CHAPTER 2 : Introduction to the POWER project

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2.1 General characteristics of the wind field over the sea

In offshore areas it is generally thought that wind speeds will be higher and there will be a smaller vertical wind gradient and less turbulence than at onshore sites. This means that it should be possible for offshore wind turbines to have higher energy outputs and suffer less fatigue loading and thereby to have a longer active life compared to those on land.

However, in coastal sea areas the wind regime is influenced by the adjoining land surfaces resulting in some complex interactions. There is evidence that in some circumstances this zone of coastal influence extends a large distance from the shore - perhaps as far as a couple of hundred km from the nearest land. This coastal zone is the region of immediate interest since, for the foreseeable future at least, technical and logistics limitations associated with water depth and distance to shore mean that offshore wind developments are likely to be restricted to seabed-mounted wind turbines in nearshore areas. Within this “coastal discontinuity zone”, there are various phenomena that may affect wind conditions, driven by differences between the land and sea such as changes in surface roughness, temperature and atmospheric stability including:

Internal Boundary Layer (IBL) development

Sea breeze circulation

Low level jets

Internal boundary layers (IBL) form downwind of a significant step change in surface roughness such as a coastline. In off-shore wind conditions, airflow in the lowest layer is in equilibrium with the sea surface, but there will be an upper layer which retains equilibrium with the air over the land. There will also be an adjustment or blending layer where the two air masses meet but the mixed wind profile can extend downstream for a significant distance.

IBL growth varies under different stability conditions. In stable conditions offshore the IBL grows slowly and can remain below 100m for considerable distances inhibiting momentum exchange and impacting on the wind speed profile. Conversely, in unstable conditions the IBL grows quickly and rapidly attains equilibrium. It is interesting to note that in very stable atmospheric conditions (with low mixing rates), it is possible for the hub of a coastal offshore wind turbine to be above the lower layer and operate in the upper airflow. Indeed, in this scenario, the turbine rotor will experience conditions characteristic of the wind over land rather than the sea and no benefit will have been gained by constructing the turbine in the sea.

Sea breezes are driven by convection. As the land heats up during the day, the overlying air warms and rises. Cooler sea air is drawn inland to replace it and a convection cell develops. The resulting on-shore winds may mask a weak weather pattern and produce very different wind conditions to those forecast by synoptic models. The convection system may reverse during the night resulting in an off-shore land breeze.

Low level jets are characterised by an increase in mean wind speed accompanied by high wind shear, which can in turn spawn high levels of turbulence. There are many postulated causes of low-level jets, one of which is advective acceleration as a mass of air is blown off-shore. They occur as low as 50 m height and up to 600m height and may increase in intensity over time (6 – 8 hours) as the air mass travels over the sea. In areas where jets appear, offshore wind turbines will experience higher wind speeds, but will also encounter more severe loading and fatigue.

The wind also interacts with the sea. As the wind passes over the water, energy is transferred from the air to form wind-generated waves. This continues until the sea state is fully developed. When the wind drops the sea state also declines, but usually at a slower rate. In most conditions, the transfer of momentum between the sea and the air mass almost cancels out, however at low wind speeds a momentum feedback loop may develop that transfers energy from swell back to the wind.

Offshore wind speeds are also known to vary over a wide range of time scales:

Diurnal cycles

Seasonal cycles

Decadal cycles - unforced/internal variations e.g. the North Atlantic Oscillation (NAO)

Long-term variations – forced/external variations e.g. greenhouse warming

The scale of these variations is sufficient to have economic implications for onshore and offshore wind farms, and given that an offshore wind farm is likely to have a design life of 30 years or more, it is important to put any period of observation/measurement into the context of the long-term cycles of variability when assessing offshore wind resources.

Finally, there are a couple of other features of the offshore wind regime which may be of particular pertinence to offshore wind farm developments:

- The spatial variability of the wind resource within an offshore wind farm may be less compared to an onshore development. This is because on land a 10-15% variation can be expected due to topographical effects that are not an issue offshore (except in near-coastal areas). However, it is possible that the issue of wakes will add a similar degree of uncertainty to the resource of an offshore wind farm – particularly in large wind farms.

- It is also worth noting that due to lower offshore turbulence the wake effects generated by each turbine in the wind farm will likely propagate over larger distances than onshore, and that the effects of stability on wake propagation are expected to be larger. The implication is that wind farm design/spacing between turbines needs to be carefully considered. [*Aside: This topic is currently the subject of an EU supported research project Ref: ERK6-1999- 00001 ENDOW (Efficient Development of Offshore Windfarms).*]

2.2 Basic POWER methodology

Perhaps the most significant obstacle to the assessment of offshore wind resources to date has been the lack of measured offshore wind data on which to base the estimates. The POWER project team has now developed a novel methodology which can, nonetheless, produce long-term and spatially detailed estimates of the wind conditions at offshore sites covering a wide area.

The POWER methodology does not rely directly on observed wind data to predict wind conditions offshore. Instead, the estimates are based on grids of atmospheric pressure data at mean sea level covering the area of interest. This means that the POWER methodology may be used to produce spatially detailed estimates of wind conditions at offshore sites covering a large area.

The methodology is built up of three basic steps:

1. The pressure gradient at mean sea level is used to calculate the geostrophic wind.
2. The geostrophic wind is transformed to the sea surface layer by applying the Wind Atlas Analysis and Application Program (WAsP).
3. In nearshore areas, a coastal discontinuity model (CDM) is used to predict wind conditions taking account of effects atmospheric stability experienced in the land/sea transition zone.

Within the POWER project, the CDM is “fine-tuned” using both existing offshore mast data and coastal SODAR (SOund Detection And Ranging) data. In addition, the estimates of wind resource are supplemented by assessments of short-term variability and information on regions of extreme environmental loading. Since historical atmospheric pressure data dates back to 1880 and beyond, the methodology allows the long-term (decade to decade) variability of the offshore wind resource also to be investigated.

A schematic flow diagram of the POWER methodology is shown in Figure 2.1.

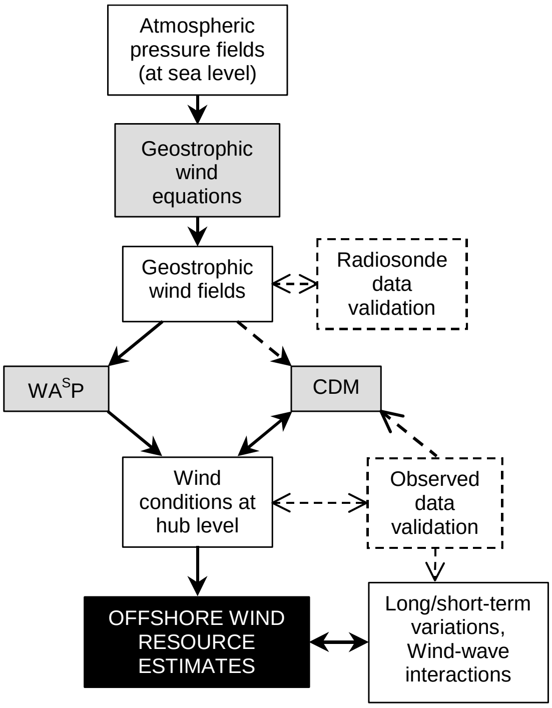

Figure 2.1 Flow schematic of POWER methodology

Note that within the POWER project, no attempt was made to model low-level jets

2.3 Application of the POWER methodology to European waters

The project team have applied this POWER methodology to the region 30ºN to 70ºN and 15ºW to 30ºE on a grid with the 0.5º x 0.5º latitude/longitude resolution. As Figure 2.2 shows, this area covers the major sea areas bordering European Union countries – the North Sea, the Baltic, the Mediterranean and the eastern North Atlantic.

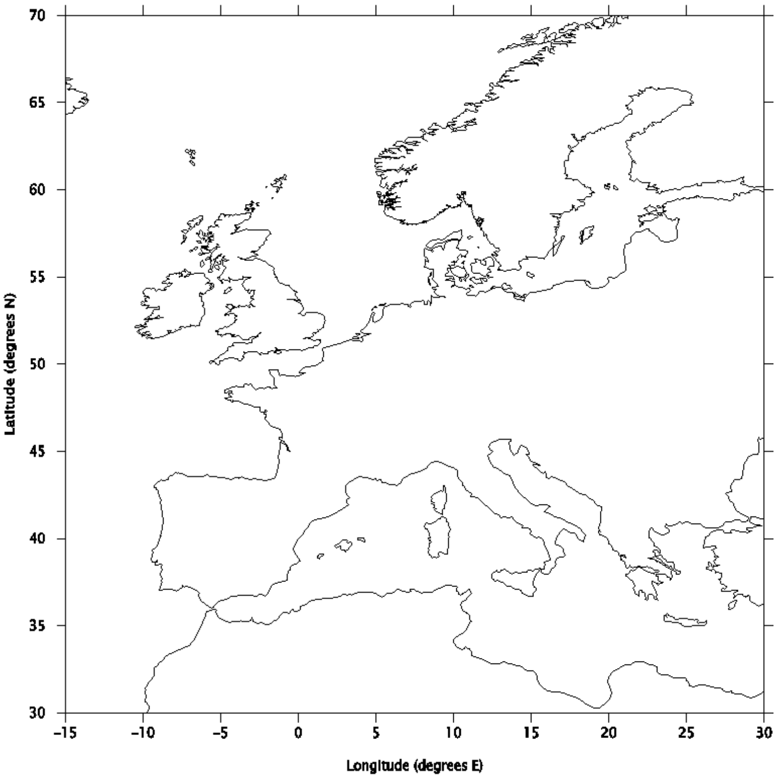

Figure 2.2 Map showing the European sea area where the POWER methodology was applied

On a regional and national scale, POWER has produced state-of-the-art estimates of the extent and distribution of Europe's offshore wind energy resources not only in the coastal zone – the current focus of the offshore wind industry's attention – but also throughout the region's far offshore areas, where there is potential for wind energy to be exploited in the longer-term by turbines mounted on floating structures. Hence, this information will enable the most appropriate and economically attractive areas for offshore wind energy development to be identified, both now and in future.

On a local scale, POWER provides detailed first estimates of the long-term environmental conditions at specific offshore locations. This information is useful to the offshore wind energy industry since this is the exactly the type of data required for initial scoping and feasibility studies for new offshore wind energy developments. It may be possible to base preliminary assessments of the turbine power output as well as other key parameters such as initial values of the design parameters for turbine support structures etc. on the POWER results. This enables the broad technical and economic feasibility of an offshore wind farm at a particular site to be established without the need to initiate costly and time-consuming an offshore meteorological data gathering campaign. If the site is suitable, more detailed (and short-term) wind and wave monitoring studies can then be performed at the site, which refine the initial POWER estimates for detailed design purposes.