There are many pipelines and cables in the seabed offshore that have been cited as a barrier to wind farm development. However, the pipes and cables are rarely a metre wide whereas wind turbines would be spaced typically 500m apart (see Figure 1 and Figure 2). Consequently, accurate pipeline mapping could remove this factor as a barrier to most wind farms. This should be studied in more detail to establish practical guidelines for safe clearances between wind turbines, their cables and existing pipelines and cables. Figure 1 shows the assumptions made in the placement of turbines and demonstrates that clearances between the turbines and pipes and cables can easily be maintained.
- As existing land-based (especially coastal) power stations reach the end of their working lives, the use of their grid connection points should be reserved for wind farm connection. In some cases it may be appropriate to locate a load-following power plant on the site to manage intermittent generation. This might be fuel cell based and hence co-siting of hydrogen production would be beneficial.

4. Benefits

4.1 Jobs and the economy

This strategic, planned approach to offshore wind farms in the region would create an annual demand for new wind turbines of 300MW in 2005 rising to a peak of 6GW in 2020. Thereafter, replacing the oldest turbines can be expected to result in an average demand of 1.5GW annually (see Figure 3).

This demand can be expected to result in nearly 6000 direct full-time jobs in 2005, rising to over 60,000 direct full-time jobs in 2020 (see Figure 5, based on experience from Denmark). These jobs could be located in East Anglia and could provide opportunity for the existing oil and gas industry. Employment multipliers[5] could result in nearly 150,000 full-time jobs in 2020. This level of employment would remain after 2020. The workforce would be employed replacing the oldest turbines with new machines and in general operation and maintenance of the wind farms and infrastructure.

If sufficient investment is encouraged into hydrogen production and use, additional jobs could flow from this new area. Some of these would be in high-technology sectors surrounding the development and manufacture of fuel cells and hydrogen storage and handling equipment.

4.2 Investment

Current land-based wind farm investment costs are typically £600–£800/kW installed. Less experience exists of offshore wind farm construction costs to provide concrete figures but it is expected that £1000/kW will be the typical costs of the first few installations off the East Anglian coast. Thereafter, it can be expected that costs will fall to around £600/kW by 2020 at 2002 prices.[6]

Consequently, the total investment would be expected to be around £300m/year in 2005 rising to £3.6bn/year by 2020 (see Figure 6). The cumulative investment by 2020 would have been just below £19bn. All these figures relate to installed wind turbines, but the investment would flow through to manufacturing facilities and operation and maintenance bases.

These investment estimates exclude the specific costs of offshore grid development because there is not yet consensus about how these should be met (see section 5.4).

4.3 Security of supply

UK reserves of oil and gas are in decline and it is predicted that the UK will become a net importer of natural gas by 2011. With this in mind, the benefits of displacing fossil fuels in electricity generation would add significantly to security of supply. This would be achieved by reducing the total consumption of natural gas, thereby both reducing dependency and extending the lives of gas wells to preserve natural gas for essential uses during the transition period. A move to a hydrogen economy based on renewables would go further by moving supplies of transport fuels to domestic renewable sources.

4.4 Emissions reductions

Utilising 30GW of offshore wind power would achieve reductions in carbon emissions rising to 10MtC/year by 2020 (based on average mix emissions of 117g C/kWh equivalent to 430g CO_2/kWh). This represents around 22% of current UK electricity industry emissions of carbon.

5. Additional information

5.1 Use of international waters

The Crown Estate owns virtually all waters up to 12 nautical miles off the UK coast. These are considered in law as national or territorial waters. Beyond this, international agreements define a 200-mile limit within which a country has rights to certain resources (e.g. minerals). In the North Sea this is replaced by a median line half way between the coastlines of the UK and the Continent. A significant proportion of the proposed wind farm locations are outside national waters. Waters up to the median line are internationally agreed to be under the economic advantage of the UK. All the proposed wind farms are within the median line. The Government grants consent to the use of waters outside the remit of The Crown Estate.

5.2 Pipelines

It is a requirement that pipelines in areas of development are mapped accurately. Given an interturbine spacing of 500m, there would be sufficient distance for construction activities to avoid proximity to a pipeline with no effect on the spacing of the turbines.

The running of cabling for a wind farm across pipelines would be minimised but would be technically possible.

5.3 Ministry of Defence

MOD firing ranges are not affected by the wind farm siting. However MOD concerns over low flying aircraft and effects of wind turbines on radar have not been considered in the siting. It is considered that alternative approaches can be agreed with MOD to respond to its concerns, through technology development such as the siting of radar systems offshore, engineering solutions and the finding of alternative sites for MOD activities.

5.4 Grid issues

The planned power transfer of the NGC in 2004/5 shows that expected annual power flows into East Anglia and the South East from neighbouring regions are equal to ~15GWh each. A further 15GWh flows from Scotland and the Northern and Midlands regions to the South of England. Consequently, generation of up to 45GWh in East Anglia could be advantageous through the elimination of the southward migration of power.

Under the current configuration of the transmission system, South Yorkshire and South Lancashire could accept up to 1.5GW of new generation, the Midlands and East Anglia could accept 1.5–2GW of new generation, Greater London could accept the same amount and the Thames estuary could accept 0.75–1.5GW.[7] This indicates that the coast of East Anglia borders electricity regions with the ability to accept a total of 4.25–7GW of new generation.

Taking the assumed growth rates of offshore wind installed capacity the total new generation limit for the grid in the East Anglian electricity regions would be exceeded between 2015 and 2017.

A report[8] published in 2001 recommends the connection of offshore wind to existing generation to combine the active power, reactive power and frequency response capability from a single substation. The report recommends that the capacity of offshore generation be sized at about 15% of the existing generation capacity located at or near the coast, under current grid guidelines. It also notes that this is not suitable for nuclear power stations due to their base load operation.

Assuming the combination of offshore generation with conventional generation as detailed above, and the use of the redundant

Bradwell connection and the Sizewell A connection when it goes offline in 2006, the projected offshore wind capacity could be accommodated by the grid until 2009 without any upgrading.

A general review of the costs of offshore high voltage direct current (HVDC) links, based on the west coast concept study by PB Power[9] suggests that to the nearest order of magnitude £10bn would be reasonable for the proposed offshore grid. There are a number of options for financing this. If this were split only amongst the developers of the proposed farms it would result in a cost increase of up to 50% for each unit of installed capacity. However, this grid would be in place for many generations and would be used by many successive wind farms. If managed properly, its life cost could therefore be much lower and strategies for achieving this should be investigated.

The investment in an offshore grid would also be in addition to restructuring the onshore grid. The electricity generated cannot be distributed to other parts of the country without upgrades to the onshore electricity transmission system. The investment required for this can only be reasonably estimated by NGC. However, upgrades are required anyway and components would necessarily be replaced over the timeframe considered in the report. Various possibilities exist for meeting the cost and mechanisms for passing it on equitably to electricity consumers would need to be explored.

5.5 Supply fluctuation

At less than 5% offshore wind in the generation mix, the costs of back-up would be insignificant. The cost of back-up[10] for 5–10% of supply would be around 0.1p/kWh and 20% would cost 0.2p/kWh. 100% offshore wind generation would need to cover intermittency with over-capacity and storage – the extra cost of generation has been estimated at 1p/kWh.

Improving the prediction of the expected quantity of wind generation over shorter time periods would enable conventional generators, including other renewables, to make up the supply by matching the fluctuations (e.g. through combustion of biomass and using fuel cells). Methods of improving wind predictability are currently being developed; it has been estimated that the need for extra spinning reserve can be reduced by over 30% (at 10% wind) using improved wind prediction methods.[11]

Significant use of offshore wind in the generation mix for the UK would require improved control of the electricity transmission and distribution network. Increased monitoring would be required to provide information on supply and demand at points across the network. Adjustments could then be made to both power station output and network properties to improve the match of supply and demand at the required power quality levels.

In addition, improved demand-side management would assist the matching of a supply including intermittent power sources with demand, while minimising the conventional generation that is required to make up the shortfall.

Existing fossil fuel power stations could provide much of this shortfall, but in the longer term, greater diversity of renewable sources would be available. One ideal solution is to use excess capacity of renewables to power hydrogen production. Hydrogen fuel cells could act as highly effective buffer-stores for renewable energy (see section 5.12). Biomass power generation also offers environmental advantages.

5.6 Offshore grid

With the large-scale implementation of offshore wind as proposed, the best option for grid connection would be to have an interconnector down the coast of East Anglia with connections to all the wind farms. The power would then be fed into the areas of high demand – i.e. London and the South East.

Towards the end of the development period, and for the large capacities projected here, selling of power to mainland Europe via a DC link to the Continent would be an option. It is expected that European electricity grids will become increasingly integrated and hence links between the UK and the Continent are increasingly a practical possibility. If designed and implemented properly, these would allow for better grid management, sharing of generation output and easier connection of offshore wind power among other technologies.

5.7 Dredging

Turbine installation plans need to be integrated with the dredging plans. Once constructed, wind farms preclude dredging (for marine aggregate), although turbines can be installed once dredging is finished in a given area. Current areas of dredging include the Thames Estuary to the east of Felixstowe and Clacton-on-Sea, the east coast to the east of Great Yarmouth and Lowestoft and the Humber region to the east and north-east of Skegness. The east coast dredging areas would be unaffected by the offshore wind farm placements.

5.8 Shipping routes

No international shipping routes are affected by the wind farm locations. The following has been assumed for unofficial shipping routes:

- The wind farms would not affect shipping routes, *or*
- Shipping routes would need to be moved, but not moved in any significant way, *or*
- Some shipping would be able to navigate through the wind farms, taking into account the distances of 500m between turbines.

The shipping routes out of Winterton cross some proposed wind farm locations.

5.9 Environmental issues

The Heritage Coast areas coincide with the Areas of Outstanding Natural Beauty (see Chart 2). The distances from the coast at which the turbines are sited are sufficient for them not to have a great visual impact from the shore. Nevertheless, the turbines have been sited well away from the above areas, leaving virtually no impact on them.

The protected Natura 2000 areas designated under European Habitats and Bird Directives (see Chart 2) are avoided completely by all wind farming activities.

This study has not been conducted to the level of detail necessary to confirm that all environmental impacts local to the wind farms are acceptable. Therefore, SEA and EIA (Environmental Impact Assessment) will still be required during the process of planning for the wind farms.

5.10 Construction and maintenance support

Wind farms would be built in planned batches and maintenance support would be developed at the best locations for wind farm convenience.

5.11 Local manufacture

With the increasing sizes of the turbines, transport of components is critical. Much of the turbine assembly would need to be local, even if some components are brought from further afield. This means that much of the manufacturing would need to be done on the coast near to the wind farms. This may benefit the Great Yarmouth, Harwich and Ipswich areas.

5.12 Hydrogen as an energy vector

Hydrogen offers long-term potential as an energy carrier (energy vector) in a low-carbon future for three main reasons:

- It can be produced by electrolysis of water using electricity from renewable sources and then stored.
- It produces water when combusted and little other pollution if carefully controlled.
- It can be used in ultra-clean fuel cells for generation of electricity.

For these reasons it could be used as means of increasing the capacity of electricity-generating renewables. At times of high output but low demand, excess electricity production can be used to make hydrogen. At times of low electricity generation from renewables but high demand, the stored hydrogen can be used to produce electricity. This can be done at central, large-scale fuel cell power generation plants or, potentially, in small-scale domestic micro-CHP (Combined Heat and Power) fuel cell units producing electricity and heat at the point of use.

In addition, a further stretch of renewable capacity could mean that hydrogen is produced from green, renewable sources for use in fuel cell cars. This could make a significant contribution to reducing greenhouse gases from the transport sector.

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6. Appendix 1 – notes and references

[1] The installed capacity (measured in gigawatts [GW]) is the total rated power of the wind turbines, each one typically being a few megawatts (MW; 1000MW is one GW). It is the maximum power output that would be produced at any instant if all the wind turbines were operating at full power. The amount of electricity generated in a typical year is expressed in TWh (terawatt hours). If a 1000MW generator ran continuously for 1000 hours it would produce 1TWh. One TWh is 1000 million kWh of electricity – kWh is the 'unit' referred to on household electricity bills. A typical household consumes 4000–5000kWh/year. The UK as a whole typically uses around 320TWh/year.

[2] Load-following plant is used to match variations in electricity demand. Only certain types of generation are capable of load following, usually combustion-based power plants (such as biomass) – c.f. base load, which generates at a fixed level and is either at that level or 'off', and peaking plant, which are generators that can come on a short notice to meet a demand spike (such as at the end of popular television programmes).

[3] We believe this could be technically possible through the implementation of some emerging technologies.

[4] Geographical Information System – a computer-based mapping system and database which allows overlaying of different sets of cartographic, geological, social and other data to study regions.

[5] Employment multipliers are a commonly used concept in economics. They are a means of recognising that the employment of people in one industry (direct jobs) generally has the knock-on effect of increasing demand for goods and services in other industries as well (indirect jobs).

[6] The data for installation costs have been taken from numerous confidential sources reflecting AEA Technology's experience working in the wind industry. For example, AEA Technology has acted as independent engineer for banks and others investing in over 400MW of wind farms. In this role AEA Technology has access to detailed information on the technical and financial data relating to the wind farms.

[7] PB Power (2002) Concept Study. Western Offshore Transmission Grid, ETSU K/EL/00294/REP.

[8] PB Power (2001) Electrical Network Limitations on Large-Scale Deployment of Offshore Wind Energy, ETSU W/33/00529/REP/1, DTI/Pub URN 01/773.

[9] PB Power (2002) Concept Study. Western Offshore Transmission Grid, ETSU K/EL/00294/REP.

[10] Electricity has to be generated at the time it is consumed. This would be relatively easy if demand for power were constant or highly predictable and if power stations and the electricity grid were perfectly reliable. Unfortunately neither is entirely the case and so back-up power stations have to be ready to generate (but not generating at full output) at a moment's notice (this is often referred to as 'spinning reserve'). This is the case even without any intermittent generation (such as wind, hydro and solar). The largest requirement for this back-up at the moment is in case Sizewell B nuclear power station stops generating or loses its connection to the grid unexpectedly (see NGC for details).

[11] D Milborrow (2001) Penalties for Intermittent Sources of Energy. PIU working paper available at www.cabinet-office.gov.uk/innovation/2002/energy/workingpapers.shtml

[12] UK Energy in Brief (December 2001) Available at www.dti.gov.uk/epa/eib/ukeb122001.pdf

7. Appendix 2 - figures

Figure 1. Turbine layout showing cable routing and exclusion zones around the turbines

To avoid turbulent wakes, turbines are spaced apart centre-to-centre at least four rotor diameter lengths, and preferably five. The example in Figure 1 assumes 2–3MW turbines with ~100m diameter rotors (the Vestas V80, for instance, has an 80m diameter rotor and a 2MW max output). The exclusion zones are on the seabed and are our initial recommendation for a zone in which no existing or future sub-sea cables or pipelines should lie (save for wind farm infrastructure) to ensure there is no unwanted interaction between turbine foundations and the cabling/pipeline.

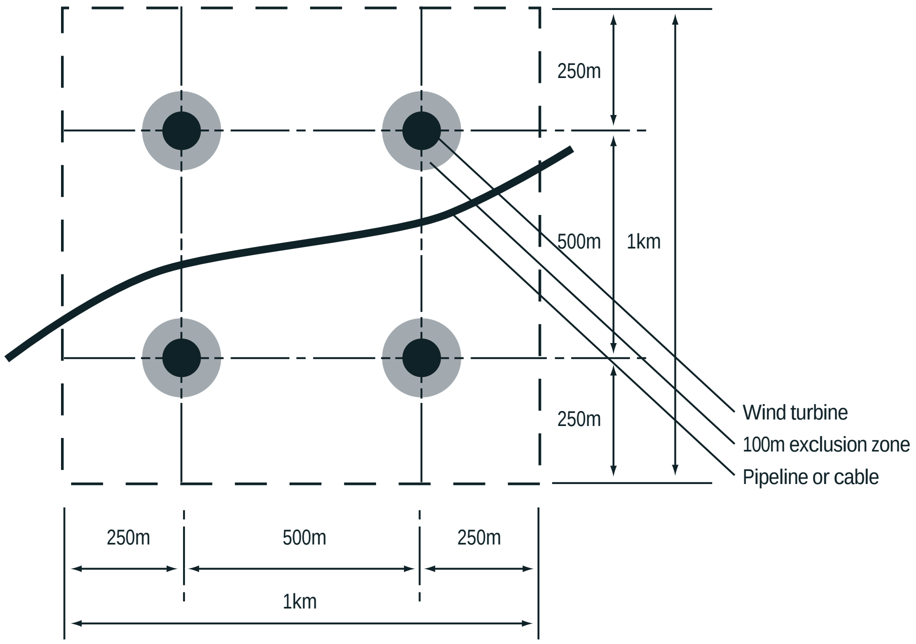


Figure 2. Layout of each 750-800MW turbine block as shown on the charts

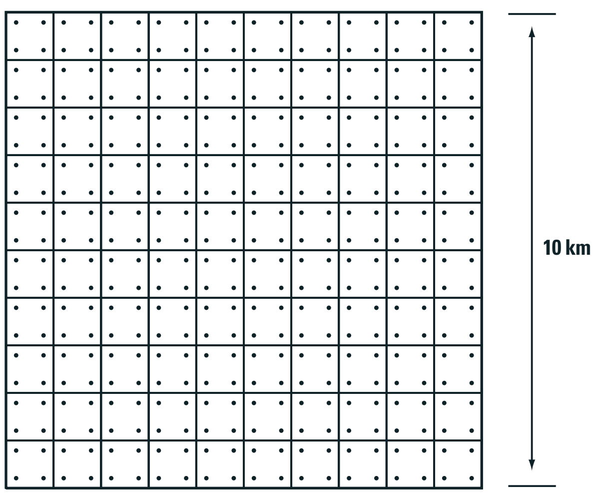


Figure 3. Installed capacity

This graph shows a viable yearly increase in installed capacity. The annual rate of installation increases each year to a maximum of 6GW in 2020, with a total installed capacity of 30GW by this time

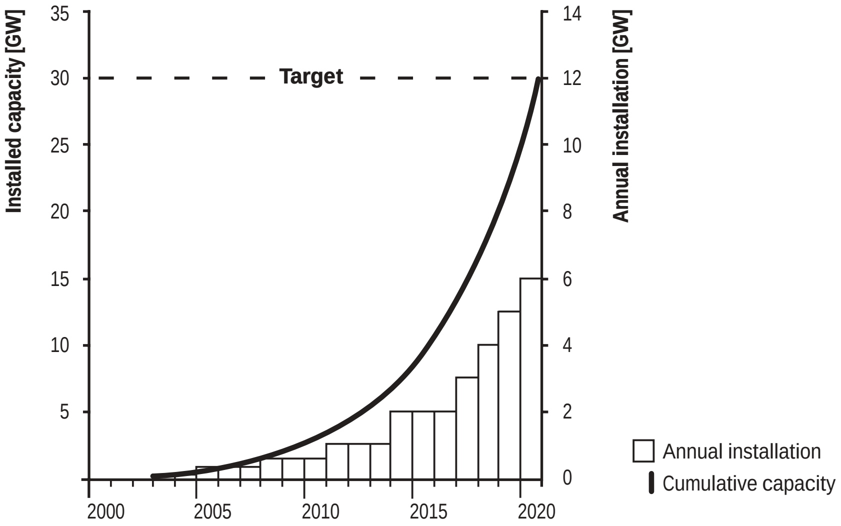


Figure 4. Energy production

As the industry develops, new turbine performance would improve and improved maintenance systems would ensure that the older turbines perform well over the period. By 2020, the target of 89TWh/year might well be exceeded.

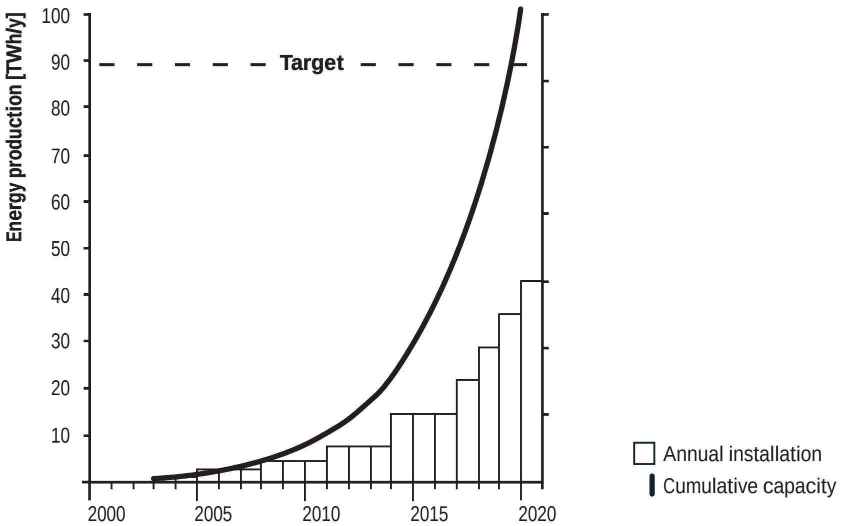


Figure 5. Job creation

As each phase of installation is completed, the number of people required for building, installing, operating and maintaining turbines, as well as the number of people in supporting jobs, would fall slightly. Because of the increasing rate of installation, the number of jobs in wind farming would nevertheless grow rapidly to just over 60,000 in 2020. After 2020 there would be enormous potential for the East Anglian workforce to export its skills and workers to other regions and countries wanting to develop offshore wind. There would also be continued demand in East Anglia as ‘replanting’ of the existing wind farms begins.

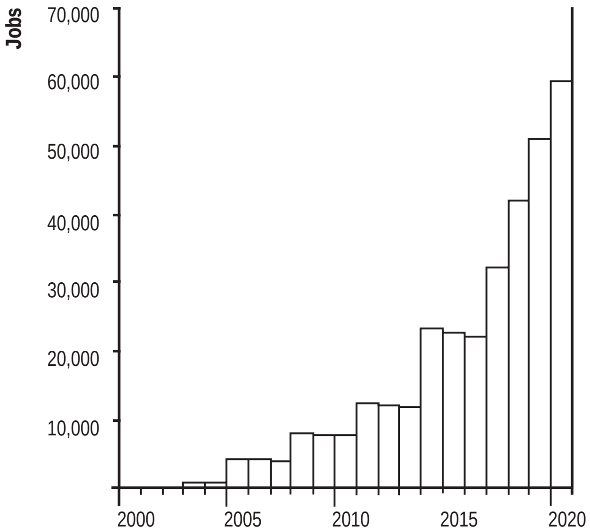


Figure 6. Annual and total investments

The costs of installing turbines would fall over time. Because the rate of installation would increase, the annual investment would rise to just under £4bn in 2020. The total cumulative investment by 2020 would be nearly £20bn. By contrast, in 2000 nearly £7bn was invested in all forms of energy.[12]

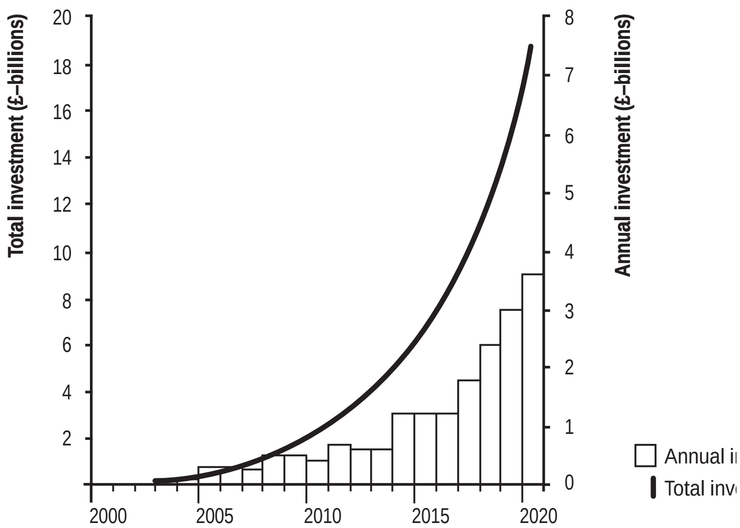


Figure 7. East Anglian Offshore Wind Vision

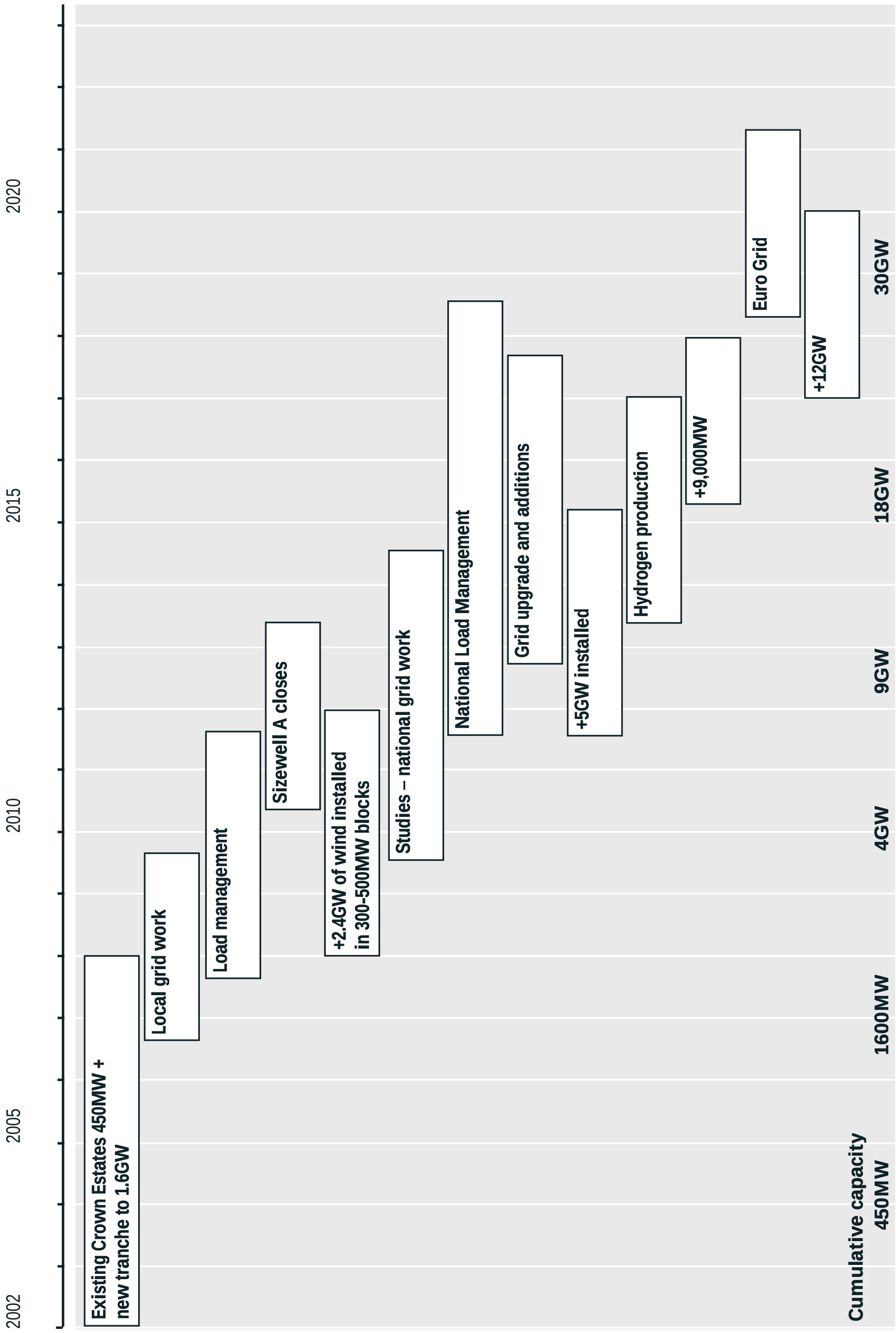
This bar chart illustrates the overall timescales attached to the plan. It indicates when tranches of wind farms could be built and what other activities would need to be carried out in support.

Grid work refers to modifying the electricity grid to take an increasing capacity of wind power. In the early years it would tend to involve small modifications to the onshore grid. Latterly it would require more significant activity and an offshore grid.

Load management activity would also be required to accommodate the output of increasing amounts of wind power. Again, this begins with local actions and tends towards larger, more strategic work in areas such as hydrogen production and use through fuel cells generating electricity.

Finally, it is expected that a European grid network could appear towards the end of the plan to help smooth supply and demand.

For full details see main report.



8. Appendix 3 – charts

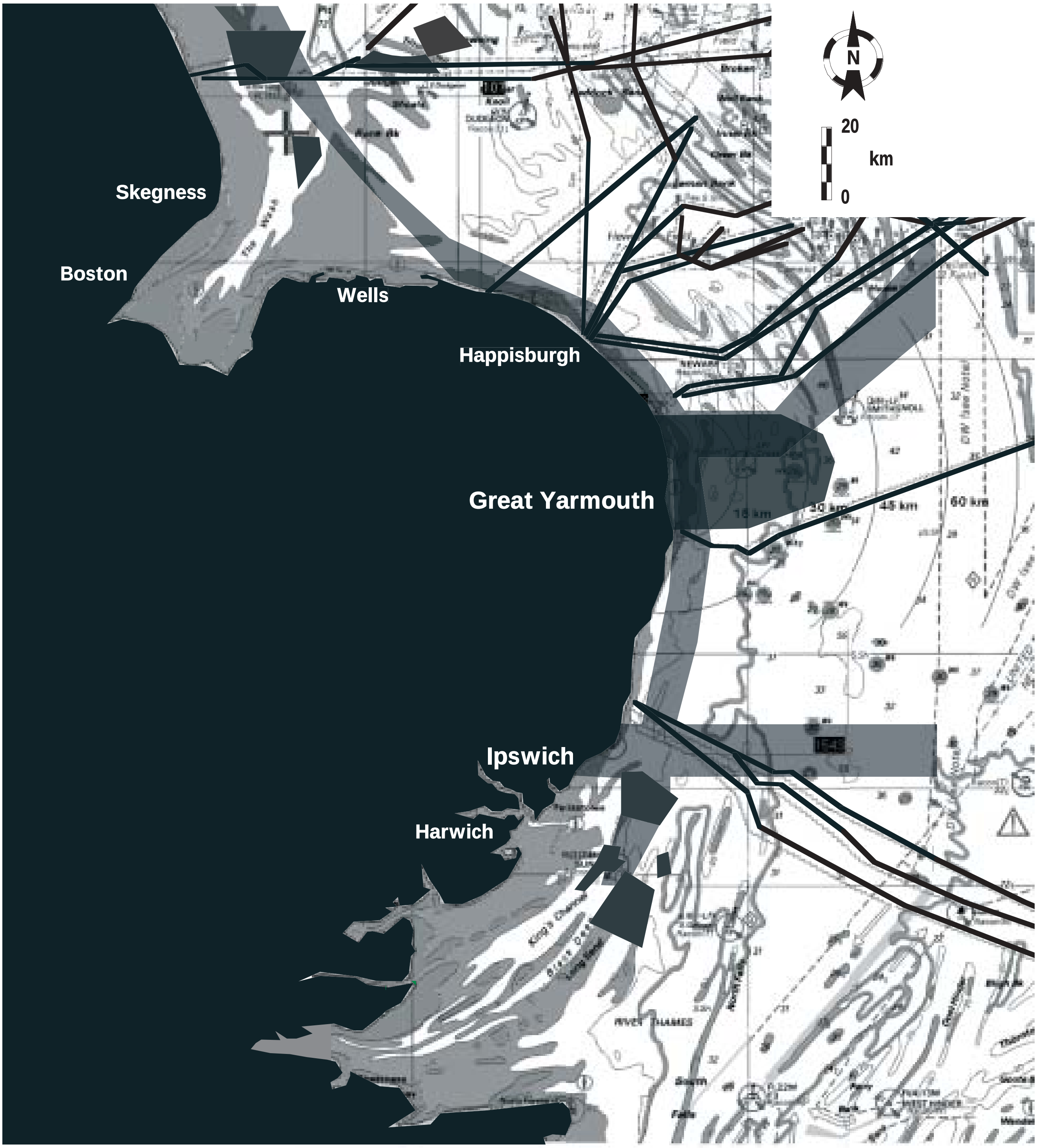
The following charts show drivers and constraints on the development of the East Anglian wind resource:

Chart 1. East Anglia situational

Chart 2. Environmental considerations

Natura 2000
Areas of oustanding natural beauty
Heritage coast (indicative)

Chart 3. Offshore obstacles

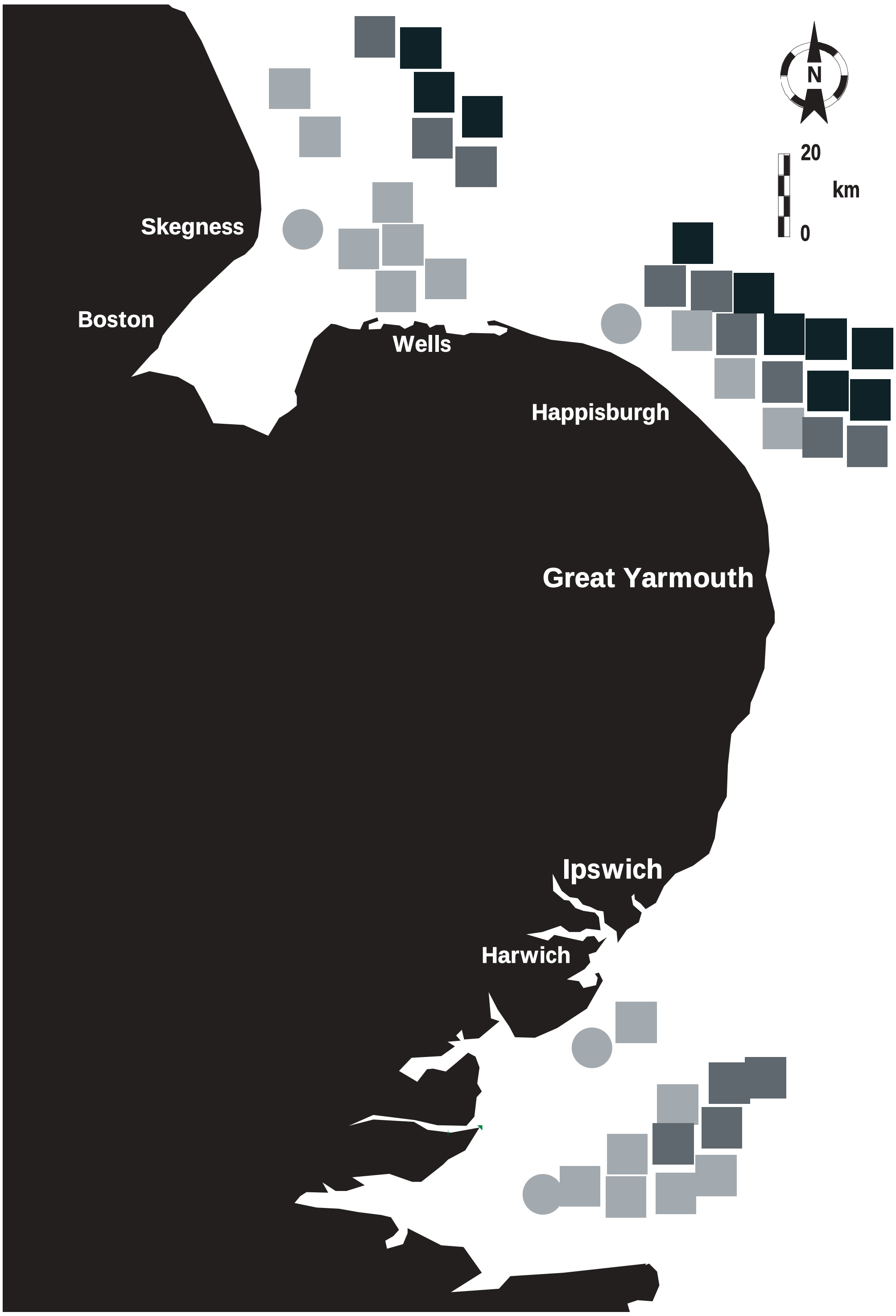


- Current dredging areas
- Known or likely shipping
- Likely ship operating areas
- Pipelines and cables

Chart 4. Electrical systems

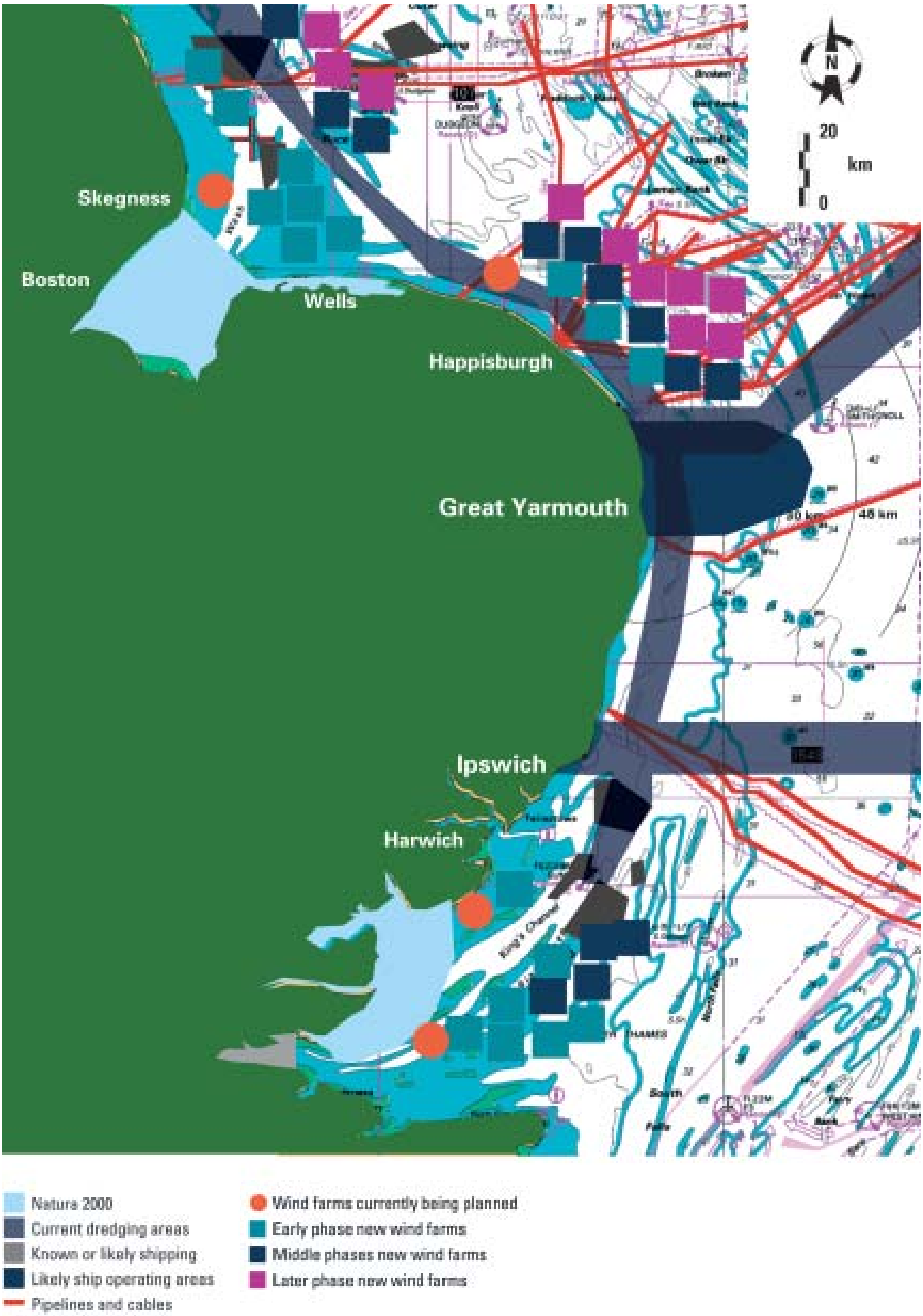
The chart shows the suggested offshore grid cabling that would be needed to bring the electricity to shore as the installed capacity gets larger.

Chart 5. Wind farm locations



Wind farms currently being planned
Early phase new wind farms
Middle phases new wind farms
Later phase new wind farms

Chart 6. Wind farm locations and offshore obstacles



If key actions are taken today, by 2020 East Anglia alone could provide 25% of UK electricity needs through clean offshore wind power, with substantial economic, security of supply and environmental benefits.

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