總編輯評論 - 有關離岸風力電場與船舶航行安全的議題

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英國的Caithness Windfarm Information Forum (CWIF) 統計了自1970年代起至2016.09.30全球風力電場(含海上與岸上)的事故與事件(Wind Turbine Accident and Incident Compilation)合計1,951起[1]。造成人員死亡案例計121起，人員受傷145起，影響健康事件77起(2012起開始記錄)，與葉片故障(Blade failure)有關事故350起，失火事件283起，結構損害部分178起，冰損(Ice throw)有關事故36起，運輸過程中的損害計166起，造成環境的損害(含鳥擊)197起，其他如雷擊或管理不善等造成的事故與事件計398起[2]。至於具體陳述事故或事件係肇因於海上航行碰撞的案例則未見計在於本資料庫之中。

雖然如此，但在有關於海上風力電場與海上航行安全的相關學術論述與研究報告倒是有不少精闢的論述值得參考研究。茲簡單列舉如下：

- Assessing the impacts to vessel traffic from offshore wind farms in the Thames Estuary[3]
- Assessment of Offshore Wind Farm Effects on Sea Surface, Subsurface and Airborne Electronic Systems, U.S. Department of Energy[4]
- Collision Safety Analysis of offshore Wind Farm Turbines[5]
- Environmental Risk Evaluation System (ERES) for Offshore Wind, Mock-Up of ERES - Fiscal Year 2010 Progress Report, Environmental Effects of Offshore Wind Development, , Prepared for the U.S. Department of Energy[6]

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1 Summary of Wind Turbine Accident, http://www.caithnesswindfarms.co.uk/AccidentStatistics.htm

2 Wind Turbine Accident and Incident Compilation, http://www.caithnesswindfarms.co.uk/fullaccidents.pdf

3 Andrew Rawson, Edward Rogers, Assessing the impacts to vessel traffic from offshore wind farms in the Thames Estuary, Scientific Journal of the Maritime University of Szczecin, 2015, 43 (115), 99–107

4 https://www1.eere.energy.gov/wind/pdfs/assessment_offshore_wind_effects_on_electronic_systems.pdf

5 https://www.dynamore.de/de/download/papers/forum05/collision-safety-analysis-of-offshore-wind

- Guidance on the Assessment of the Impact of Offshore Wind Farms: Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind Farms, DTI, MCA, DOT[7]
- Interaction between offshore wind farms and maritime navigation, PIANC WG 161[8]
- Methodology for Assessing Risks to Ship Traffic from Offshore Wind Farms - VINDPILOT- Report to Vattenfall AB and Swedish Energy Agency[9]
- Modelling of Safety Distance Between Ships' Route and Wind Farm[10]
- Navigation In The Vicinity of Offshore Renewable Energy Installations, Risk Alert, Steamship Mutual[11]
- Navigation Risk Assessment Beatrice Offshore Wind Farm[12]
- Offshore Renewable Energy Installations (OREIs): Guidance to Mariners Operating in the Vicinity of UK OREIs, MGN 372 (M+F), MARINE GUIDANCE NOTE, MCA[13]
- Offshore Windfarm development and the issue of maritime safety - Case Study „Kriegers Flak" I, II and III, September 2007, EU[14]
- Quantitative risk assesment for offshore wind farms in the North Sea[15]
- Ship Collision Risk for an Offshore Wind Farm[16]

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6 http://www.pnl.gov/main/publications/external/technical_reports/PNNL-20020.pdf
7 http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file22888.pdf
8 https://imo.amsa.gov.au/iala-aism/arm/arm1/8-1-5.pdf
9 https://corporate.vattenfall.se/globalassets/sverige/om-vattenfall/om-oss/var-verksamhet/vindkraft/kriegers-flak/5-kriegers-flak-risk-assessment_11335732.pdf
10 Ryszard Wawruch, Tadeusz Stupak, Modelling of Safety Distance Between Ships' Route and Wind Farm, The Archives of Transport VOL. XXIII NO 3 2011, http://aot.czasopisma.pan.pl/images/data/aot/wydania/No_3_2011/10_Modelling_of_Safety_Distance_Between_Ships_Rou.pdf
11 https://www.steamshipmutual.com/Risk-Alerts/RA02NavigationOREI.pdf
12 Navigation Risk Assessment Beatrice Offshore Wind Farm (Technical Note), Anatec Limited & Beatrice Offshore Wind Farm Limited, 15th February 2012. http://sse.com/media/341118/ES-Volume-4-Annex-18A-WF-Shipping-NRA.pdf
13 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/440734/MGN_372.pdf
14 http://www.balticmaster.org/media/files/general_files_713.pdf
15 Quantitative risk assesment for offshore wind farms in the North Sea, https://www.noordzeeloket.nl/images/Quantitative%20risk%20assesment%20for%20offshore%20wind%20farms%20in%20the%20North%20Sea_994.pdf
16 https://dvikan.no/ntnu-studentserver/reports/Ship%20Collision%20Risk%20for%20an%20Offshore%20Wind%20Farm.pdf

- Ship Collision, Risk analysis - Emergency systems - Collision dynamics[17]
- Strategic assessment of impacts on navigation of shipping and related effects on other marine activities arising from the development of Offshore Wind Farms in the UK REZ, The Crown Estate (TCE)[18]
- Wind Farms and navigation: Potential Impact for radar, Air Traffic and Marine Navigation, NOAA[19]

至於直接與海上風力電場有關的事故案例，在OffshoreWind.biz中也是略有記載[20]，茲簡列事故概述如下：

- 2012.02.08挪威Kvaerner風力電場工作基地，吊車斷落在工作平台船上[21]。
- 2012.03.13中國江蘇海外風力電場工作基地平台翻覆造成五人死亡四人受傷[22]。
- 2012.11.21工作船船長Geoffrey Whinfrey應風力電場運營商Scira Offshore Energy Ltd要求載運風力電場上的人員上岸，由於是時天後黑暗、風速高達45mph，海上雨勢與海象惡劣。船長在未有適當的航行計畫下冒然的以試圖通過風力發電機塔上的安全燈來作為導航的依據，不料其中一部風力發電機組的安全導燈沒有照明，致使工作船以12節的速度撞擊該塔，造成船員及乘員的受傷。本案中風力電場工作船船長違反公司政策並違反避碰章程第五條為保持適當的瞭望，造成船舶與風車基座擦撞，罰款£3,000[23]。

17 http://www.germanischerlloyd.org/pdf/ship_collision_dal.pdf
18 https://www.thecrownestate.co.uk/media/5385/ei-strategic-navigation-assessment-report-and-appendices.pdf
19 http://www.miseagrant.umich.edu/wp-content/blogs.dir/1/files/2012/05/Wind-Brief-9-Navigation.pdf
20 http://www.offshorewind.biz/about/
21 http://www.offshorewind.biz/2012/03/13/norway-kvaerner-completes-investigation-following-serious-crane-accident/
22 http://www.offshorewind.biz/2012/03/13/china-five-workers-die-in-accident-at-offshore-construction-site/
23 http://www.offshorewind.biz/2014/09/03/master-fined-after-accident-at-sheringham-shoal/

- 2013.06.17德國Emden's Great Sea Lock風力電場，二艘荷蘭及工作拖船拖帶載運三座三角管式基座(tripod foundation)的平底船時(pontoon)時，碰撞繫柱(Dolphins)[24]。

- 2014.07.06 德國 Butendiek 風力電場一名丹麥及員工遭受強烈撞擊送醫治療[25]。

在這麼長的離岸風力發電的發展歷史，這麼多的海上航行風險評估與研究，但卻僅有微乎其微的真正與海上航行安全相關的事故。這樣的結果，與其可以高興的推論其實離岸風電是不會有航行安全的顧慮的，不如反過來想想，是不是因為一直有航行安全的憂患意識與努力提升船舶與離岸風力機組間的安全互動，才能有這樣的成績？

台灣的離岸風力電場與船舶間的航行安全議題，是否會和歐洲的情況一樣平安順遂呢？還是可能與國際上會有很大的不同？這是個值得思考的好問題。

24 http://www.offshorewind.biz/2013/06/19/germany-accident-in-emden-during-transportation-of-tripods/

25 http://www.offshorewind.biz/2014/07/08/ballast-nedam-investigation-to-reveal-cause-of-accident-at-butendiek-owf/

依據2016.12.05公共電視「我們的島」第884集「御風行」中[26]，針對彰化外海地理條件特殊，是傳統的好漁場，而且平均50米的大陸棚地形，也很適合設風機，未來漁民該如何面對滿佈風機的海洋，彰化區漁會總幹事陳諸讚先生的訪談指出：「彰化總共有640幾艘漁船、船筏，當中都是小型的漁船比較多，然後這些漁船又是90%都是流刺網，就是一張網二公里左右，它隨潮汐漂流、漂流四五公里後起網，就是這樣子來抓魚。風機是五至六百米一支，流刺網根本行不通了。就是要改變捕撈方式，從事一支釣或是觀光漁船，或是以後有配套措施，或是這個風場需要運補、維運的部分，能夠讓漁民來做。」

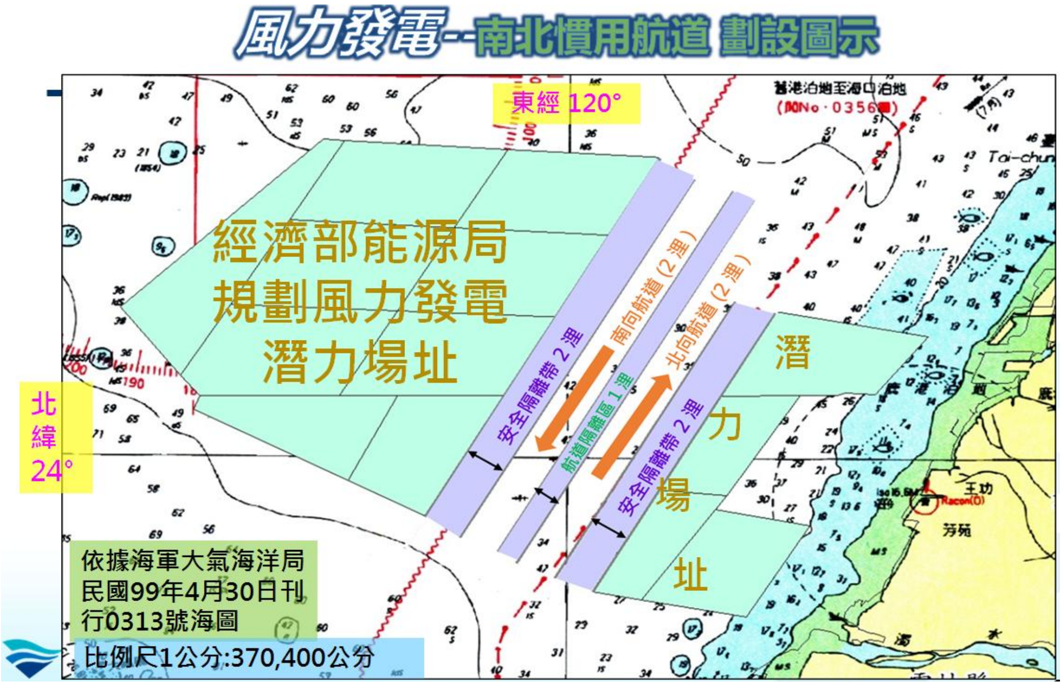
雖然這個節目聚焦在風場的投資廠商與漁民的補償間的一些爭議，但是從節目所引發的下列的幾個議題，倒是很值得我們再仔細思考：

- 漁場是存在的，而風場就設在漁場上頭；
- 漁船也是存在，而傳統的捕魚方式肯定是會危害方場的；
- 魚，我所欲也，風場，亦我所欲也；二者不可得兼，政府捨「魚」而取「風場」固然是勢在必行；但是漁民會捨？還是不會捨「魚」？則是另外一個問題。無論如何，漁網、漁船對於未來台灣的離岸風力電場可能造成的事故風險，將是個不可不正視的重大議題。

復依據2016.10.19交通部航港局研商「現行兩岸直航航道調整與南北慣用航道劃設」及「出具船舶航行安全意見書標準作業流程草案」會議紀錄顯示[27]，南北慣用航道採分道航行制，分為南向及北向航道、南向及北向安全隔離帶（即最小安全距離）各2浬寬，航道中央隔離區1浬寬，總寬度9浬之方案劃設（如下圖所示）。

[26] http://vod.pts.org.tw/ptsvideo/20161205-我們的島-第884集-御風行/

[27] 「1051026調整與南北慣用航道船舶航行安全意見書標準作業流程草案」會議紀錄



換言之，原來的台灣海峽東側航道，也就僅剩二海里寬的北向航道以及二海里寬的南下分道通航(TSS)航道。這如同狹管效應般地將船舶聚合於此，可以想見的的就是交通流量的變化，以及將不同船型與不同船速船舶的聚合競道的精彩畫面。特別在強烈東北季風盛行的季節以及惡劣天候下，跑得動的船和跑不動的船，彼此相會在二海里寬的水道中，並在夾雜著大小漁船穿越或作業期間時，賭上風險的，當然是海上所有的生命、財產與環境，但是將被嚴格考驗的，則應該是當時規劃與未來負責管理這個TSS的主管機關吧？

在前述所列近二十餘個與離岸風電有關的航行研究中，所顧慮的、所分析的、所因應的，皆各有所本。例如依據歐盟(2007)[28]以及美國能源局(2010)委託執行的研究報告指出[29]，即使離岸風場經過詳細規劃的避開主要海上航行航路，或是航路經過適當的變更以最低化的減低碰撞風險，船舶與離岸風力發電機組碰撞所將產生顯著的環境傷害風險的脆弱性和概率(vulnerability and probability)仍是存在的。

參考丹麥(2001)[30]、瑞典(2008)[31]、波蘭(2011)[32]以及英國(2015)[33]的研究報告指出離岸風場附近的航路決策機制固然除了要確保大型商船的航道與風力機組至少要有1000公尺的間距外，尚需考量包括：

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[28] http://www.balticmaster.org/media/files/general_files_713.pdf
[29] http://www.pnl.gov/main/publications/external/technical_reports/PNNL-20020.pdf
[30]

https://dvikan.no/ntnu-studentserver/reports/Ship%20Collision%20Risk%20for%20an%20Offshore%20Wind%20Farm.pdf

31 https://corporate.vattenfall.se/globalassets/sverige/om-vattenfall/om-oss/var-verksamhet/vindkraft/kriegers-flak/5-kriegers-flak-risk-assessment_11335732.pdf

To estimate the probability of collisions between ship and wind farm, the following type of information is generally required:

- Wind farm data including:
  - Position of each wind turbine
  - Distance between turbines
  - Pile diameter
  - Hub height
  - Rotor diameter
  - Installations of navigational aids (lights etc) at the wind farm
- Vessel traffic information in the vicinity of the proposed wind farm, including:
  - Position of typical shipping lanes/operating routes (from AIS data and other sources)
  - Number of vessels (from AIS data and other sources)
  - Types of vessels such as cargo, tanker, passenger, etc. (from sources such as AIS data and general statistics for the Baltic Sea)
  - Characteristics of vessels such as size, length, breadth, draught, operating speed (from sources such as AIS data and general statistics)
  - Seasonal traffic variations (from AIS data, etc.)
  - Day/night traffic variations (data sources include local ports)
  - Future traffic scenarios (from Helcom, VTT, The Institute of Shipping Analysis in Göteborg, etc.)
  - Distance from the shipping lane to the wind farm (estimated from
  - AIS data; estimations for lanes shifted to new location)
  - Standard deviation and mean for lateral distribution in cross-section (from AIS data (histogram) or general estimations)
  - Statistical distribution for course deviation, e.g. standard deviation and mean for Gaussian distribution in cross-section (may be possible to derive from AIS data or statistics)
- Climatological data including:
  - Wind speed distribution and wind direction distribution (10
  - meters over sea level)
  - Wave information
  - Current information
  - Ice conditions
  - Fog conditions (to assess hazards such as reduced visibility)
- Site data including:
  - Coast line geometry
  - Water depth, bathymetry and sea level variations
  - Type of sea bottom such as rock, clay, sand, etc.
- Frequency of machinery breakdown– blackout
- Ship self repair function (time for self repair)– duration of blackout
- Probability of unsuccessful emergency anchoring
- Tug boat assistance information including:
  - Distance from tug boat position to disabled ship
  - Operating speed of the tug boat (depends on the weather conditions)
  - Time to activate the tug boat, to connect and take control of the disabled vessel
- Probability of:
- human failure during planning and execution of the passage of an object (navigation past an obstacle)
- technical failure of navigational equipment or watchkeeping failure due to causes such as lack of attention during lookout on the bridge or bad visibility

- 考量離岸風力電場水域附近的船舶交通流模式以及交通流量；
- 考量離岸風力電場水域附近的海氣象特性，特別是潮流方向與強度；
- 考量離岸風力電場水域各個風力發電機組的佈置型態與水文特性；
- 考量船與離岸風力機作必須保持舒適的緩衝區，特別是在與其他船舶會遇時仍應有足夠的水域空間可以激動地迴避與運轉；
- 考量風力發電機組所產生的遮蔽效應以及對雷達的影響的問題；
- 考量離岸風力電場水域的無線電助航與監控設施能量如：civil aviation radars and systems, national defense radars, weather radars, vessel traffic services (VTS) radars, Radiocommunications (GMDSS), Automatic Identification System (AIS), Direction finder (D/F), GNSS & others navigation systems的能量；
- 考量因為風力電場造成習慣航路的改變以及航行距離增加的問題；
- 考量因為風力電場所改變的航路規劃，很容易地會減少了船舶避免碰撞空間以及運轉的機動性，也會形成新的「阻塞點(choke point)而導致碰撞風險的變化；

- failure of the wind farm safety equipment/crew or a potential stand-by boat to warn the passing ship in time to avoid a collision
- the crew onboard being unable to react in time to correct the navigational error (dependent on the distance between ship and wind farm)

[32] Ryszard Wawruch, Tadeusz Stupak, Modelling of Safety Distance Between Ships' Route and Wind Farm, The Archives of Transport VOL. XXIII NO 3 2011, http://aot.czasopisma.pan.pl/images/data/aot/wydania/No_3_2011/10_Modelling_of_Safety_Distance_Between_Ships_Rou.pdf
The following shipping risks were identified to be potentially affected by the pro- posed wind farm:
1. ship to ship collision;
2. grounding;
3. foundering;
4. fire/explosion;
5. risk caused by influence of wind farm on worst of navigational and radio communication equipment. Estimation of threats caused by include probability assessment of every risk with may arise or change on particular phase of farm building and exploitation and comparison of these results with results for period time before starting of this building. Additionally analyze can include:
   (1) expected future dangers from increase ship traffic tension, her speed, displacement and drought;
   (2) possibilities of alternation of risk level resulting from future rebuild or ex- tension of farm or exchange of construction of wind turbines.

[33] Andrew Rawson, Edward Rogers, Assessing the impacts to vessel traffic from offshore wind farms in the Thames Estuary, Scientific Journal of the Maritime University of Szczecin, 2015, 43 (115), 99–107

- 考量造成船舶擱淺或是在通過離岸風力電場水域時發生其他事故的風險，特別是人因、或機械故障等失誤狀況時的因應。

Type	Subtype	Cause	Exposure measure
Ship/Ship collision		Human error	Encounter
Ship/Anchored ship collision	Ramming ship/anchored ship in port approach area	Human error	Anchored ship ramming opportunity
	Ramming ship/anchored ship in anchor area	Human error	Anchored ship ramming opportunity
	Ramming ship/anchored ship outside port approach area or anchor area	Human error	Ship miles
	Drifting ship/anchored ship	Engine failure	Danger miles
	Ramming anchored ship during anchoring		Danger miles
	Drifting anchored ship/ anchored ship after breaking anchor chain	Engine failure	Danger miles
Contacts	Objects with fixed position	Engine failure	Danger miles
	Objects with fixed position	Navigational error	Ramming opportunity
	Contacts with object that can take place everywhere.		Ship miles
Foundering (Sinking)			Ship miles
Fire and Explosion			Ship miles
Stranding		Engine failure	Danger miles
		Navigational error	Stranding opportunity
Incident Hull/Machinery			Ship Miles

Overview of the different types of accidents distinguished in SAMSON[34].

總體來說，在有關離岸風力電場與船舶航行安全的議題上，上述的這些風險與憂慮，對於台灣勢在必行的離岸風場的建置是無可避免的。未來台灣的離岸風力電場水域船舶分道通航(TSS)的規劃是一定要的，而且也已經規劃了；符合IALA Recommendation 0- 139助導航系統[35]的建置也是必須的。

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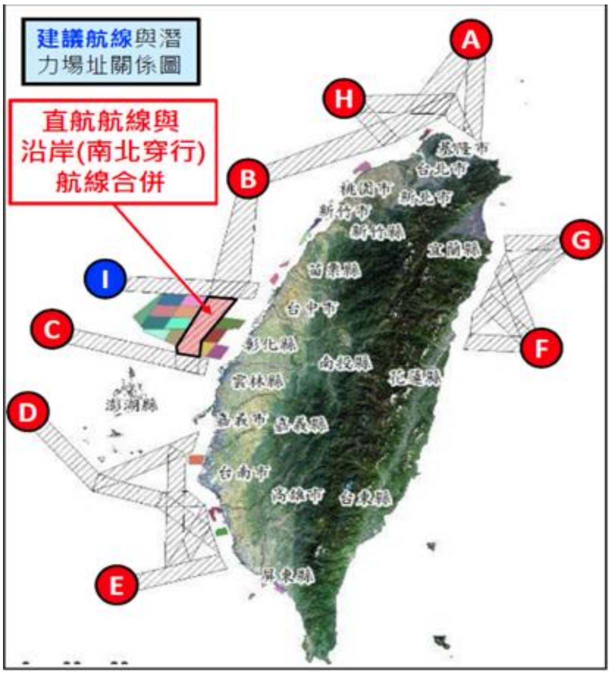
[34] Quantitative risk assesment for offshore wind farms in the North Sea, https://www.noordzeeloket.nl/images/Quantitative%20risk%20assesment%20for%20offshore%20wind%20farms%20in%20the%20North%20Sea_994.pdf

[35] Navigation Risk Assessment Beatrice Offshore Wind Farm (Technical Note), Anatec Limited & Beatrice Offshore Wind Farm Limited, 15th February 2012.
http://sse.com/media/341118/ES-Volume-4-Annex-18A-WF-Shipping-NRA.pdf
The markings for the Beatrice Site will be agreed in consultation with NLB once the final turbine layout has been selected. Based on IALA guidelines it is likely that the lighting of Beatrice Offshore Wind Farm will be:

- All corner towers will be marked as Significant Peripheral Structures (SPS) and where necessary, depending on spacing, intermediate towers on each of the north, west, east and south facing boundaries will be marked as Intermediate Structures (IPS).
- In all the layouts, towers designated as SPS are to exhibit Flashing Yellow 5 second (Fl Y 5s) lights of 5nm nominal range and omnidirectional fog signals with a character of 1 blast of 2 seconds duration every 30 seconds and an IALA usual range of 2nm. Towers designated as IPS are to exhibit Fl Y 2.5s lights of 2nm nominal range.
- All the lights are to be visible to shipping through 360 degrees and if more than 1 lantern is required on a tower to meet the all-round visibility requirement, then all the lanterns on that tower should be synchronised.



然而，接下來的是航行在這個水域船舶的主動「守規」的議題、「誰」在提供資訊與服務讓這些船舶有可以助於「守規」，以及「誰」在監控這些船舶有沒有「守規」的議題。

至於，如果真有船與船或船與風力發電機座發生碰撞，或是因而造成船舶擱淺事故的因應機制與應急拖帶船舶(Emergency Towing Vessel (ETV))能量[36]則又是另外一個議題了。

自從1991年，全球首座的離岸風電(Vindeby)在丹麥安裝迄今已逾25年，二十餘年的漸進發展，進步的不單單是離岸風力發電的設施與技術，而是人們對於與離岸風電共存的磨合與適應。這些「漸進式」的發展所牽涉的是各不同區域間的「海洋文化的」、「航海習慣的」、「民族習性的」自我調整、磨合與修正。

- All the lights are to be exhibited at the same height at least 12 metres above Highest Astronomical Tide (HAT) and below the arc the turbine blades.
- All the lights are to be exhibited at least at night and when the visibility is reduced to 2nm or less. Fog signals are to be sounded at least when the visibility is 2nm or less.
- All the structures in the boundary of the turbine towers are to be coloured yellow from at least HAT to the height of the lights (the equivalent height on the unlighted structures).
- Any lighting required for aeronautical purposes is to be shielded / arranged such that it is not visible to shipping. If this cannot be achieved, then the requirement will be considered as having been met if the aviation light is reduced to 10% of its peak intensity when the visibility is more than 5km.

36 An Emergency Towing Vessel (ETV) to recover drifting ships can deliver a reduction in the probability of drifting of more than 50%. https://www.noordzeeloket.nl/images/Quantitative%20risk%20assesment%20for%20offshore%20wind%20farms%20in%20the%20North%20Sea_994.pdf

然而對於海洋台灣而言，雖然挾新時代、新科技的優勢，是可以相對有效率的建設出優良的風力電場，但或許相對「軟性」的「漁船作業文化」以及「船舶航行習性」的調整與適應，才將是台灣離岸風力電場能「安全」站立與運作的根本議題。