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Sustainable Engineering Worldwide

CRESP

Fujian Offshore Wind Farm Development Methodology

Deliverable 4

June 2008

Contents

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1 INTRODUCTION

SgurrEnergy has been appointed by CRESP to assist with the development of a methodology leading to production of an implementation plan to exploit the offshore wind resource of Fujian province. Deliverable 4 of this assignment requires that practical application of the suggested methodology be described with regard to offshore wind farm site selection, wind resource measurement and wind resource evaluation. The most appropriate way for this requirement to be delivered was considered to be by way of example and this report applies the suggested methodology to a fictitious offshore wind farm near to Pinghai Peninsula, Putian.

It should be noted that the location and offshore wind farm design described in this report are for illustration only to assist in the understanding of the development methodology. In the final analysis based on field measured wind data, it is possible that the illustration presented may not be economically attractive as an offshore wind farm development. However these decisions require a detailed knowledge of the wind resource and the likely tariff levels for offshore wind power plants. For example, a wind resource considered marginal in one country may be viable for wind farm development in another country where favourable renewable energy tariffs are in place. As China's southern provinces, including Fujian, have the highest power prices in the country, it is feasible that marginal wind resources may be exploited economically in that region.

The constraint map and provisional design methodology presented herein would have to be applied to several potential sites in the region at varying distances from the coast and at different water depths to determine which were most likely to be economically attractive. Although this is beyond the scope of this assignment it is hoped that CMA will be able to progress the work to identify suitable offshore wind farm locations following the example given herein.

2 OVERVIEW

SgurrEnergy believes that by illustrating the application of the suggested methodology using an actual offshore location it will be possible for CMA and other interested parties to apply the suggested methodology to other areas of the Fujian coastline.

The methodology suggested in previous SgurrEnergy reports requires that a high level constraint map be produced to identify primary search areas. This step has been missed out of the description in Section 4 as CMA has provided SgurrEnergy with the primary search area.

As scale is important with regard to making offshore wind farms economic it is the opinion of SgurrEnergy that large offshore wind farm developments should be the design objective. For the sake of discussion the nominal project building block will be 300 MW, which is comparable to the largest European projects. Note that this would not have to be constructed in one season, allowing a phased approach to development over several years.

The following sections outline how a nominal 300 MW wind farm could be developed in the vicinity of Pinghai Peninsula.

3 LOCATION

SgurrEnergy has recommended that a high level constraint map be produced to enable the most promising offshore wind farm development areas to be identified, ranked and selected for further investigation. This has not been done as it has not been possible to obtain the information needed to complete this task.

As a reference, it may be relevant to note that the UK currently has the largest number of operational offshore wind farm developments. An important observation here is that although the UK has some 12,500 km of coastline, the UK's offshore wind farms are concentrated along a small fraction of the coastline, the same being true of mainland Europe. From the methodology suggested by SgurrEnergy, the first step in identifying the small zones of viable wind farm development, whether in China or the UK, would be to produce a high level constraint map that would enable identification and characterisation of as many of the key issues described in SgurrEnergy's site visit report 6509/001/O/R/07/003 as possible.

CMA has suggested that the coastal area in the vicinity of Pinghai Peninsula, as illustrated in the Figure 1 below, be investigated with regard to its suitability for wind farm development. It is anticipated that in the future CMA would engage other relevant organisations for the detailed development of a constraints approach that would more clearly define China's priority wind farm development areas, combined with a growing network of coastal wind monitoring stations.

Figure 1 - Pinghai Peninsula, Suggested Offshore Wind Farm Location from CMA

4 FUJIAN OFFSHORE WIND FARM SITE SELECTION METHODOLOGY

4.1 BACKGROUND

Due to issues of national security that have limited the provision of wind farm constraint information to SgurrEnergy in Fujian, it has been difficult to guide the reader through the offshore wind farm development process. Therefore, by way of illustration SgurrEnergy will describe development of a fictitious offshore wind farm at Putian to present application of the proposed methodology and develop a high level constraint map for the area. As mentioned previously, the actual economic viability of such a wind farm cannot be evaluated with present information, but these issues may be clarified later by CMA and other relevant organisatons.

4.2 Putian Offshore Wind Farm Development Methodology

The Putian offshore wind farm development will follow the following basic steps:

1. Identification of primary search areas (See Section 3)
2. Identification of secondary search areas through the production of constraint maps
3. Prioritisation of potential sites based on key factors affecting capital cost and energy yield
4. Consultation with appropriate organisations
5. Performing a high level economic assessment to identify the most appropriate routes
6. Characterisation of the sites through direct measurement
7. Undertaking a final design of the wind farm
8. Performing an economic assessment and decide on whether to develop or not.

The first three steps of this methodology are discussed in more detail below.

4.3 Primary Search Area Identification

SgurrEnergy was requested to study the area around Pinghai Peninsula, as described in section 3.

4.4 Secondary Search Area Characterisation

Fujian province has two key characteristics that are new to the operational experience of current offshore wind farms, namely the frequency and strength of typhoons and the proximity to geological faults, both of which will ultimately have to be given special attention. The many other technical and environmental constraints, such as grid connection and environmental exclusion zones, are more straightforward to deal with and once identified and characterised these can built up on a constraint map.

SgurrEnergy employs GIS software to produce constraint maps. This software enables those constraints that are identified and characterised to be entered as individual layers and categorised appropriately, for example, into technical and environmental constraints. Once all of the constraints are identified appropriate mitigation can be applied for example, buffer zones can be applied to all the constraints to reflect the importance or sensitivity of a particular constraint.

The process described in the remainder of this section represents a partial constraint mapping process using information that SgurrEnergy has been able to obtain from publicly available sources.

4.4.1 Initial Site Selection

Simplistically, the profit from a wind farm development is the difference between the tariff and the total cost of generation. Therefore, the lower the cost that electricity can be generated from a particular site the more attractive the site will be to developers. Consequently, for a given tariff, the most attractive sites will be those that can be built at the lowest cost with the highest annual energy production. For offshore developments, capital and operational costs will typically increase with increasing distance from shore. However, this cost increase is mitigated in part as the wind resource generally improves with increasing distance from the shore. Therefore there will be an optimum location at which to site an offshore wind farm development and this optimum location will yield the lowest cost of generation in terms of ¥/kWh.

4.4.1.1 Wind Resource

Nominal Wind Speed

As a first filtering process it is appropriate to select a wind speed below which locations are rejected and above which locations are selected for further analysis. As mentioned above the electricity tariff has a major impact upon wind farm economics and in the UK, which has one of the world's highest tariffs for wind power, operational offshore wind farms all have capacity factors in excess of 30%. It is clear that Fujian's energy policy and power tariff structure will have a dominant role in determining where wind farms are built in the Province. Government decisions on both the development of the electricity transmission network and the tariff will guide developers to zones where grid connection points are close and the wind resource is adequate. To be on a par with large European offshore wind farm sites it would be reasonable to consider hub height wind speeds of 9 m/s to 10 m/s for economically viable projects. Given the typical uncertainties of at least 1 m/s inherent in large scale wind flow models, it is thought that those sites with an estimated annual average hub height wind speed around 8 m/s would be appropriate for initial consideration.

Estimating the Available Wind Resource

CMA has produced an onshore wind resource map for Fujian province and has advised SgurrEnergy that this will be extended to cover the offshore region. A map of this nature will be required to enable the areas with the highest energy yield to be identified. It is not known precisely what the uncertainty may be in such a wind resource map, however, as a minimum the data can be used to rank sites and highlight what are likely to be the most economic opportunities.

In the absence of a formal offshore wind resource map NCAR reanalysis data can be employed. NCAR reanalysis data are synthesized from the assimilation of data from a global network of meteorological stations combined with meteorological observations from the land, the sea (from ships and marine buoys), aircraft, weather satellites and other data sources to produce global fields of various meteorological parameters, including wind speeds at various heights. NCAR data are available from nodes that cover the planet which are positioned every 2.5 degrees in both the latitudinal and longitudinal axes.

NCAR reanalysis data from the nearest grid node at 120E 25N (Figure 2) to the proposed wind farm were used as the reference data for the wind flow model (WAsP), which was used to generate the wind resource map shown in Figure 3. The accuracy of WAsP wind speed estimates reduces with increasing distance from the reference mast position (or in this case NCAR grid node) and increasing complexity of topography and roughness. The topography was represented by Shuttle Radar Topography Mission (SRTM) height data. The SRTM was a joint project between the National Aeronautics and Space Administration (NASA) and the National Geospatial Intelligence Agency (NGA). To characterize surface roughness, details of the vegetation, buildings and composition of ground cover must be obtained from field surveys or satellite images such that surface roughness can be represented appropriately in the wind flow model. As such an exercise was beyond the scope of this assignment it was assumed that the surface roughness class for the Pinghai Peninsula, Nanri Island and all the other nearby islands was 2.0, which is equivalent to farmland with some buildings and crossing hedges of 8 m height and 800m apart. Therefore, the wind speed estimates are indicative only and must be viewed as relative rather than absolute figures.

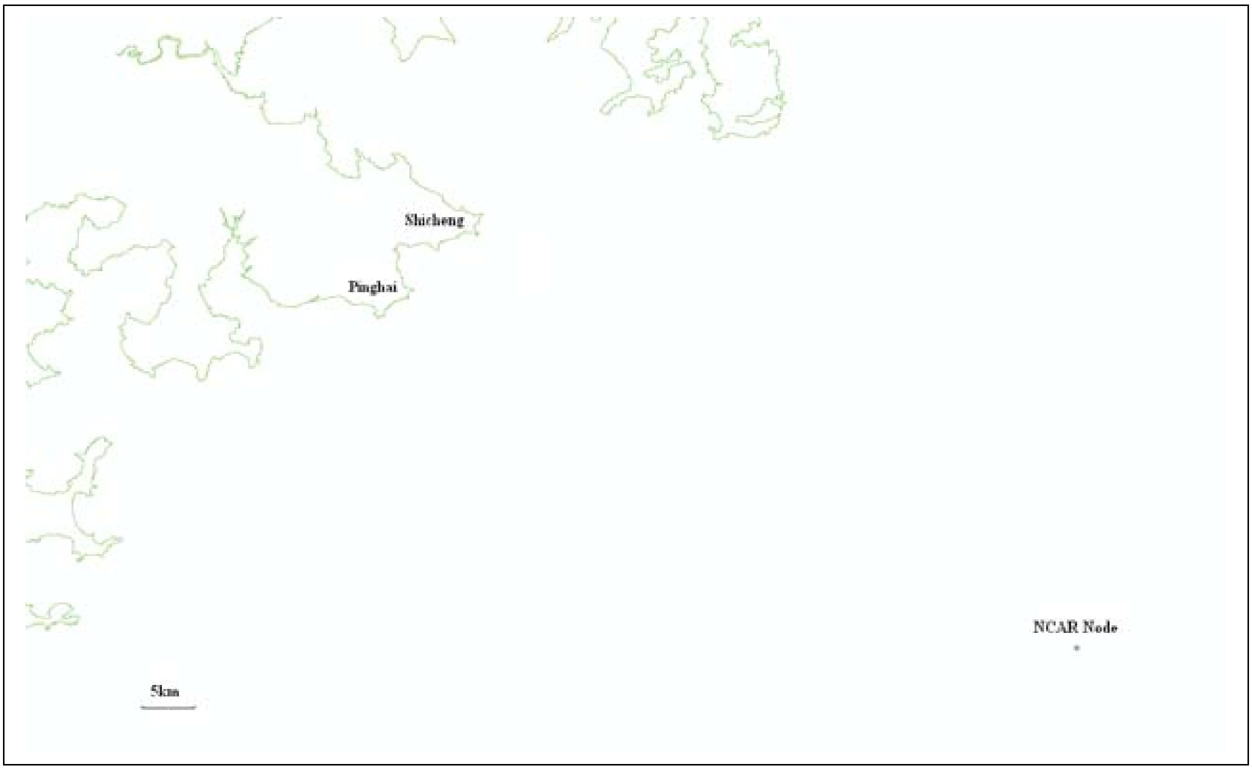

Figure 2 - NCAR Node at 120E 25N around 70km away from Shi Cheng

As a result of the aforementioned limitation on wind speed accuracy a coarse resolution of 500 m was chosen to create the wind resource map shown in Figure 3 as opposed to the higher resolution of 50 m that would typically be used for an actual wind farm development using measured data. The wind resource has been modelled using at a nominal wind turbine hub height of 90 m. It is important to note that wind resource maps produced by wind flow models using coarser resolutions will indicate lower average wind speeds than finer resolution maps because they average out higher wind speed areas on topographic features. Thus there will be an increase in the range of wind speeds with increasing model resolution. For sea areas this effect will be less obvious than for land areas with topographic relief.

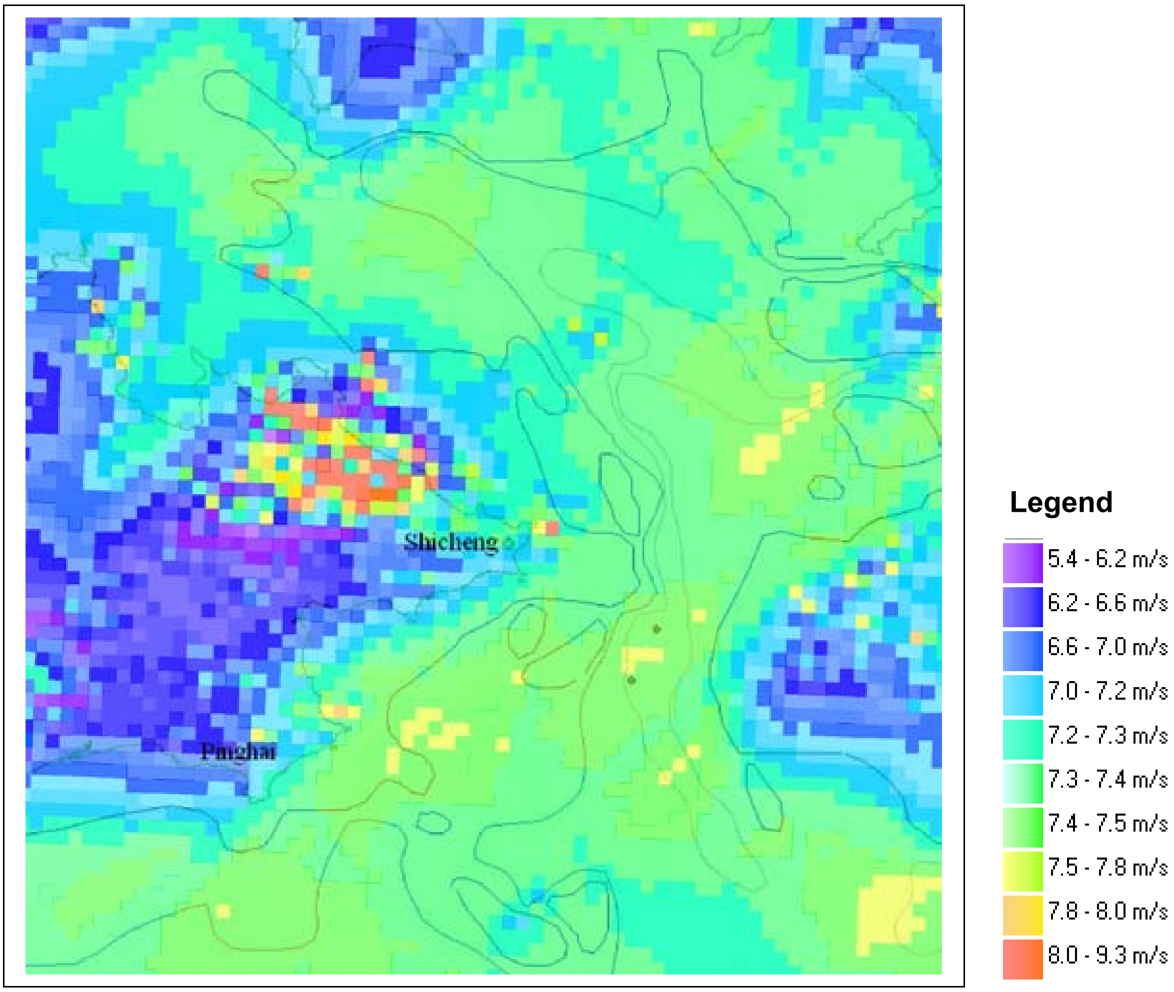

Figure 3 - Wind Resource Map Modelled at Height of 90m and Grid Resolution 500m

What is interesting to note from Figure 3 is that the best wind resource is appears to be onshore (presumably due to elevated topography) to the northwest of Shicheng, with the best offshore resource bounded by Shicheng, Pinghai and Nanri Island. The offshore wind speeds just meet the criteria for further investigation as suggested above in the interval between 7.0 m/s and 8.0 m/s. For the purpose of better distinguishing wind resources offshore for later wind farm design, the legend is divided into smaller intervals between 7.0 m/s and 8.0 m/s in Figure 3.

As long-term measurements from the field enable the most accurate estimates of the wind resource, when measured wind speed and wind direction data become available from meteorological masts on or adjacent to the suggested wind farm site the resource map in Figure 3 should be revised using these measured data, which would ideally be corrected to reflect long term wind speeds. It is also recommended that a more representative surface roughness map is produced based on information gained from a detailed survey of ground cover for the second revision of the wind resource map.

A UNDP wind measurement project was undertaken in Shi Cheng (see Figure 1) and Shi Jing which concluded that the annual average wind speed at 70 m height was 8.045 m/s. The wind resource map of Figure 3 shows wind speeds in the vicinity of Shi Cheng to be lower than this, which may result from various reasons, such as low resolution of the wind resource map which will miss small areas of high resource on hills, low accuracy of the roughness classification that may artificially reduce the extrapolated wind speed to higher levels, and uncertainty about the long term correction of the UNDP data which may result in a lower long term average than actually measured. Further investigated around Shi Cheng could be conducted to help reconcile the model with measured data.

4.4.1.2 Sea Depth

Water depths of 0 – 25m cover the range that is currently being targeted by offshore wind farm developers in Europe and North America. Water depths from 25 – 50m could potentially be exploited in the future, as has been demonstrated by the Beatrice project in the Scottish North Sea, which is a demonstration project deployed in approximately 50m of water. For the purpose of discussion this report will only consider the 0 – 25m water depth range.

From the Pinghai Peninsula sea depth map presented in Figure 4 it can be seen that the water depth only exceeds 25m in the channel between the mainland and Nanri Island. The channel between the mainland and Nanri Island would most likely be avoided due to the potential for fast currents to undermine the turbine foundations, which at the low depths shown would most likely be gravity bases and or monopiles.

The area of highest wind resource in Figure 3 coincides with the sea depths of less than 25m enabling flexibility with regard to layout design. It is worth noting that it should be possible to exploit areas father from shore that are likely to have a better wind energy resource should those areas closer to shore not appear to be attractive.

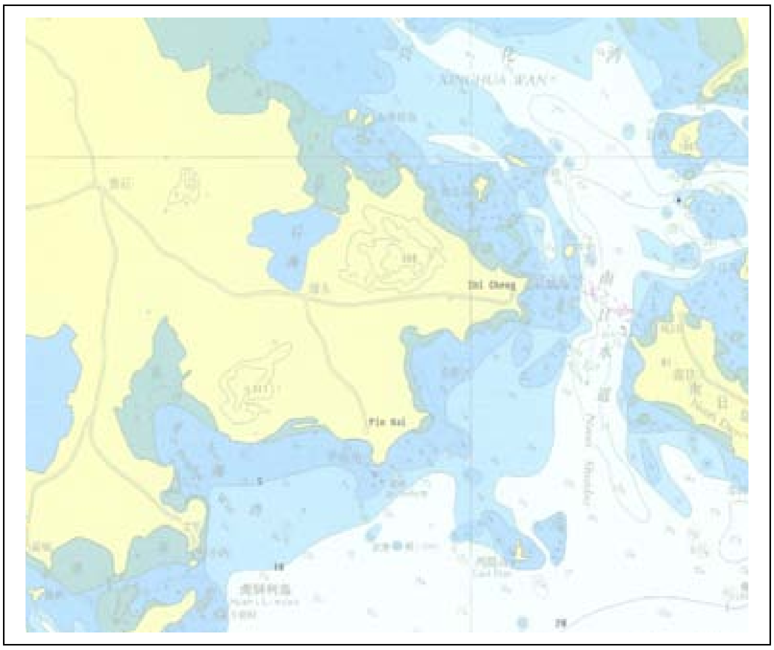

Figure 4 - Sea Depth Map around Pinghai Peninsula

4.4.1.3 Wind Farm Shore-Side Boundary

A second criteria placing the wind farm shore-side boundary greater than 10 km from the shore is arbitrary. When the wind blows from the mainland out to sea the effect of the land in terms of reducing wind speed and promoting turbulence can prevail for as much as 50 km from the coast. As the primary reason for taking wind farm developments offshore is to exploit higher wind speeds and reduced turbulence levels compared to onshore some degree of separation between the coastline and the wind farm boundary is desirable.

To specify an appropriate separation between the coastline and an offshore wind farm boundary, detailed knowledge of local wind character is required and of particular interest is the wind rose. If winds blow towards the coast then separation can be less compared to that required where winds blow mainly from the mainland to the coast. In the case of Fujian province it is known that the predominant winds are approximately parallel to the coastline, and although this may suggest that wind farm spacing to the coast could be reduced, it must be noted that the coastline is not straight and therefore significant influence may be felt from upwind land areas. Offshore wind speed measurements will therefore be essential to enable determination of an appropriate location for the offshore wind farm boundary.

The coastal topography is also extremely important as the influence of topographic features, for example hills and ridges, can propagate for many times their height. A recognised rule of thumb is that the influence of a topographic feature on wind flow can extend for 20 times the height of the feature. In SgurrEnergy's experience this is an underestimate.

The wind rose obtained from UNDP (Figure 5) wind measurement project shows that the prevailing wind blows from the northeast which means that the wind generally blows towards the coast and there is therefore less reduction of wind speed due to the coastal topography. This should enable selection of a near shore location which will have reduced capital and operational costs without corresponding reduction in annual energy production, leading to a lower cost of electricity production. This near shore location will be subject to the same or similar constraints as any other location and compromises will have to be made to take account of other activities and interests that are discussed in more detail below.

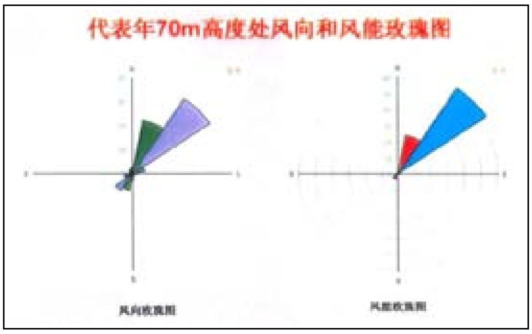

Figure 5 - Wind Rose from UNDP wind measurement project[1]

4.4.2 Constraint Mapping

The methodology described in the section above will enable identification of fairly large areas that could be exploited for the purpose of offshore wind farm development. These areas need to be overlaid with constraints that can be many and varied. A selection of these is discussed below.

4.4.2.1 Shipping Routes

Shipping routes in Europe follow well defined corridors marked by navigation buoys and are concentrated around major ports. Offshore anchorages are often used to decant material from large ships that may not be able to gain access to ports into smaller more navigable ships. Potential risk level of hazards to both wind turbines and vessels are associated with vessel types. In a scenario involving a larger ship, it is expected that a head-on collision at steaming speed would lead to the collapse of a turbine. In terms of smaller vessels such as fishing and recreational craft, the worst case scenario would be risk of damage leading to sinking of the vessel.

[1] Provided by Fujian Climate centre and CMA

It would normally be possible to define shipping corridors and constraints around offshore anchorages based on information presented in navigation charts and discussions with relevant statutory bodies.

In the seas around the Pinghai Peninsula, there are no major shipping routes. However, there is a ferry route from Shi Cheng to Nanri Island and some small offshore anchorages exist. Discussions will have to be held with the relevant authority to determine what an appropriate buffer should be applied between the ferry route and the anchorages. For illustration it is assumed that a 100 m buffer will be acceptable, which is illustrated in the constraint map in Figure 6 at the end of the report.

4.4.2.2 Fishing Grounds

Fishing grounds can be very important for local and national economies and must therefore be treated with a high degree of sensitivity. Discussions with government bodies and relevant stakeholders are therefore advised at an early stage, such that these areas can be clearly identified on the constraint map as illustrated in Figure 6.

Fisheries may be affected by construction activities, construction and operational noise and vibration, electromagnetic fields and habitat modification. The noise and vibrations from the construction phase will be the result of increased vessel activity in the area and excavation works when ploughing to install the power cables and during foundation installation. The increased noise in the area during construction phase will be temporary, a factor that should be considered when applying mitigation particularly to sea mammals. The presence of the marine electrical cables may cause electromagnetic interference on particular fish species and also on sea turtles which are known to navigate over long distances back to their birth beaches by means of magnetic imprinting, therefore consultation with those that are an authority on particular marine species in the area of interest is important. However, by the pre-armouring and burial of the cable to a depth of 2m or more below the sea bed, the impact from the wind farm cabling system is thought negligible as the influence from the cables will be less than the normal background magnetism. To determine whether this would be possible site investigation work would have to be undertaken to understand the sea bed geology.

Habitats and feeding grounds could be lost and/or disturbed as a result of construction of the foundations and the cable-laying activities. On the other hand, foundations can create a hard substrate where none existed before, this allows colonisation by marine flora and invertebrates, which subsequently attracts larger fish for feeding. The end result is similar to the creation of an artificial reef, a practice which is now common along the coast of China to reduce the negative environmental effects of over-fishing. Therefore offshore wind farms may complement marine conservation zones and may assist in the enforcement of no-fishing zones for commercial vessels.

Significant discussion with appropriate authorities is required at an early stage in the development process to ensure that the effects of offshore wind farm development on fisheries is acceptable.

4.4.2.3 Radar

Wind turbines have the potential to interfere with military and civil aviation and shipping radar operations due to reflection and shadow effects. Two radar installations have been identified near Pinghai Peninsula with 15 km radius and 30 km radius zones. One is located about 21km in the northeast direction of Shi Cheng and the other one is approximately 19 km from Pinghai in the southwest direction. Figure 6 shows these installations together with notional buffer zones of 15km and 30km.

Radar is employed to track civil and military ship and aircraft movements and release of detailed information about these installations has not been possible. However, as large wind turbines can have an impact upon radar installations it is essential that planning is undertaken to enable turbines to be sited in locations that are not in the *field of view* of radar installations.

The 15km and 30km buffer zones shown in Figure 6 are simply for illustration. The actual exclusion zones required by the radar installation operators could potentially restrict construction of any offshore wind farm development in the vicinity, highlighting the need for early consultation and production of a high level constraint map to rule out areas at which it will not be possible to build wind farms due to radar interference.

4.4.2.4 Major Infrastructure Constraints

Wind turbines have the potential to disrupt local communication systems. The routes of major power cables, gas and oil pipelines, gas and oil platforms, telecommunications links and cables all need to be clearly identified and appropriate safeguarding zones defined around these.

A telecommunication cable has been identified which runs from the east end of Nanri Island and passes the area of interest. Most telecom companies in UK prefer wind turbines to be at least 150 m from fixed links, a constraint shown in Figure 6.

4.4.2.5 Grid Connection and Capacity

Nodes into which offshore wind farm power export cables can be connected and the capacity of these nodes must be identified and specified.

This issue is crucially important as it will have a major bearing on the likely project economics. For example, as the distance to a point of grid connection increases the overall cost will increase. However, larger projects will be more able to accommodate being farther from a point of grid connection compared to a small project.

Figure 7 shows the Putain grid where there is a mixture of 500 kV and 220 kV substations with a total capacity in excess of 700 MW. Discussion would be required with the appropriate authorities to establish what the future plans for this network are, how much capacity will be available in the future and where the most appropriate points of grid connection are located. Ideally, if available in the appropriate GIS format this map could be included in the constraint map of Figure 6 to better understand the options for grid connection, particularly with regard to the offshore cable route.

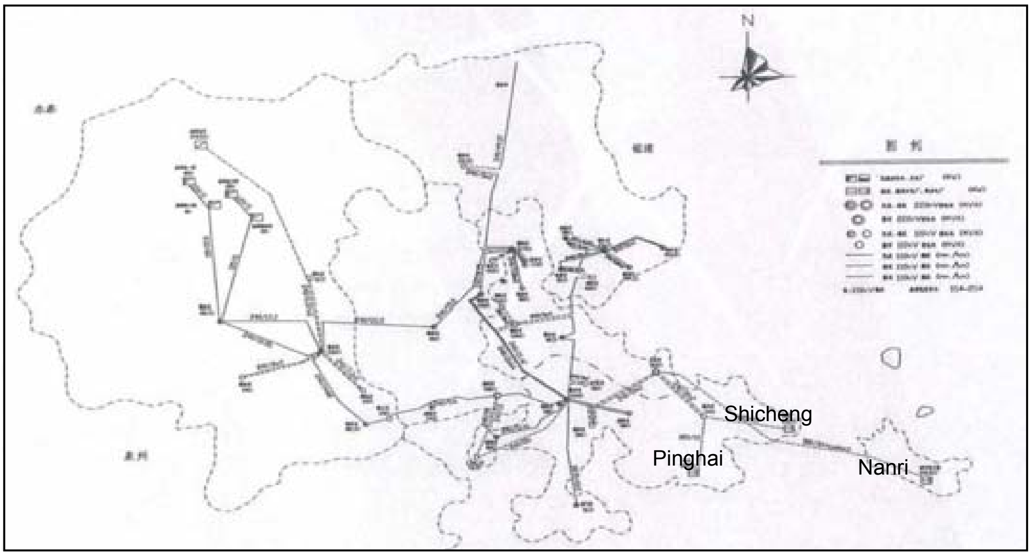

Figure 7 - Putian Grid[2]

With regard to historical data, the peak demand of electric power in PingHai Peninsula in 2005 was approximately 86 MW. It is estimated that the demand for electric power will increase at a rate of 17.2％ each year from 2005 to 2010, giving a likely peak demand by 2010 of 189 MW. Anecdotally therefore there is the likelihood that PingHai Peninsula will be able to absorb power from a significant offshore wind farm in the near future.

4.4.2.6 Lightning Damage

Lightning is a phenomenon that has often caused severe damage to wind turbines. During summer time lightning is an issue near Pinghai Peninsula. To minimise the damage from lightning hitting a turbine, a turbine can be equipped with a lightning protection system. The primary damaging effect of the lightning current is a direct one and related to the current carrying capacity of the protection system. This effect can damage blades by penetrating at unwanted locations or melting down the protection system and can damage bearings by melting down material from balls and raceways. The secondary damaging effects of the lightning current are indirect and related to the mechanical forces coming with the high pulse energy and also to the raising of earth potentials and/or induction of high voltages in wiring. The mechanical effects can crack or rupture blades and the raising of earth potentials can damage the electrical installation by breaking down the insulation or overloading sensitive components.

Statistics on damage due to lightning strikes show that the rotor blades seem to be the most vulnerable components. In addition they show the highest repair costs and the longest downtime.

It is to be expected that damage due to lightning may influence the cost effectiveness of offshore wind farms to a large extent for the following reasons:

- Costs for repairing lightning damage are higher offshore than onshore, because more expensive transportation equipment (supply vessels or helicopters) and cranes are needed.
- The downtime for certain damage events and thus the revenue losses will be higher because repair can only be carried out if the weather conditions are suitable for the equipment.

Before developing an offshore wind farm, it is necessary to gain insight in the effects of lightning on the operational costs. Aspects that contribute to the cost of lightning damage and which are covered with uncertainties are among others the following:

- The frequency of thunderstorms and lightning flashes at an offshore location.
- The amount of damage resulting from a lightning strike (which is strongly dependent on the lightning protection of the turbine) and the material costs.
- The actions needed to repair the damage, including costs for personnel and hiring transportation and lifting equipment.
- The downtime and revenue losses due to time needed for mobilisation of necessary equipment and time waiting for good weather conditions.

The lightning information available in this area is recorded in Putian City. However, it can be used as a reference to the offshore area near Pinghai Peninsula to quantify the risk and apply mitigation as appropriate. By including statistical data on lightning strikes as a layer in the constraint map it will be possible to avoid any areas that, for whatever reason, have an uncharacteristically high incidence of lightning strikes, thus mitigating the risk posed by this phenomenon.

[2] Provided by Fujian Climate centre and CMA

4.4.2.7 Typhoon Damage

Typically, wind turbines will produce electricity when the wind speeds are in the range of 3 to 25 m/s. The wind turbine will shut down when the wind speed is above 25m/s to avoid damage, however some turbines continue to operate in winds up to 35 m/s to extract maximum energy from these powerful storms. Where strong typhoons have impacted upon wind turbines the damaged parts are not only blades and nacelles, but also structural elements including tower and foundations. Fujian province is a typhoon-prone area which poses a challenge to wind turbine designs and their backup systems. Fortunately due to the shelter of Taiwan Island, extreme wind speed is reduced as the strongest typhoons lose much of their energy over Taiwan before making landfall on Fujian province.

According to work undertaken by the Fujian Climate Centre and CMA for the Pinghai area[3] the extreme wind speed of 98% typhoons that affected the potential offshore wind farm area was less than 25 m/s, only 2% of the wind speeds were in the range 25 - 30m/s and no wind speeds were recorded above 30m/s. This work is summarised in Figure 8. However, the highest extreme wind speed recorded in Fujian province was 75.8m/s[4] which exceeds the IEC Class I extreme wind speed of 70m/s and underlines the need for special attention to be given to the extreme wind speeds likely to be observed during typhoons.

It is important to note that one of the main reasons for damage of wind turbines by typhoons in south China is due to the loss of grid power as the typhoon advanced over the coast. In this case, wind farms without adequate backup power will leave the wind turbines locked in emergency shutdown mode, a condition in which they are unable to follow the wind direction and feather the blades appropriately. In this situation the wind turbines are vulnerable to damage from winds blowing from the side or the back of the turbine, a condition which is likely to cause blade damage. In extreme cases the unbalanced forces cause the turbine tower to buckle or even the foundation to overturn. Therefore insurance against typhoon damage includes not only correct wind turbine selection, but also correct design of backup power systems to keep turbines operating during major storms.

[3] Fujian Climate Centre and CMA report on the typhoon record around Pinghai since 1950

[4] World Meteorological Organization, http://www.wmo.ch/pages/mediacentre/bilis_en.html

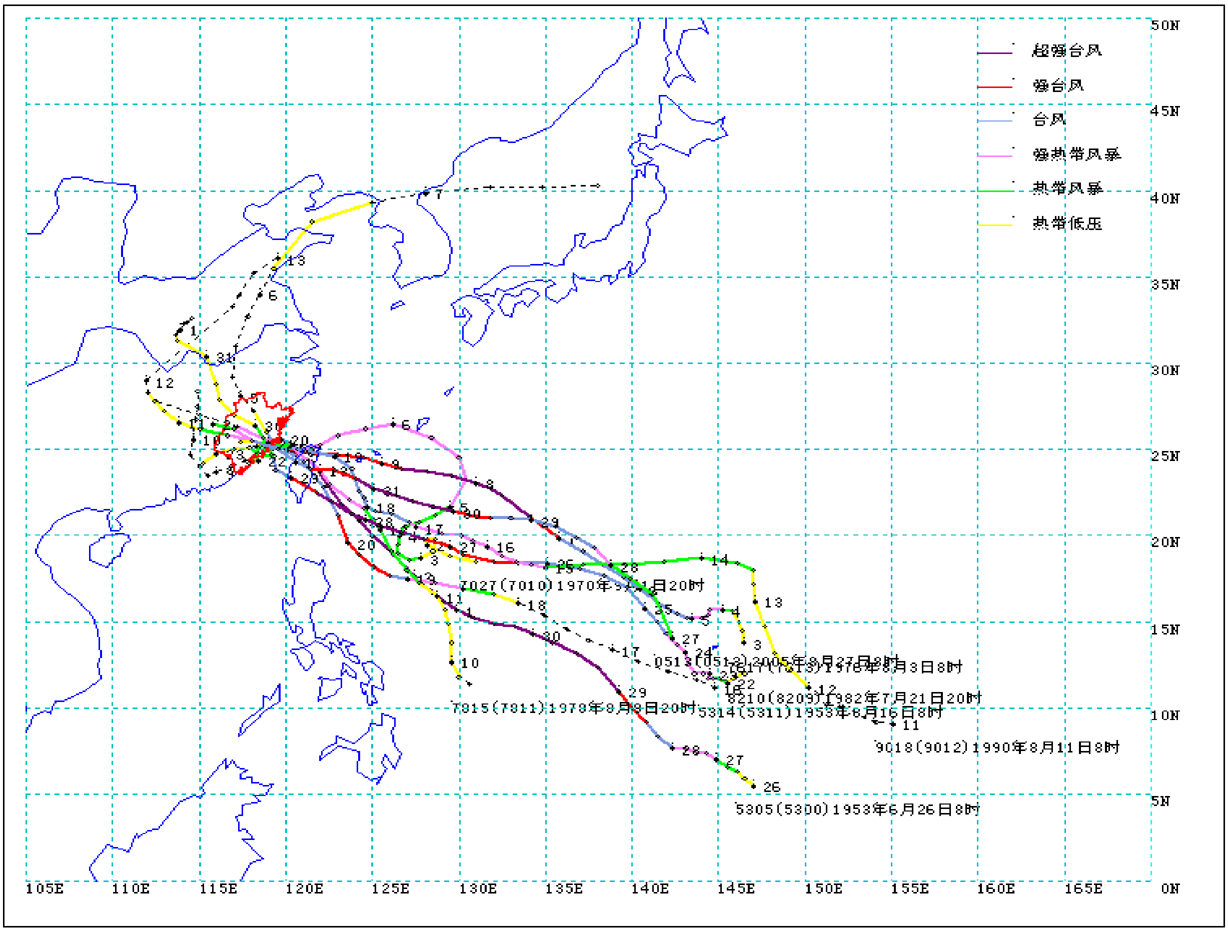

Figure 8 - Typhoon Routes[5]

It will be essential for the development of offshore wind farms in the Fujian province to produce maps showing the probability of encountering extreme wind speeds for the two main IEC classifications, namely IEC Class I, 70m/s, and IEC Class II, 59.5m/s. This map will further develop the constraints map shown in Figure 6 and enable buildable and financeable sites to be identified as the risk of typhoon damage will have been adequately quantified.

4.4.2.8 Environmental Constraints

Environmental constraints will require early consultation with the relevant statutory authorities. Such constraints can include, but are not limited to the following:

- Designated or considered world heritage sites or areas over which there are special protection orders, such as reefs.
- Bird, fish or sea mammal breeding areas.
- Bird, fish or sea mammal migration routes.

Detailed maps of the location of such areas are required to enable these to be added to the constraint map shown in Figure 6. To date no such information has been made available.

[5] The affected typhoon routes is from proposal of Fujian Climate centre and CMA

4.4.2.9 Naval/Military Exclusion Zones

Areas of the sea could potentially be excluded due to the requirements of the military, for example missile or other weapons testing whereby munitions are fired from the coast into the sea. Similarly, certain areas of the sea may be used for sea trails for ships or other equipment or naval exercises. SgurrEnergy does not need to know what activities are likely to be conducted in such areas; all that is required are the co-ordinates of exclusion zones such that appropriate constraint maps can be constructed as outlined in Figure 6.

4.4.2.10 Archaeology, Wrecks & Munitions

Areas of the seabed may be protected due to the presence of archaeology that has now below sea level, ships that have sunk due to weather or warfare or munitions or other hazardous materials that have been dumped at sea and should remain undisturbed. Such areas must be included in the constraint map shown in Figure 6.

4.4.2.11 Mineral Extraction

Areas of the seabed can be designated for the purpose of mineral extraction by dredging. During the Fujian site visit mineral extraction was being undertaken by a number of large vessels that could be seen from the Nanri Island ferry. If areas of the seabed have been reserved for mineral extraction these areas and the access and egress routes must be identified for the purpose of constraint mapping.

4.4.2.12 Noise and Visual Impact

Placing wind farms in the offshore environment is in itself mitigation regarding noise and visual impact and these issues are unlikely to have a determining impact upon the siting of offshore wind farm location.

As a matter of good practice it would be sensible to produce noise contours to ascertain whether there was likely to be a negative impact as a result of both construction and operation of the proposed wind farm.

Visual impact is considered with regard to wind farm layout design discussed in Section 5.

4.4.2.13 Aviation and Marine Safety

Turbines may cause physical hazard to aircraft flying down to 300 m, and increase risk to aircraft flying or ships sailing at night or in adverse weather. Therefore, on completion of a provisional design that shows the actual height and area of a proposed development it is essential that early discussions on aviation and marine safety are undertaken with the appropriate authorities as constraints imposed by these authorities may have an impact on the final wind farm design.

4.4.2.14 Seabed Geology and Seismicity

It will not be possible to suggest a foundation design appropriate for the sites in question without developing a better understanding of the seabed and its associated seismic risks. A critical component here is the location of the local geological fault systems and appropriate separation from these areas. No information on the fault zones has been provided to SgurrEnergy and therefore this cannot be included in the constraint map shown in Figure 6. Fujian province faces a seismically active region offshore as the island of Taiwan has a high frequency of earthquakes due to its location on a transverse geological plate boundary. As for the issue of typhoons, wind turbines can be designed to operate in challenging environments, however adequate information is required to make the engineering and financial decisions.

4.4.2.15 Sea State Averages

General long term sea state conditions are used to compare sites for their relative weather windows and delay risks for during wind farm construction, for the expected wind farm accessibility during the operation phase.

Knowledge of sea currents is also very important with regard to positioning wind turbines as strong currents can undermine the turbine foundations.

If such information were available it could be added to the constraint map of Figure 6 such that the sea state could be considered during design of the wind farm layout.

4.4.3 Outline Wind Farm Design

The exercise described in this section has enabled the simplified constraint map presented in Figure 6 to be produced. As information described in the sections above becomes available it can be added to the constraint map to provide a very detailed picture of what areas are technically, environmentally and politically suitable for development of an offshore wind farm development.

Using the information available, provisional design for a large scale wind farm will be produced based on the most appropriate technology. This process is described in Section 4.5 below.

4.5 Turbine Selection and Layout Design

Some knowledge of seabed conditions is required to gauge which foundation type is most appropriate. For example, gravity base, piling and related techniques are very influenced by the geology and condition of the seabed. As we do not have any information on seabed conditions in terms of geology or seismicity at this time the turbine foundations will not be considered further.

4.5.1 Turbine Selection

Wind turbines are available in various sizes from a number of wind turbine manufacturers, agents and developers. Size however is not the only aspect of the wind turbine that should be thoroughly investigated by developers when deciding which turbine to use with their project.

The main technical and commercial considerations in turbine choice are:

- The wind profile and wind speeds at each specific site need to be evaluated to identify which turbine is suitable for the particular site conditions. As the wind turbine itself may be as much as 50% of the total project cost it is vital that it produces optimal electricity for the given site.

- Economics – Larger wind turbines tend to cost less per kWh produced and make better use of good sites.

- Availability of wind turbines. Due to the high demand for wind turbine, lead times can be long and turbines difficult to procure for smaller sites.

- Access to the site and transportation issues.

Wind Turbine Selection Should Reflect:

- Wind profile at site
- Technology availability
- Electricity production and investment cost
- Experience of similar models
- Experience of similar climatic conditions
- Size of site
- Capacity availability at grid access point
- Noise level certification
- Warranty and maintenance costs
- Insurance

These considerations are usually investigated at a later stage in the development process. It is also useful to consider some of the main planning issues affecting wind turbine choice.

Larger turbines will have higher hub heights giving better exposure to the wind and longer blades. Higher hub heights will be more visible to radar, telecommunications and people. Therefore a full visibility assessment must be carried out to ascertain whether there are any problems and design appropriate mitigation.

The constraint map of the proposed area for wind farm development around Pinghai Peninsula does not have many constraints (with the possible exception of radar) and therefore there may be adequate space to place large wind turbines. The initial assessment would indicate that it is technically possible to use 4.5 MW wind turbines with rotor diameter from 120m to 130m and hub height between 90m and 124m. For the purpose of the design a rotor diameter of 120m with a hub-height of 90m shall be employed.

4.5.2 Conceptual Wind Farm Layout Design

Within the technical constraints of the site, turbine layout design was guided principally by four considerations:

- Physical Location: mean wind speed, water depth, seabed characteristics, sub-surface geology, coastal processes, seascape and landscape assessment.
- Biological Environment: protected areas, habitat type and character, and marine life (benthos, fish, bird, mammals, etc.).
- Human Environment: electrical infrastructure, economic development opportunities, tourism / leisure, archaeology, navigation, fisheries, port facilities, civil and military aviation industry, radar facilities.
- Performance: turbine spacing, array alignment, infrastructure optimization, turbine selection.

Studies show that birds can collide with wind turbines in significant numbers. Cumulative negative impacts with an increasing amount of wind turbines must be taken into account, especially for wind farms developed along fixed bird migration corridors. Proper wind farm layout design plays a very important role in limiting the impact of wind farms on nature. However, without the necessary information to include in the constraint map of Figure 6 it will not be possible to take these and other crucial issues into account. However, a corridor was applied to be used by endangered and threatened species such as the Black-faced Spoonbill. The Black-faced Spoonbill is a migratory species that flies north in early spring when they leave their wintering sites to accomplish the mission of breeding. Satellite tracking was performed which indicated that birds from the Tsengwen estuary moved to northern Taiwan and onwards to the coast of northern Fujian.[6]

It was seen to be of key importance to design a wind farm layout that minimized the visual and landscape impacts when viewed from the coast for a given number of turbines. Normally for large capacity offshore wind farm, linear layout was employed to improve visual acceptance and ease marine navigation.

4.5.2.1 Turbine Layout Optimisation

The area lying offshore from Pinghai Peninsula between Pinghai and Shicheng has a water depth below 10 m and a reasonably flat seabed. There is adequate space to locate a large number of high capacity wind turbines.

In the offshore environment the low turbulence means that a larger distance must be observed between individual turbines. Onshore inter turbine spacings of 4D – 6D are normal, in the offshore environment this can increase to 6D – 10D.

Another difference between the process for offshore layout design compared to onshore is that there is no topography to exploit, enabling a grid layout to be employed, which has further advantages during construction.

The selected turbine layout design spans approximately 9km north to south and approximately 9.3km east to west (at its widest point) with in-row distance of 6 rotor diameters and distance between rows of 9 rotor diameters. This was felt to minimize landscape and visual impacts as far as possible and allow for positive visual effects. Figure 9 exhibits the proposed 60 turbine layout of the wind farm.

- First phase wind farm designed to have 121.5MW capacity with first row of 6 turbines and the other three rows of 7 turbines each covering approximately 23.5km^2.
- Second phase wind farm 148.5MW capacity with two rows of 6 turbines and 3 rows of 7 turbines covering approximately 27km^2.
- An offset of 0.5 rotor diameters in-row distance for every second row was designed to reduce wake losses and optimize energy production.
- The corridor between the two diamond grids for the proposed two phase development was essential for bird migration.
- All the constraints such as wrecks, shipping routes, no fishing zone were excluded from the wind farm area. The tidal flow channel with deep sea depth was also excluded to avoid scouring.

[6] www.ktmc.edu.hk/bio_web/f6endanger.doc

- Wind turbine foundations were located in water depths below 10 m to reduce deep water installation costs while minimizing exposure to breaking waves. Most of the proposed turbines were chosen to be placed on relatively flat seabed to avoid construction on steep slopes.

- Wind turbine rows were not oriented perpendicular to dominant wind direction (northeast) but have a 30 degree angle with reference to horizontal because of alignment with sea depth contours to avoid areas of strong current from tidal flow in the adjacent water natures.

- Power cable connection to shore is short as there is one substation at Shicheng.

- Minor effect on energy production of existing land wind farms.

- Parallel rows of wind turbines make attractive visual geometry from beach to enhance the tourism development potential of the area.

- An array losses calculation was carried out for the proposed wind farm. The calculated array losses are 8.4%, annual energy production is approximately 54GWh and the gross energy yield capacity factor is 22.7%[7].

[7] In practice therefore a capacity factor of less than 23% is more likely.

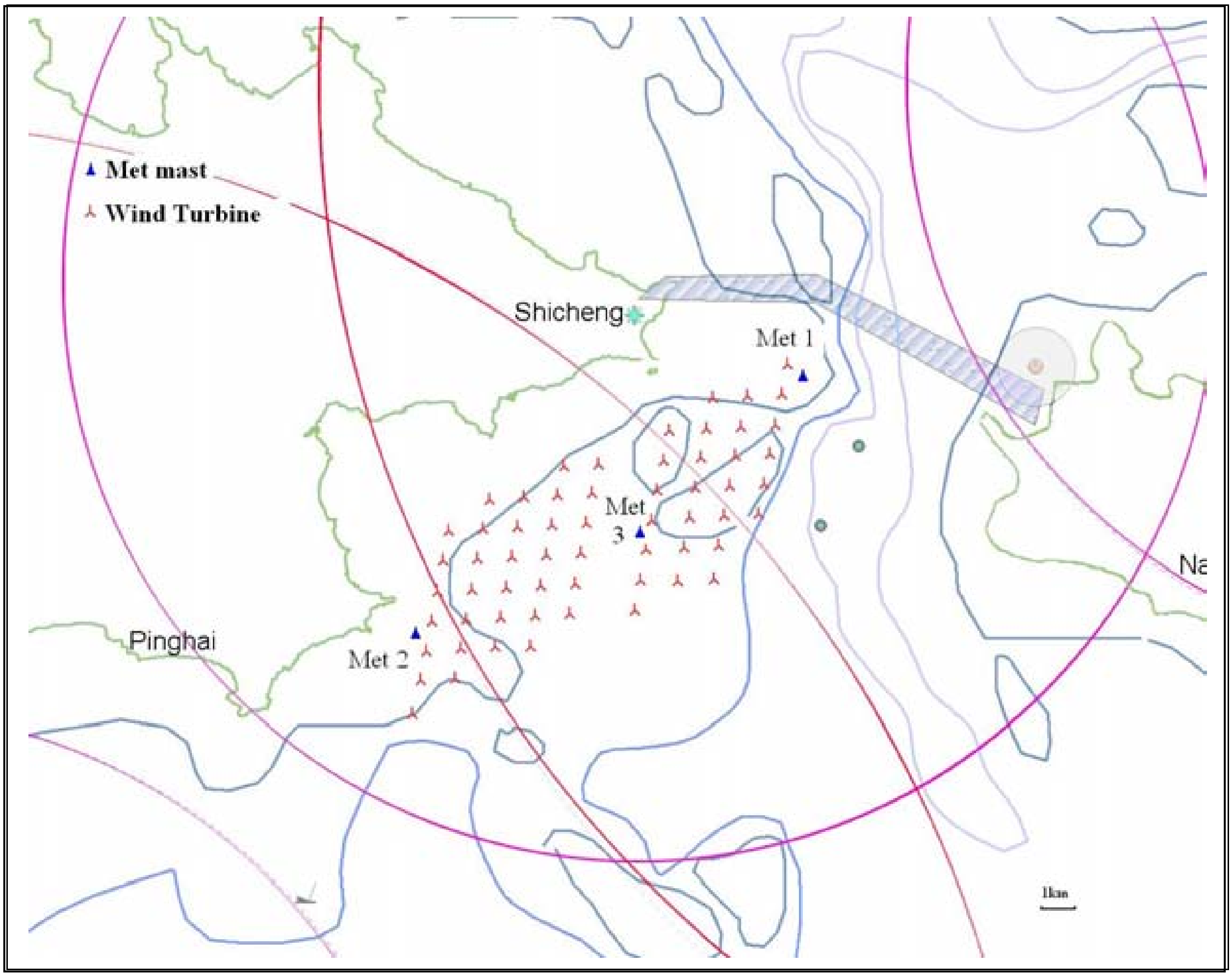

Figure 9 – Provisional Wind Farm Layout

The first point to note is that with a capacity factor of 22% it is unlikely that this example of an offshore wind farm would be economic. Although there is a high uncertainty associated with this calculation and measurements from Shicheng suggest a higher wind speed than that predicted form NCAR, a capacity factor in excess of 30% might not be observed at this site. Therefore, the design process would need to be repeated for a number of locations, more likely farther offshore, until suitable opportunities arise for which more detailed work on costing can be undertaken.

It is also worth commenting on the measurement strategy. Far from the coast a single meteorological mast will be representative of a wide area as wind flow is likely to be very uniform. A single mast will therefore cover an area spanning several kilometers. In this particular location it is unlikely that one mast will be sufficient to represent the site as wind flow will be affected by many factors for example the topography of the shore and the adjacent islands. Therefore one mast could be positioned in an anomalous location of high or low wind speed that cannot be modeled accurately. Consequently, without a second mast to check the wind flow model against there is a significant risk of overestimating or underestimating the wind speed over the site and therefore the annual production from the wind farm. Therefore a single mast is acceptable for a site several kilometers from the nearest land mass but very high risk for sites near the coast.

To mitigate the energy yield prediction risk at this coastal site more than one mast would need to be deployed. The more masts the lower the risk to the energy yield prediction. Two masts located in the centre of each of the wind farm arrays would be better than a single mast on the Met 3 location in Figure 9. However, modeling wind flow near the coast is likely to have the highest uncertainty, which will remain high with two masts remote from the cost. In the example of Figure 9, a compromise arrangement would be to install anemometer masts onshore at suitable locations near to Met 1 and Met 2.

5 MONITORING STATION SITING AND SPECIFICATION

5.1 Background

All discussions up to this point have related to the methodology for offshore wind farm development only and it is application of this methodology that will lead to the specification of an appropriate offshore met mast and instrumentation. For this reason a met mast specification will be produced which is specific to the Pinghai example.

5.2 Monitoring Station Siting

- Three met masts were proposed to set up at positions of upwind, downwind and the corridor (shown in Figure 9), which can be used later to calculate wake losses based on site measurements. Met 1 at upwind of the conceptual wind farm should be set up the earliest and can be used as permanent met mast after the construction of the whole wind farm. The second met mast to be set up is Met 2, at downwind direction along the coastline. Met 3, which is slightly farther away offshore, can be built the last during the construction of the wind farm between phase 1 and phase 2.

- Three sea state monitoring stations also need to be set up at where met masts are located.

5.3 Equipment Specification

5.3.1 Station Design

Offshore wind monitoring stations have been set up with different designs around the world, and their structures are also evolving with time as new wind measurement technologies are adopted in the wind power industry. The choice of station design will be determined by the purpose of the tower, how long it will be left on site, the project budget, and the complexity of the wind resource or environment in which the wind farm is being built. As a simplification there are three broad classifications for offshore wind monitoring stations, these are:

a. <u>Research platforms</u>

- Usually large and expensive structures.
- Intended for long term deployment in a region to benefit the collection of data for developing a large wind farm zone.
- Important for collecting long term baseline data on atmospheric and marine environments, this baseline will assist with the analysis of shorter term measurements in the region from commercial monitoring towers.

- The research platforms are designed for ease of access under most weather conditions (they may have helicopter landing facilities), and they may have short term accommodation for research personel.

- The platforms are intended to have maximum flexibility to set up different monitoring systems. Data collection strategies may be changed when more is learned about a new operating environment and additional types of monitoring are needed, or if new technologies become available to improve the range of monitoring. The knowledge gained from the research platform can be applied to reduce costs and improve monitoring reliability at short term commercial monitoring towers in the region.

- Research platforms are generally supported by government funding with the purpose that all data is publicly available. This investment of public funds is considered beneficial as the published research information assists commercial wind farm developers to reduce their wind farm development costs, and therefore to reduce the price of wind generated electricity delivered to the public.

- Examples of offshore research platforms include FINO 1 (shown below in figure 10) and FINO 2 in Germany. FINO 3 is now under development for the investigation of wind farms in deep water.

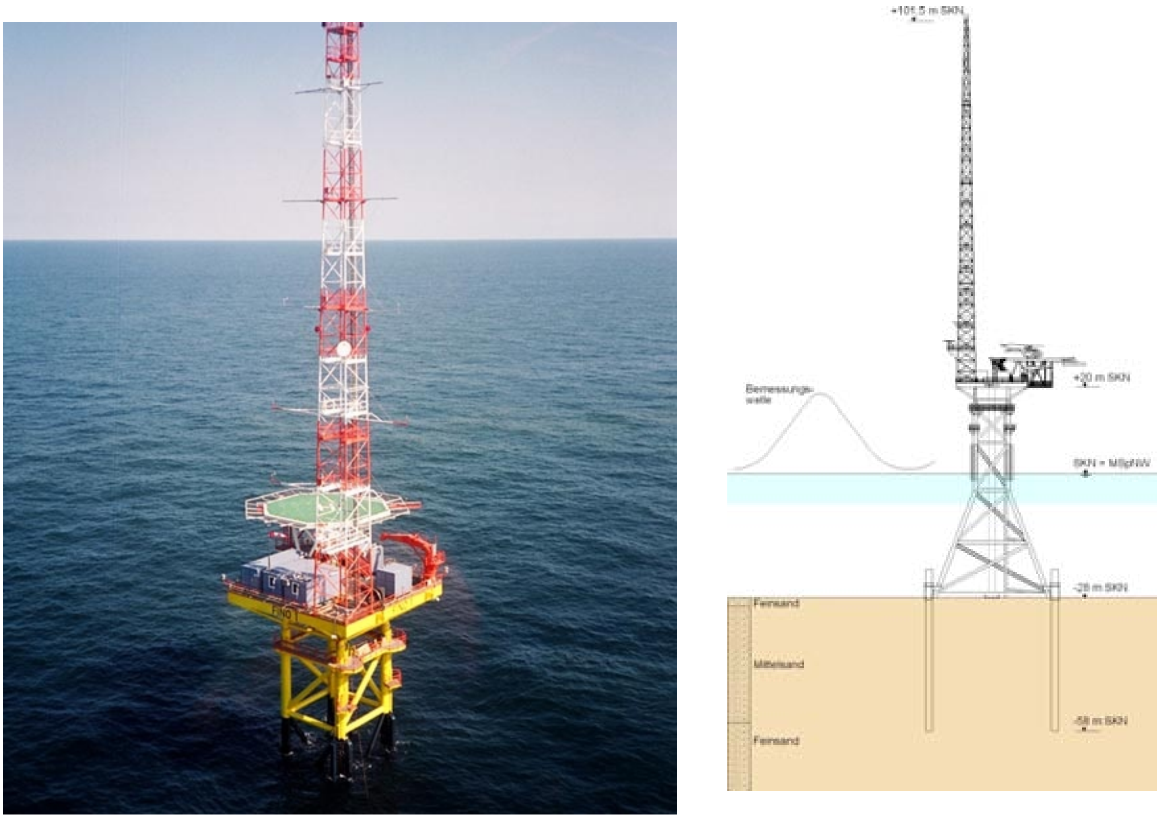

Figure 10. Photo and schematic of FINO 1 research platform.

b. <u>Commercial long term platforms</u>

- Designed to measure wind and marine data at a specific wind farm site.
- Reduced flexibility for changing monitoring systems, the station design is intended to provide essential monitoring at a reasonable price.
- The platform may be used for the initial wind resource and site assessment and then may continue to be used as a permanent station for turbine performance monitoring after the wind farm construction.
- Presently, most offshore wind monitoring stations are of this type, a typical example is the Amrumbank monitoring tower shown in figure 11.

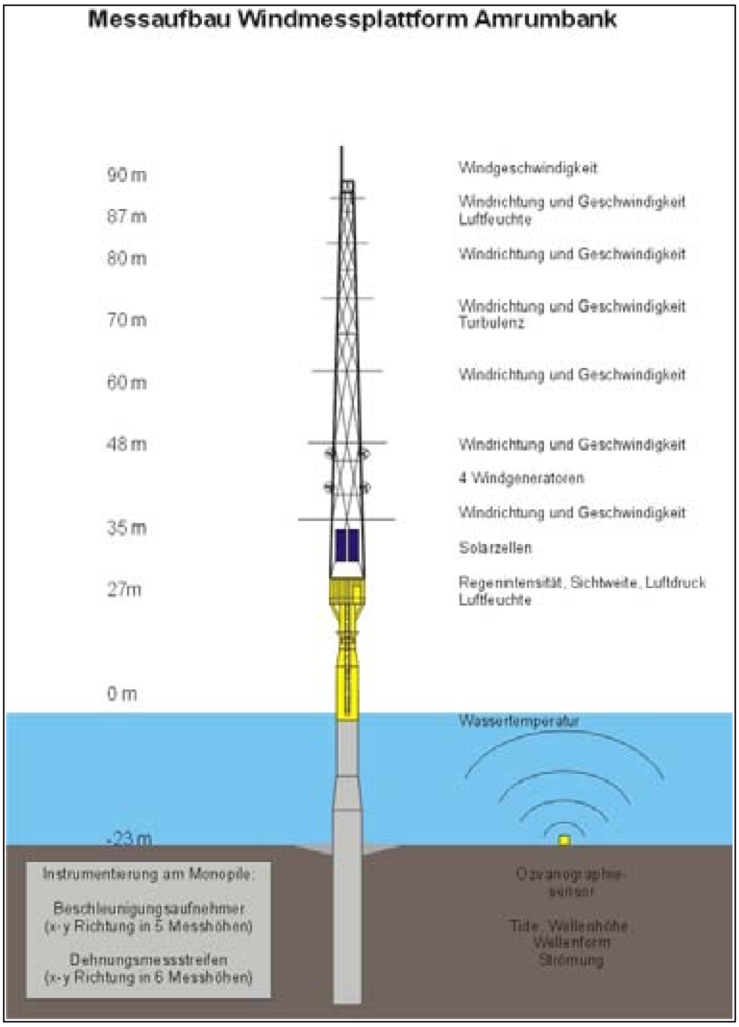

Figure 11. Schematic of the Amrumbank monitoring tower, Germany

c. Commercial short/medium term platforms

- Designed to measure wind and marine data at a specific wind farm site that may not be required for the lifetime of the wind farm, and / or to monitor environmental impacts during the wind farm construction phase.

- These platforms are characterised by the elimination of the hub height lattice tower structure in favour of using a short tower combined with remote sensing LIDAR or SODAR equipment.

- Elimination of the hub height lattice tower allows the monopile foundation to be less than half the mass of a conventional platform.

- Reduced foundation mass and elimination of tall lattice tower structure allows simplified installation procedures that are less expensive.

- Cost savings on installation can be preferentially invested in LIDAR technologies to measure the wind resource dynamics across the full rotor disk of the wind turbines.

- Examples of this classification of monitoring platform include the offshore monitoring platform for the NaiKun wind farm project in Canada where a LIDAR unit is installed, and the Sky2000 monitoring platform in Germany which has included SODAR measurements, shown in figure 12.

Figure 12. Photos of the Sky2000 platform with and without SODAR.

<u>General platform design guidelines</u>

There are many variables for the design of offshore monitoring platforms, some of these will be determined by local safety requirements for navigational marking, other technical factors will be determined by how much is already known about the study area. More monitoring details are required when less baseline data is known. Some general design guidelines are:

- Tower height at least to reach hub height of 4 MW wind turbine, or should be related to the type of turbine intended for installation. Hub heights will generally be lower offshore than onshore for the same turbine capacity.

- Provide a free standing lattice tower with internal climbing ladder to access wind sensor equipment for installation, adjustment and replacement. Careful consideration needs to be made about the boom lengths and orientations to reduce tower induced flow distortions to acceptable levels.

- Full grounding system to protect electronics from static discharge, including a tower-top lightning rod as well as side-strike lightning conductors.

- Cathodic protection to prevent corrosion from sea water.

- Raised and locking platform at 10 m level or higher (depending on local extreme wave conditions) for protection of data collection and communication equipment.

- A docking and landing strategy appropriate for the local situation to ensure reliable access of personel to the platform under most conditions if maintenance is required.

- Full time video cameras on the platform are highly recommended to provide verification of weather and sea state conditions, to assess potential damage, to monitor nearby shipping activity, and to confirm the security of the platform from unauthorised access.

5.3.2 WIND SENSOR AND DATA LOGGER PACKAGE

The specification for the wind sensor and data logger package needs to be tailored to each individual site, however there are basic strategies for the setup that can applied to most locations. The following guidelines refer to the case where a 90m hub height tower is to be installed:

- There should be at least two independent data loggers for security. A preferred option is for each data logger to be connected to sensors at the same levels. This strategy allows sensors at each level to be correlated so that data can be patched if one sensor fails, and more importantly, if one logger fails and data is lost from all of it's channels, then the backup logger still provides wind data from all levels.

- Wind speed measurements at six levels (40, 50, 60, 70, 80, 90m). Additional levels may be added, such as at 20m or 30m to increase the resolution of the vertical wind profile, or to make better correlations with other weather stations. A conceptual wind monitoring tower setup is shown in figure 14 for reference.

- Wind direction measurements at three levels (38, 63, 88m) are recommended to confirm wind direction veer over the wind turbine rotor disk.

- Temperature measurements at two levels (for example 15, 85 m) to estimate sensible heat flux and atmospheric stability. The objective for these measurements includes the correlation of vertical wind profiles with specific atmospheric stability states, however this requires that accurate thermometers are used. The temperature differential between the sea surface and the atmosphere also has a strong influence on the vertical wind profile, therefore the temperature measurements on the tower need to be combined with the sea state data.

- Atmospheric pressure measurement at data logger level (for example 10m). This may be extended to include two levels for additional information about atmospheric stability.

- Data loggers should send regular updates via modem to the project office. Daily data updates are normally adequate via GPRS, VHF, or satellite connections (as appropriate for the site). Real time or "near time" data transfer is also possible but this may increase the communications cost significantly. Each data logger should have it's own modem for data security purposes.

- Data averages of 10 minutes are normally adequate, provided that 3 second wind gusts are also measured for each interval. High resolution sensors such as sonic anemometers can be used but these increase data storage and transmission costs. An alternative to constant high resolution monitoring is to have the sonic anemometer operate on a trigger basis to record only extreme events such as the passage of a typhoon.

- Additional wind sensors to consider including are vertical propellers to record vertical wind speed vectors. While the flat topography of the ocean is not normally associated with inclined wind flow, significant vertical flow may occur as part of large storm activity. Measurement of downbursts and other storm events may by useful in specifying the frequency of extreme operating conditions of the offshore wind turbines for specific locations.

- Special design of sensors and booms may be required to prevent bird perching and damage to sensors. This precaution is most important at near shore installations where birds may perch on the tower structure for extended periods. The interaction of birds with the tower causes two main problems. Firstly they will cause flow disturbance around wind sensors which causes erroneous measurements, however this may not be identified as a data error unless video cameras record the time of bird perching. Secondly, large scavenging birds such as sea eagles may use sensors to clean their claws and beaks after feeding, due to their strength, they may destroy the sensors, however the damage risk highly depends on the type of sensors used.

5.3.3 Sea State Monitoring Station Package

The sea state monitoring package is important for the wind farm design because the collected data helps to define the parameters for the foundation design. For offshore wind farms the extra cost of foundation installation means that design errors can be very expensive. In addition it is considered essential to combine wind and wave loading data in order to develop the most appropriate and cost effective designs for the foundation structure. Therefore wind and sea state monitoring should be deployed simultaneously at a potential wind farm site.

Offshore wind farms are placed with priority in shallow water to reduce foundation costs, however these same areas may be at higher risk of tidal currents, storm surges and sediment transport. The effect of placing turbine foundations in these dynamic environments is that the structures will create a scour effects, and the long term design of scour protection is one important function of the sea state monitoring program.

The following guidelines are useful principles for the specification of a sea state monitoring package, however the detailed setup varies significantly between locations. A sample sea state monitoring station is shown in figure 13.

- Doppler Current Profilers (DCP) are a useful and reliable tool to measure the speeds and directions of currents at different sea depths from a single point. Depending on the sea depths and local conditions, the DCP may need to be deployed in a downward looking or upward looking orientation, or one in each orientation if water depths require it. The deployment of the DCP needs to consider the effect of sediment transport and bio-fouling on the data quality.

- Quartz based pressure sensors are used to measure wave parameters such as wave heights, wave periods, wave steepness, and the wave spectrum. The deployment depth of the pressure sensors has a major impact on their sensitivity to different wave heights, therefore the deployment depth needs to consider the range of wave heights and frequencies that are relevant for the turbine foundations. The pressure sensors may be combined systems with the DCPs, or separate. Radar based wave measurements are an alternative strategy using equipment attached to the platform above the water line.

- Sensors for conductivity, temperature, turbidity and oxygen content in the sea water column and visibility at the sea surface are all useful parameters as they allow the detailed design of corrosion protection, diving / construction strategies, turbine accessibility statistics, and other issues. Due to the local conditions, some of these sensors may be co-mounted with the DCP, or independently on a buoy system.

- Data loggers should send regular updates via modem to the project office. Daily data updates are normally adequate via GPRS, VHF, or satellite connections (as appropriate for the site). Real time or "near time" data transfer is also possible but this may increase the communications cost significantly. Each data logger should have it's own modem for data security purposes.

5.4 Data Collection And Quality Control

5.4.1 Measured Wind Data

The following recommendations are typical procedures taken to compile and process measured wind data for subsequent stages of analysis. This list is not exhaustive and many other approaches are equally valid.

- Daily data download from wind monitoring station.

- Daily verification of data quality: lightning damage, storm damage, bird damage, flow interference, change of correlation coefficient with other sensors.

- Patch data where required to maintain continuous time series and / or perform site visit for sensor repairs or adjustments. Publish monthly and final year reports of wind statistics, including:

    - Average wind speeds at all measurement levels;

    - Maximum wind gusts recorded at all measurement levels;

- Wind rose at all measurement levels;
- Energy rose at all measurement levels;
- Weibull wind speed frequency distributions for each direction sector using raw and filtered data if required;
- Turbulence intensities in each direction sector;
- Wind speed, direction and turbulence time series;
- Vertical wind profiles for different average wind speeds;
- Estimated wind gradient exponent for typical conditions;
- Wind energy (W/m^2) for different hub heights;
- Temperature gradient and atmospheric stability;
- Comparison of wind statistics with other wind monitoring stations and with reference weather stations to identify location and yearly variations and trends.

5.4.2 *Reference Wind Data Station*

- Visit potential reference stations for selection of long term wind record.
- Analyse the reference station history and re-calibrate the wind data time series as required due to changes in sensor models, mounting locations, and surrounding obstacles.
- Publish a final report of the calculated monthly and yearly long term wind statistics in terms of Weibull distributions from the re-calibrated reference data and compare these to the measured wind statistics from the offshore wind monitoring station.

5.4.3 *Measured Sea State Data*

- Daily data download from sea state monitoring stations.
- Daily verification of data quality: storm damage, boat collision damage, loss of calibration, change of correlation coefficient with other sensors.
- Patch data where required to maintain continuous time series and / or perform site visit for sensor repairs or adjustments.
- Publish monthly and final year reports of sea state statistics, including:
    - Specific and maximum wave heights;
    - Peak, mean, and mean zero crossing periods;
    - Energy wave periods;
    - Steepness of waves;

- Irregularity of sea state;
- Wave spectrum;
- Wave time series;
- Sea current speeds and directions from the sea floor to near surface;
- Tides;
- Time series of conductivity, temperature, turbidity and oxygen content in the sea water column;
- Record of visibility at the sea surface;
- Evaluation of maintenance ship accessibility rate to the potential wind farm based on wave conditions, visibility and wind speeds during the month.
- Comparison of sea state statistics with other sea state monitoring stations to identify location and yearly variations and trends.

5.5 MAINTENANCE

- Keep inventory of spare parts to perform maintenance at short notice on the wind monitoring station and the sea state monitoring stations.
- Store a motor vessel at or near the existing Nanri wind farm substation to be used for regular maintenance visits to the offshore wind monitoring station and sea state monitoring stations.
- Monthly maintenance visits to the wind and sea state monitoring stations to confirm structural integrity of tower and foundation, boom and sensor alignment, grounding system integrity, interference by birds and other wildlife, bio-fouling of sea sensors, collision damage, vandalism, warning system functioning, and other parameters.

6 WIND RESOURCES ASSESSMENT METHODOLOGY

6.1 OVERVIEW

The amount of power in the wind is dependent on the speed of the wind and the power in the wind is proportional to the cube of the wind speed. A 10% difference in speed makes about a 33% change in power. This gives rise to the primary reason for wind resource assessment based on measurement rather than reliance upon wind resource maps. In order to more accurately predict the potential benefits of a wind power installation, wind speeds and other characteristics of a site's wind regime must be accurately understood.

6.2 STANDARD WIND YEAR CALCULATION

- Obtain wind speed and direction time series from the long term reference station that is parallel to the one year measured period at the offshore monitoring station. The data averaging interval at the reference station should not be less than one hour.

- Calculate the monthly Weibull parameters[8] (in each direction sector) for the reference station one year wind time series that is parallel to the measured time series.

- Compare reference station and offshore station wind direction time series and adjust sector-to-sector correlation for wind direction changes between the reference and measured stations using Matrix MCP[9].

- Calculate the average expected long term wind speed and direction at the offshore monitoring site for each month using a Weibull scaling method based on values from:

  - Reference station long term time series;
  - Reference station one year time series;
  - Offshore monitoring station one year time series;

- Publish final report of expected long term average wind statistics at the offshore wind monitoring station.

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[8] The structure of a Weibull distribution varies throughout the world. Local phenomena, such as seasonal or diurnal winds, can affect the shape of the Weilbull distribution. Consequently, it may be more appropriate to calculate Weibull parameters not on a monthly basis but based on other more appropriate criteria such as time of day or direction sector. The particular choice of criteria will be dependent upon local conditions. Ultimately, making the right choice will improve the prediction accuracy.

[9] Matrix MCP places counts of measured data from the site and the parallel reference measurements into wind speed/direction matrices. (As mentioned in the note above the width of the direction bin does not need to be uniform and can be tailored to suit the particular characteristics of local wind behaviour.) The ratio between the counts in each of the concurrent matrices is determined and then applied to a comparable long term reference matrix to obtain the long-term wind speed distribution for the site in question. This process is only successful where the reference site is of good quality and has a relatively high annual average wind speed. Three reference papers regarding matrix method for MCP are provided as supplementation.

6.3 IEC Wind Site Classification[10]

- Analyse the long term reference station time series to calculate the maximum gust wind speed with 50 year return period and classify according to IEC wind turbine standards. Scale maximum gust wind speed if required based on correlation between the reference and measured stations during the one year parallel monitoring period.

- Calculate the standard turbulence intensity (TI15) for the dominant wind energy directions at the offshore wind monitoring station and classify according to IEC wind turbine standards.

- Analyse the vertical wind profile for the dominant wind energy directions at the offshore wind monitoring station and compare with standard wind profiles used for wind turbine power curve measurement.

- Publish a final report of the recommended IEC wind turbine classification for the offshore wind monitoring station site and the potential wind farm development area, including a summary of all statistics. The IEC wind turbine classification at the Nanri site will be dominated by the extreme wind gust speed due to the passage of strong typhoons. A main focus of the report will be to quantify a realistic extreme wind gust design guideline

7 CONCLUSIONS

This report has as far as has been practicable applied the methodology developed in SgurrEnergy document 6509/001/O/R/07/001 and modified based on the recommendations of SgurrEnergy document 6509/001/O/R/07/003 to a fictitious offshore wind farm site at Pinghai Penisula in the vicinity of Nanri Island and completes Task 4 of the CRESP contract No. A2-B12-CS-2007-004.

The methodology described in this document can be developed into a practical implementation plan if the information necessary to enable primary search areas to be identified can be provided, followed by the information needed to produce detailed constraint maps.

[10] http://www.awea.org/standards/iec_stds.html
This website contains some details of each section of the IEC 61400 standards. The proper reference for part 1 would be: IEC 61400-1:2005, Wind Turbines - Part 1: Design Requirements ISBN 0 580 47146 2. [This ISBN refers to a British standard which reproduces the IEC standard]

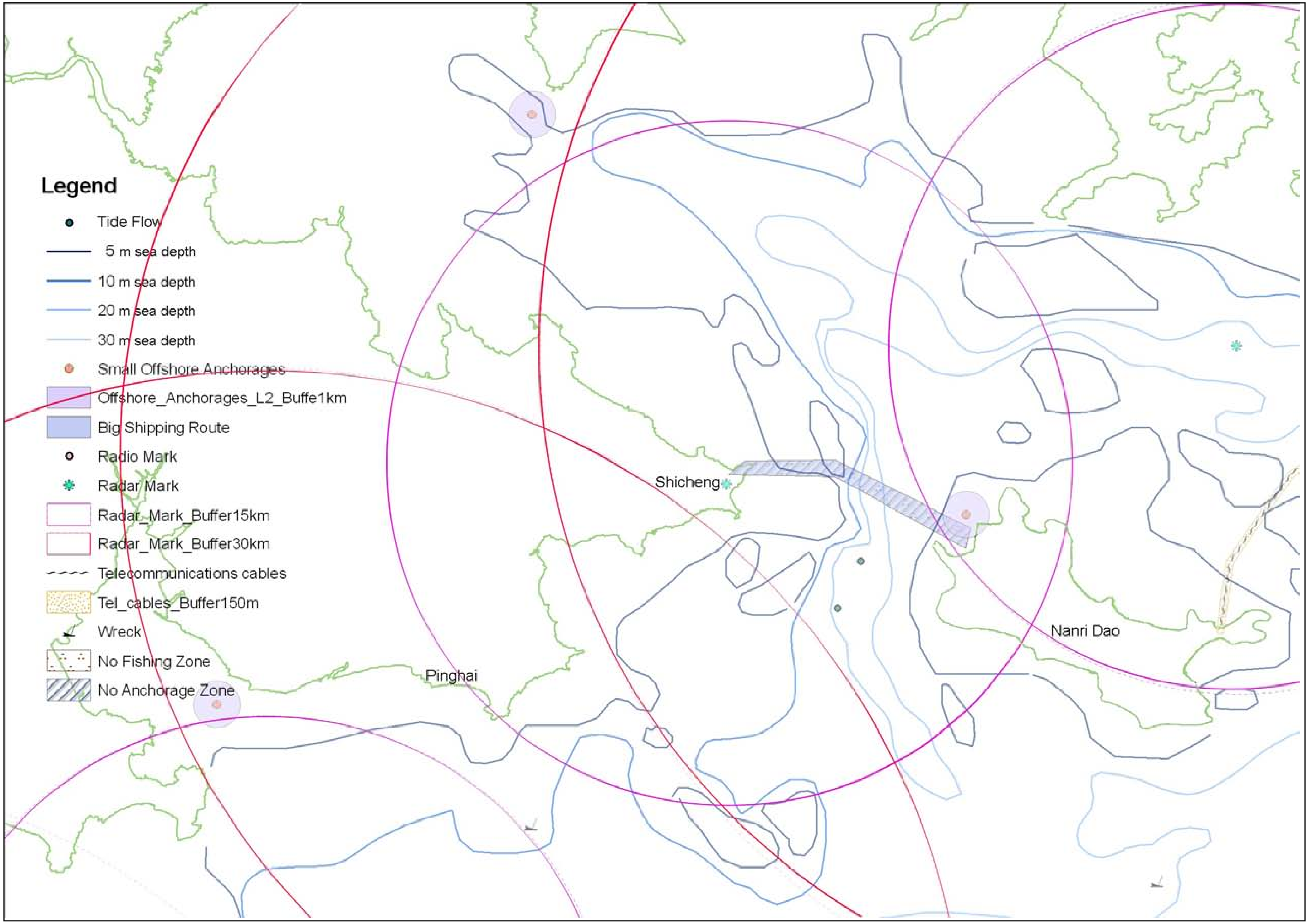

Figure 6 - Constraint Map for Pinghai Peninsula

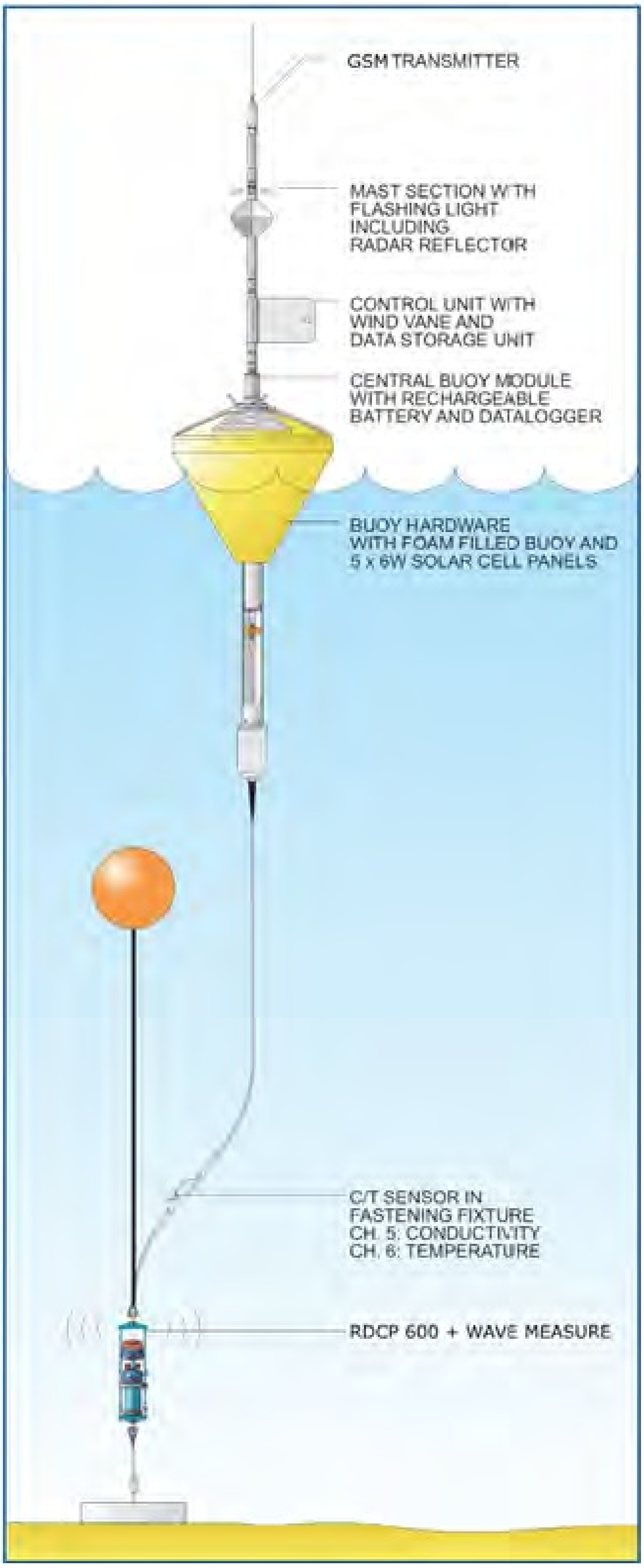

Figure 13 - Sample setup of bottom moored, upward looking DCP with data buoy.

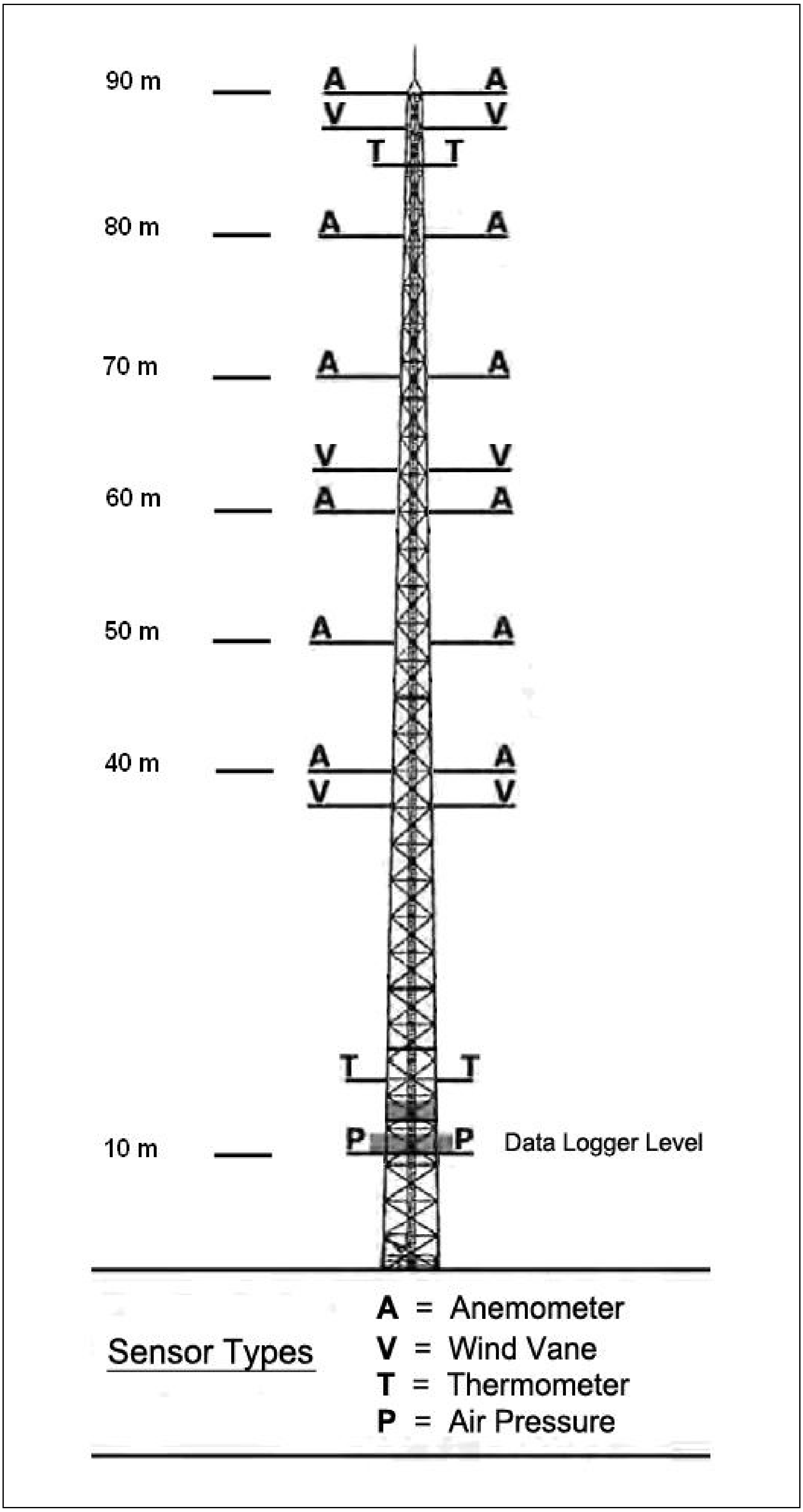

Figure 14 - Sample setup of sensors on 90m lattice tower.

Contract No. A2-B12-CS-2007-004

CMA National Consultant:	SGURRENERGY International Consultant:
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