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# Off-shore wind power generation for coastal sustainable urban development

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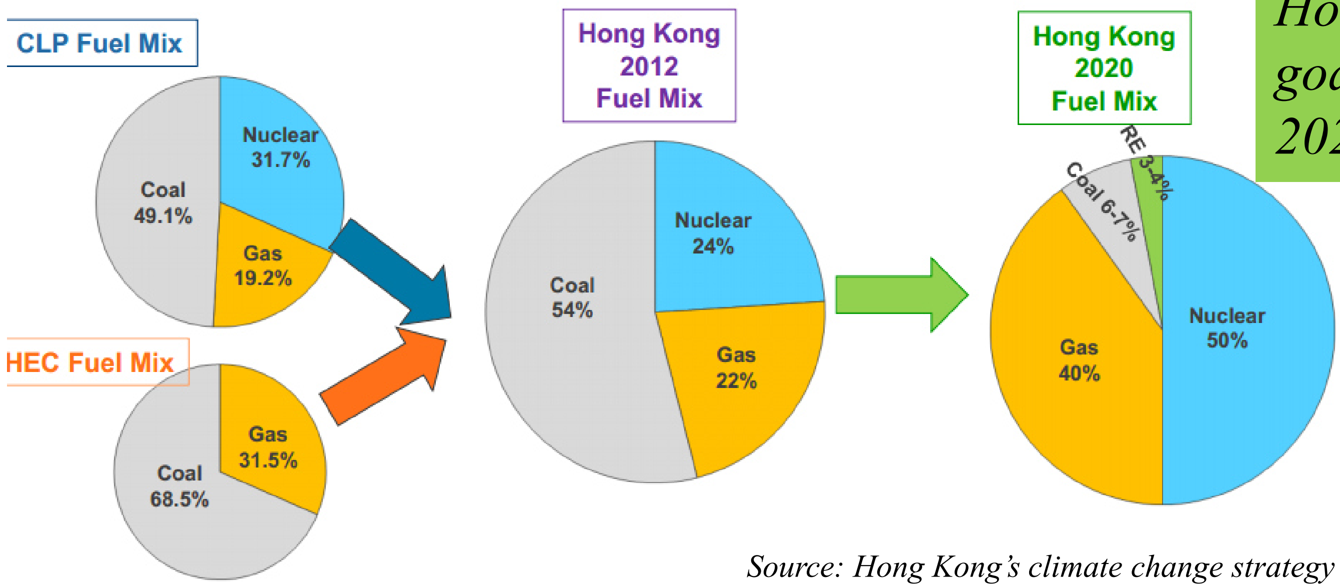
# Outlines

- Current development of wind power generation in the world
- Potential offshore wind power generation in Hong Kong
- Development of wind turbine wake models and optimization of wind turbine layout
- Conclusions

# Status of local electricity generation

- In 2012, the electricity mix in Hong Kong is constituted by
  - ✓ 24% nuclear power
  - ✓ 22% natural gas
  - ✓ 53% coal
  - ✓ **0.1% renewable energy**

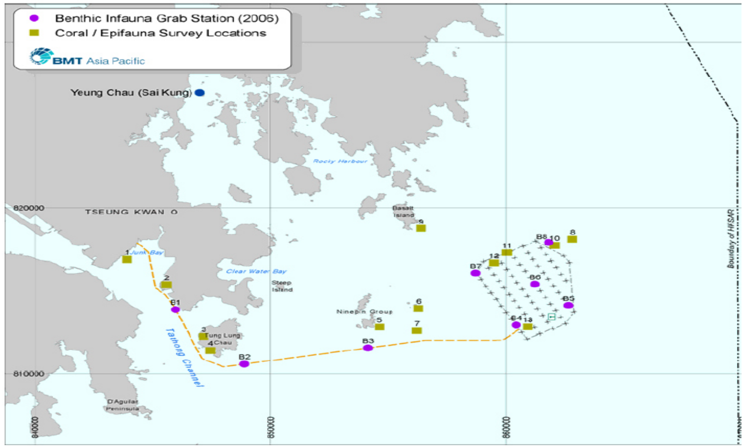



*How to achieve the goal of RE 3-4% in 2020?*

*Source: Hong Kong's climate change strategy and action agenda*
*Hong Kong Energy End-use Data 2013*

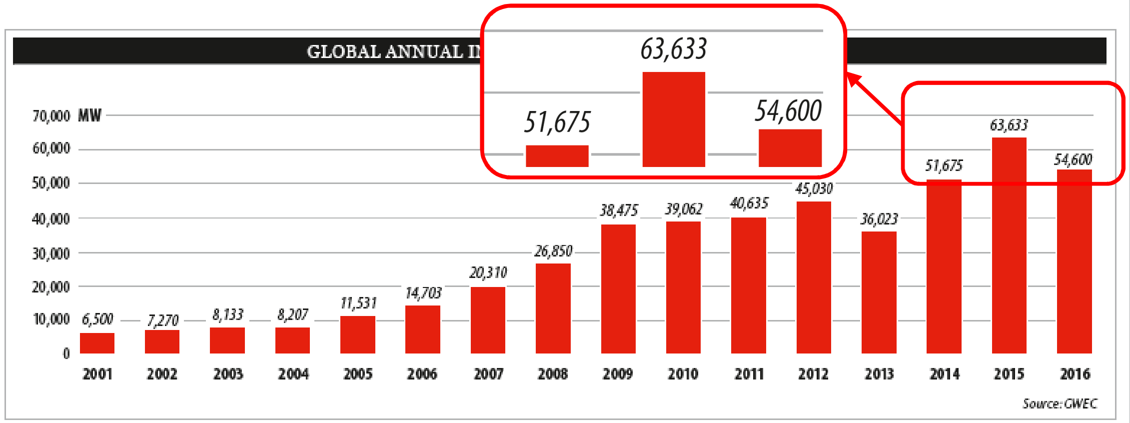
# Potential renewable energy resources in Hong Kong

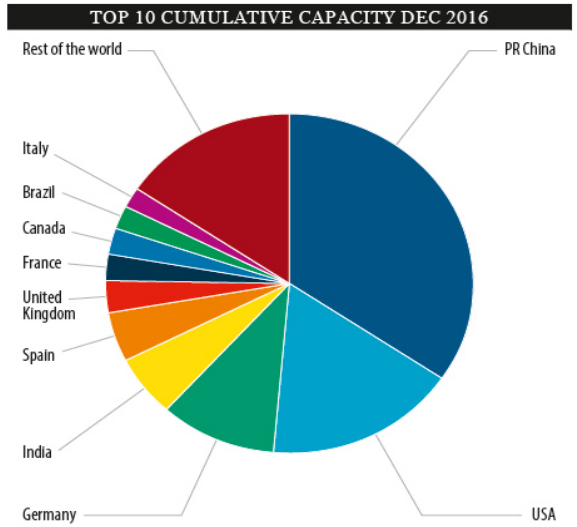
- Abundant solar and wind energy resources.
- <u>59.91% </u>of HK area is covered by water
- Two offshore wind farms are proposed by CLP and HKE which are the initial attempts in offshore wind development.




# Global annual installation of wind power

- 2016 was a record year for the wind industry as it is the third consecutive year that annual installations crossed the 50 GW. The new global total for wind power at the end of 2016 was 486.7 GW, representing cumulative market growth of more than 12.6%.

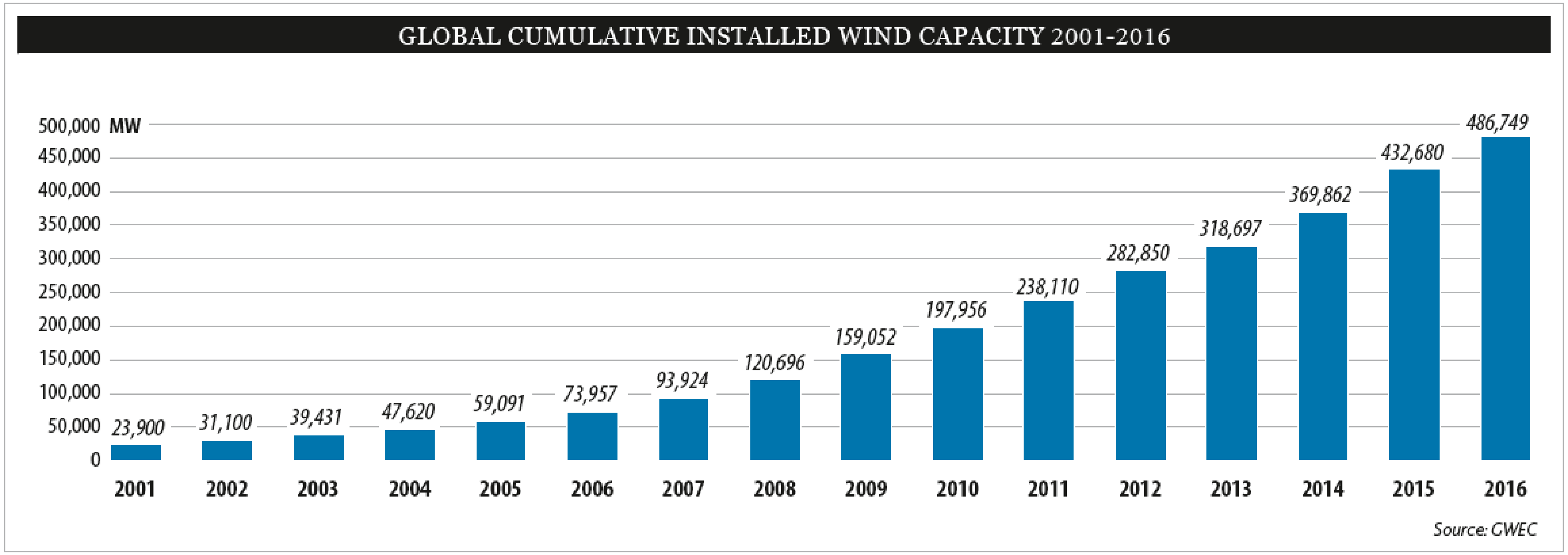



| Country | MW | % Share |
|---|---|---|
| PR China* | 168,690 | 34.7 |
| USA | 82,184 | 16.9 |
| Germany | 50,018 | 10.3 |
| India | 28,700 | 5.9 |
| Spain | 23,074 | 4.7 |
| United Kingdom | 14,543 | 3.0 |
| France | 12,066 | 2.5 |
| Canada | 11,900 | 2.4 |
| Brazil** | 10,740 | 2.2 |
| Italy | 9,257 | 1.9 |
| Rest of the world | 75,577 | 15.5 |
| **Total TOP 10** | **411,172** | **84** |
| **World Total** | **486,749** | **100** |

Source: GWEC

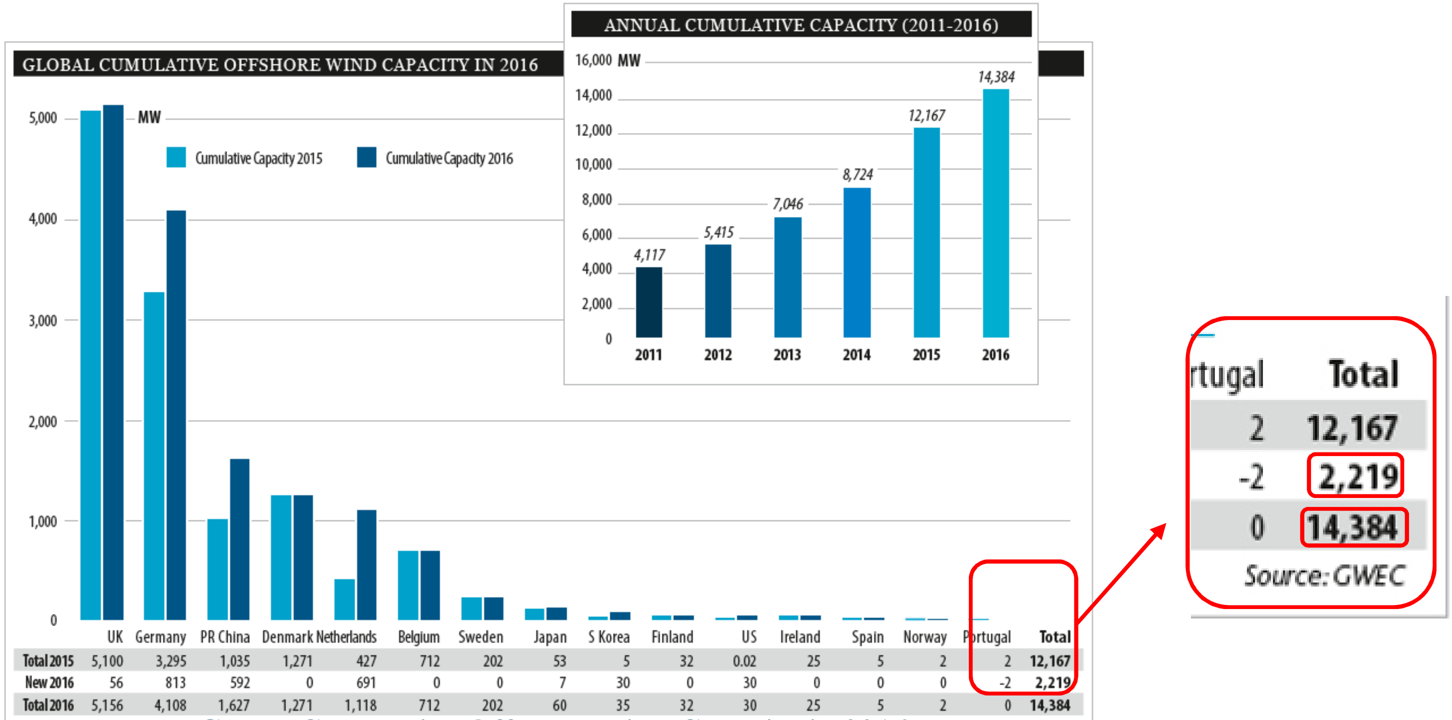
# Total cumulative installation of wind power




- By the end of last year the number of countries with more than 10,000 MW installed capacity was 9: including 4 in Europe (Germany, Spain, UK and France); 2 in Asia-Pacific (China & India); 2 in North America (US & Canada) and 1 in Latin America (Brazil).

# Development of offshore wind power in the world

◈ In 2016 only, new capacity additions totaled nearly 2.2 GW across five markets globally. This brought total offshore wind installed capacity to over 14.4 GW.




Global Cumulative Offshore Wind Capacity in 2016

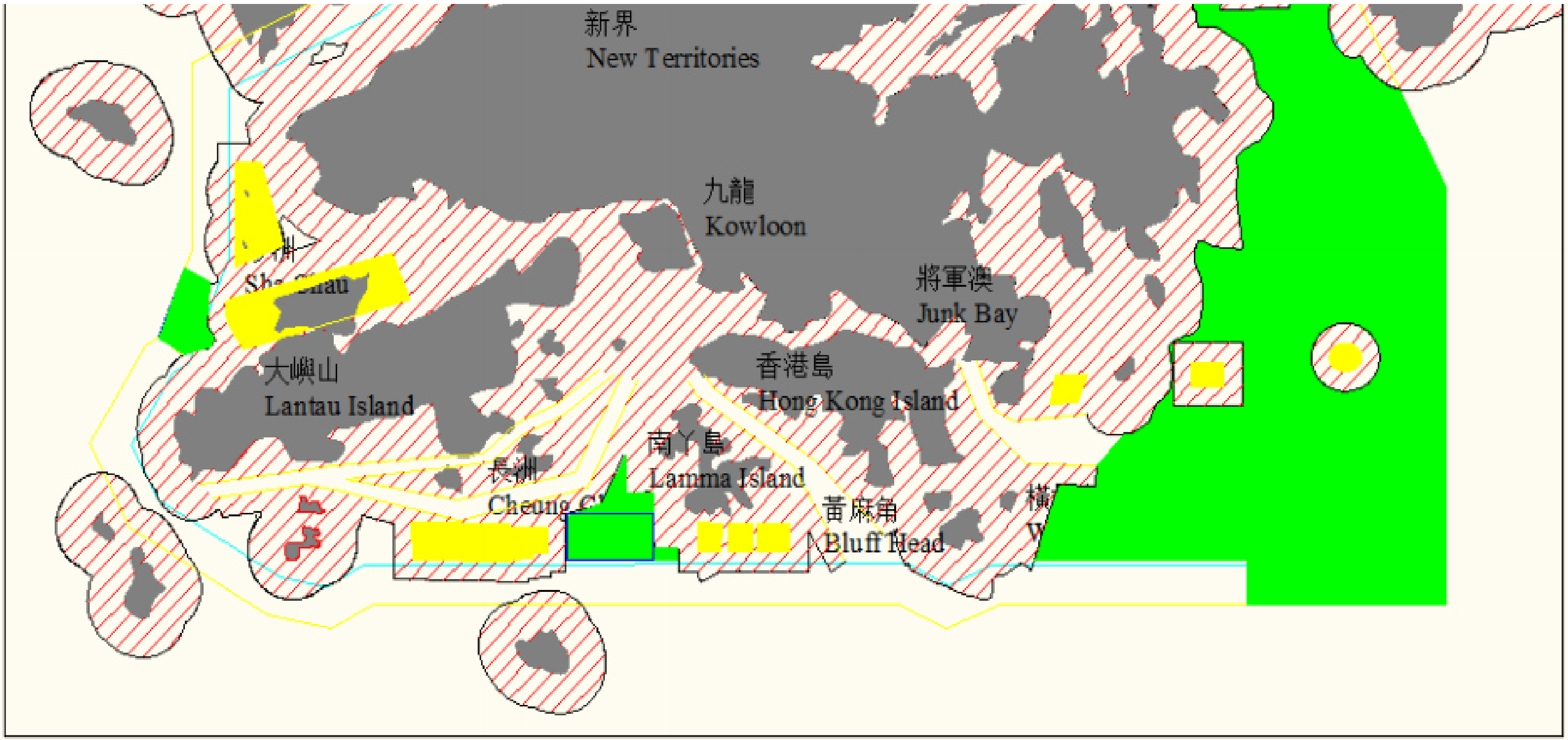
◈ Annual installations of wind power in the EU have increased over the last 15 years from 3.2 GW in 2000 to 14.4 GW in 2016. The total offshore wind capacity is still limited, but growth rates are very high!

# Hong Kong offshore wind power potential assessment

## Offshore wind farm site selection:

*The water area in Hong Kong: 1650.64 km², 59.91% of the Hong Kong territory area.*

| Area | Anemometer tower nearby | Potential wind farm location | Total area |
|---|---|---|---|
| 2320m × 4706m | Lamma Island | Southwestern Lamma Island | 16.86 $km^2$ |
| Total potential offshore wind farm location area | | | 421.48 $km^2$ |



# Hong Kong offshore wind power potential assessment

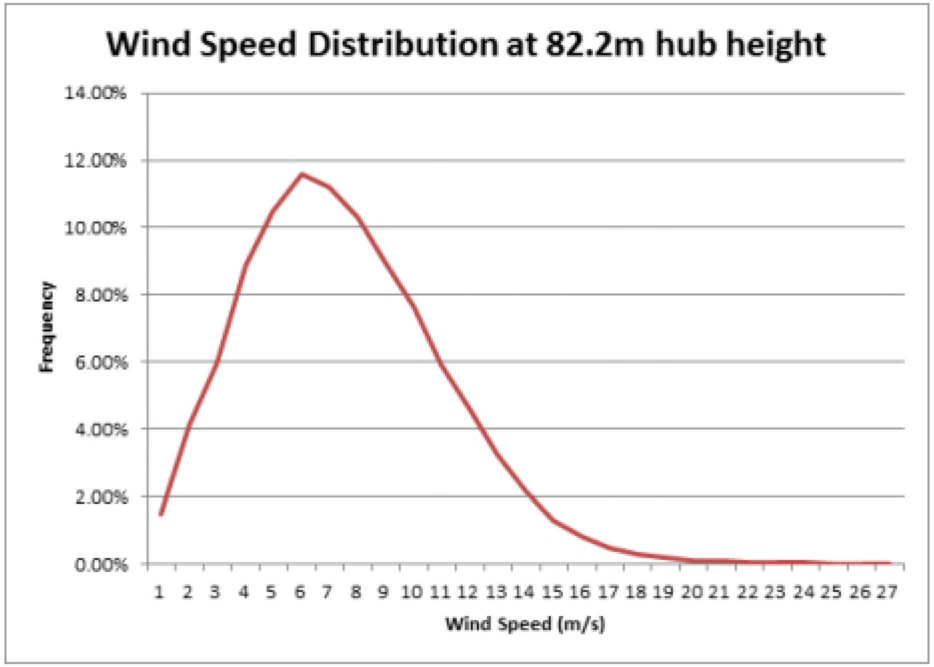
## Data collection from the site near Lamma island

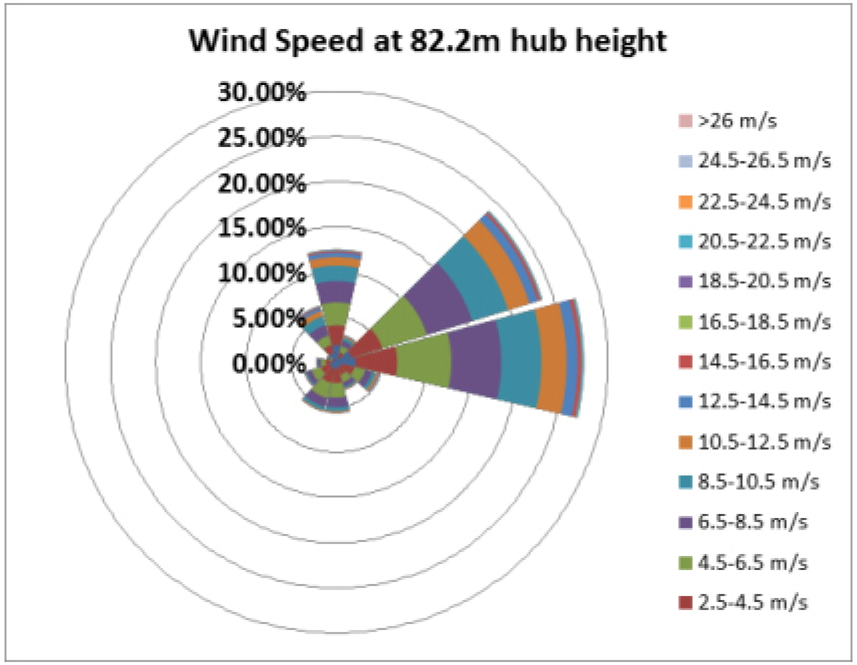
# Hong Kong offshore wind power potential assessment

## Input Data Source for the Selected Offshore Wind Farm

### Wind in the offshore wind farm near Lamma Island

*One year's wind data measured by The Hongkong Electric Co., Ltd. (HK Electric) has been used for the wind power potential analysis.*



# Hong Kong offshore wind power potential assessment

## Wind turbine:

*5 MW wind turbine is selected.*

| Name of parameters | Value |
|---|---|
| Hub height $z$ (m) | 85 |
| Wind turbine rotor $R_r$ (m) | 63 |
| Downstream rotor radius $R_d$ (m) | 77.06 |
| Turbine thrust coefficient $C_T$ | 0.7486 |
| Roughness length of ground $z_0$ (m) | 0.001 |
| The entrainment constant α | 0.044 |
| The axial induction factor a | 0.249 |

*Power generation:*

$$P(v)=\begin{cases} 0; v < 3.5 \\ 5140\times\exp(-((v-13.31)/5.162)^2); 3.5 \le v < 13.31 \\ 5140; 13.31 \le v < 30 \\ 0; v \ge 30 \end{cases}$$

# Objective function: Lowest COE

*Cost factor calculations:*

| Cost factor(€/MW) | Variables | Model |
|---|---|---|
| Turbines | Turbine size | $1.1*10^6$ |
| Foundation | Water depth( $h_w$ ) | $(499h_w^2+6219h_w+311810)\times1.4(0<h_w<25)$ |
| | | $(440h_w^2+19695h_w+901691)\times1.4(h_w\geq25)$ |
| Grid | The least subsea cost distance $d_s$ (km)<br>The least land cost distance $d_l$ (km) | $(0.38d_s+0.4d_l+76.6)\times10^6/600$ |
| O&M | Least cost distance to service harbour $d$ (km) | $(0.29d^2+159d+50415)\times0.4$ |
| Other | The percentage of investment costs | 10% |

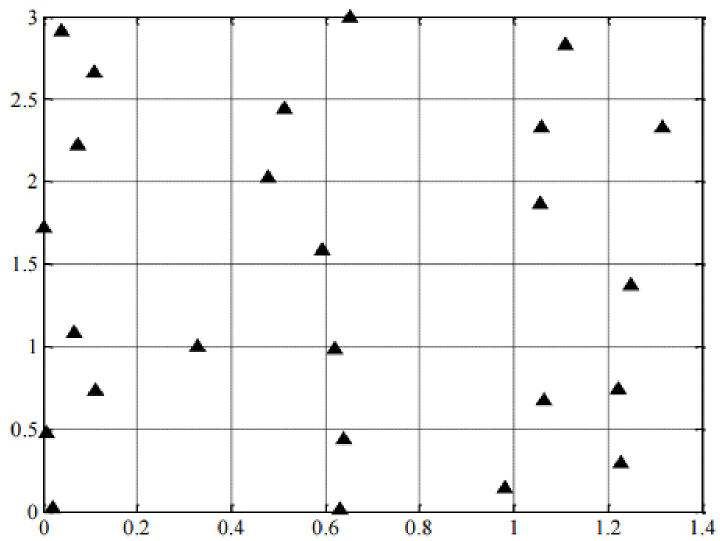
*COE calculations:* $COE=(C_c.FCR+C_{O\&M})/AEP$

- Fixed Charge Rate = 15%
- The wind farm is operating 24 hours a day
- The price for electricity is 0.143USD/kWh =1.45HKD/kWh

# Hong Kong offshore wind power potential assessment

**Optimization results of the selected wind farm near Lamma Island and the assessment of Hong Kong offshore wind power potential**

| Number of WTs | Total Power ($10^8$ kWh) | Total Cost ($10^8$ HKD) | COE(HKD/kWh) |
|---|---|---|---|
| 25 | 5.78 | 27.24 | 1.55 |




| Item | Offshore wind |
|---|---|
| Power potential | 14449 GWh |
| Proportion of electricity use in HK in 2014 | 32.91% |
| Saving coal's importation | 33374845 |
| Proportion of importation coal | 53.79% |
| Saving natural gas's importation | 4531514 |
| Proportion of importation natural gas | 156% |
| COE (HKD/kWh) | ~1.5 |

# Determination of the optimal layout patterns

| WF configuration | WT layout distance | APG ($\times 10^8$kWh) | WT numbers | APG per WT ($\times 10^6$ kWh) | LCOE (HK$/ kWh) | WFE (%) |
|---|---|---|---|---|---|---|
| Aligned WF | 14.5D×11.0D | 5.48 | 28 | 19.56 | 1.474 | 86.84 |
| | 14.5D×11.5D | 5.57 | 28 | 19.90 | 1.475 | 88.37 |
| | 14.5D×8.5D | 6.58 | 36 | 18.29 | 1.476 | 81.15 |
| | 14.5D×9.0D | 6.56 | 36 | 18.22 | 1.478 | 80.93 |
| | 14.0D×9.5D | 6.33 | 32 | 19.78 | 1.480 | 87.85 |
| | 14.5D×12.0D | 5.44 | 28 | 19.44 | 1.483 | 86.31 |
| | 14.5D×10.0D | 6.39 | 32 | 19.95 | 1.484 | 88.59 |
| | 15.0D×12.0D | 5.32 | 28 | 19.00 | 1.484 | 84.35 |
| | 14.0D×12.0D | 5.44 | 28 | 19.43 | 1.489 | 86.25 |
| | 12.0D×11.5D | 6.84 | 35 | 19.54 | 1.491 | 86.74 |
| Staggered WF | 14.5D×11.0D | 5.43 | 28 | 19.39 | 1.467 | 86.07 |
| | 14.5D×8.5D | 6.57 | 34 | 19.33 | 1.473 | 85.80 |
| | 14.0D×9.5D | 6.33 | 32 | 19.29 | 1.476 | 85.59 |
| | 14.0D×11.0D | 5.38 | 28 | 19.21 | 1.480 | 85.30 |
| | 14.5D×9.5D | 6.13 | 32 | 19.16 | 1.485 | 85.08 |
| | 14.5D×10.0D | 5.74 | 30 | 19.13 | 1.487 | 84.95 |
| | 14.5D×9.0D | 6.50 | 34 | 19.12 | 1.489 | 84.92 |
| | 14.5D×11.5D | 4.94 | 26 | 19.00 | 1.497 | 84.36 |
| | 15.0D×10.0D | 5.69 | 30 | 18.97 | 1.500 | 84.23 |
| | 12.0D×11.0D | 6.65 | 35 | 18.99 | 1.501 | 84.34 |
| Scattered WF | - | 6.29 | 30 | 20.97 | 1.290 | 93.12 |
| | - | 5.55 | 27 | 20.57 | 1.315 | 91.34 |
| | - | 5.32 | 26 | 20.48 | 1.321 | 90.94 |
| | - | 5.73 | 28 | 20.47 | 1.322 | 90.90 |
| | - | 7.84 | 39 | 20.10 | 1.346 | 89.25 |
| | - | 6.61 | 33 | 20.03 | 1.351 | 88.94 |
| | - | 6.96 | 35 | 19.88 | 1.361 | 88.28 |
| | - | 4.97 | 25 | 19.86 | 1.362 | 88.19 |

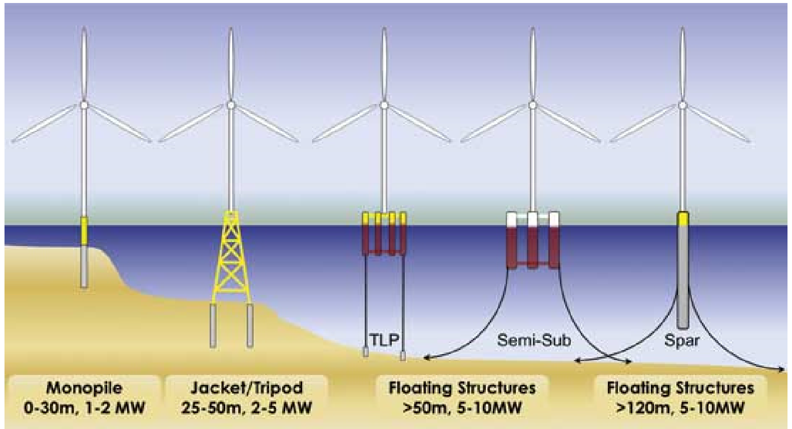
# Study on Offshore Decommissioning Cost

- The year 2015 is the first time that offshore turbines were decommissioned. At one offshore wind farm of UK, the other five were installed at Sweden. In the year 2016, the decommissioned offshore wind capacity were approximately 520 MW.

First Decommissioning of an Offshore Wind Farm

- **The unexpected increase in decommissioning costs is a crucial factor that cannot be ignored as for the huge economical burden.**

- Some institutes estimate it will cost €200,000-500,000/MW, equals to 60-70% of installation costs (DNV GL) or 2.5% of the total project cost (The Contact Programme) to decommission offshore turbines.




Types of offshore wind turbine foundations

- The life expectancy of the offshore wind turbine is around 25–30 years. However, the foundation is always overdesigned.

- **It is possible and meaningful to develop the decommissioning strategy to reduce the cost from the initial design phase of an offshore wind farm.**

# Decommissioning Strategy

$$Cost_{total} = Cost_{capital} + Cost_{O\&M} + Cost_{levelised}$$

Wind Turbine costs, foundation costs, installation, grid connection cost and decommissioning cost);

Operation and maintenance costs;

Related to wind, varies depending on the wind resource and project costs, but at good wind sites can be very competitive.

## ◈ Decommissioning Strategy

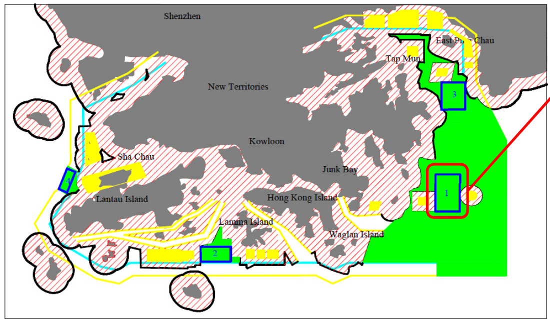
**When the first generation offshore wind turbines are decommissioned, foundations can still be on service after some strengthen strategies in the second generation.**

$$Cost_{capital} = Cost_{WT1} + Cost_{f1} + Cost_{install1} + Cost_{strengthen} + Cost_{WT2} + Cost_{install2} + Cost_{decommission2}$$

## ◈ Offshore Wind Farm Optimization

The wind turbine layout optimizing process is based on the Multi-Population Genetic Algorithm (MPGA). The Cost of Energy (COE) is regarded as the criteria to judge the new method. The COE is on account of two generations' energy output and total cost.

# Application of Decommissioning Strategy

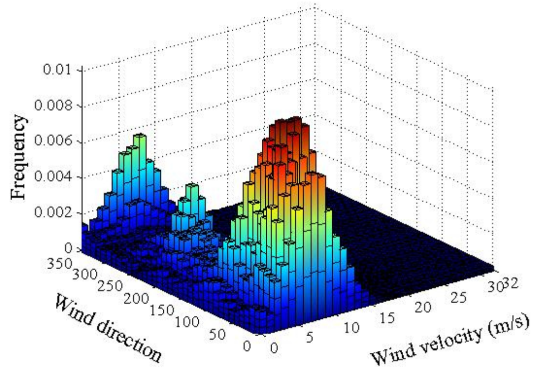



Potential Offshore Wind Farm Selections (Gao. et al)

**Waglan Island Sea Area**

**Selected area: 3740m×5828m**

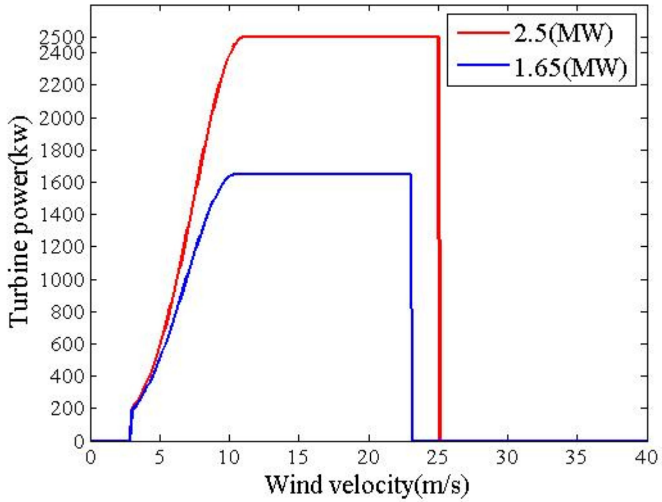
Wind data source:
Royal Observatory, Hong Kong




Wind Velocity Frequency Distribution in Waglan Island Sea Area

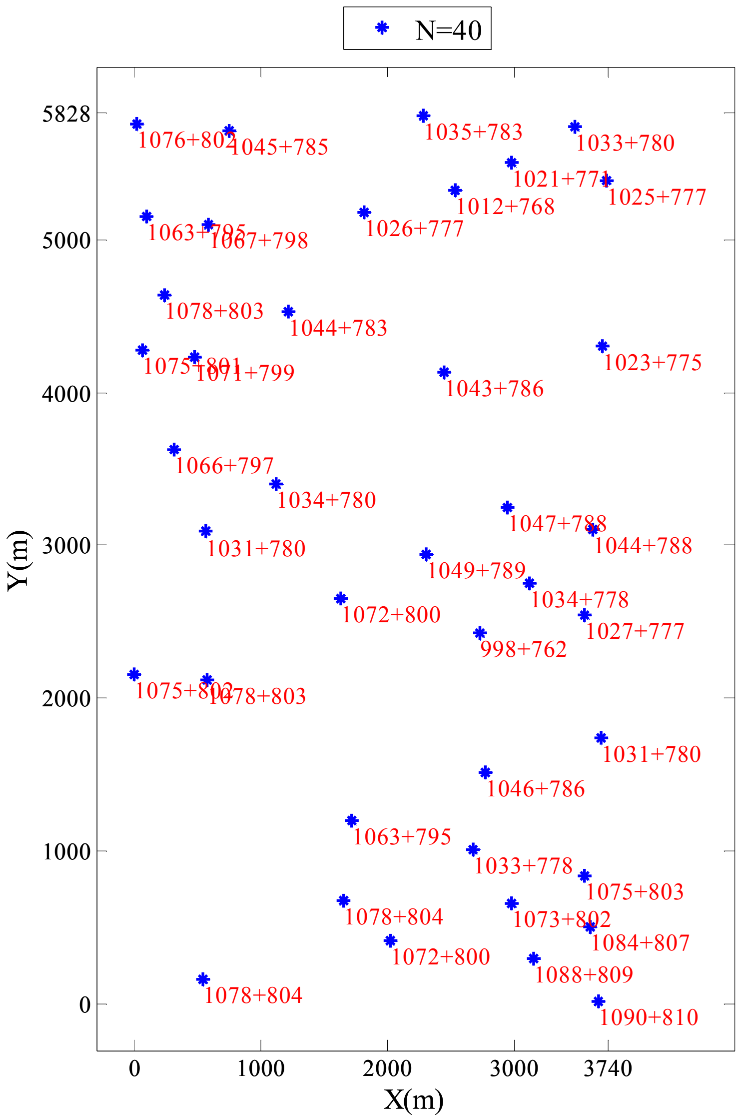
**Parameters of Wind Turbines**

| Parameters | Turbine1 | Turbine2 |
|---|---|---|
| Rated power | 2.5MW | 1.65MW |
| Cut-in wind speed | 3 | 3 |
| Rated wind speed | 11.1 | 10.5 |
| Cut-out wind speed | 25 | 23 |
| Rotor diameter | 108 | 88 |
| Hub height | 80 | 70 |




Wind Turbine Power Curves

# Application of Decommissioning Strategy

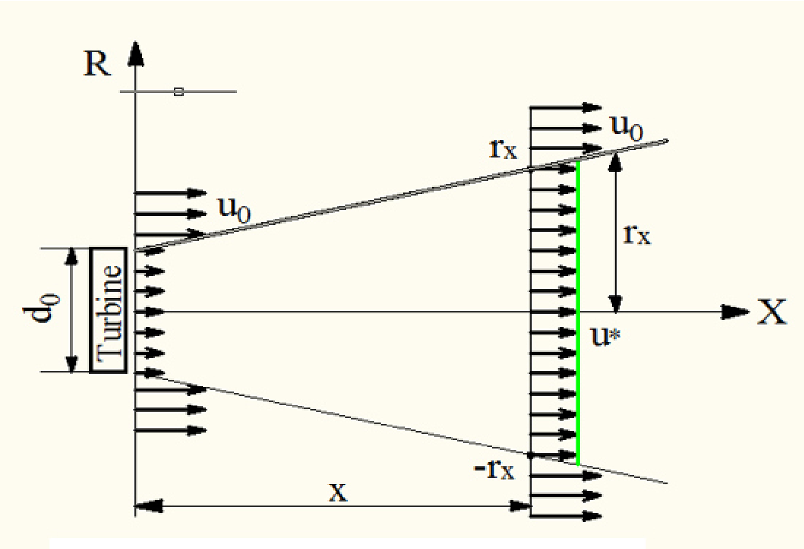


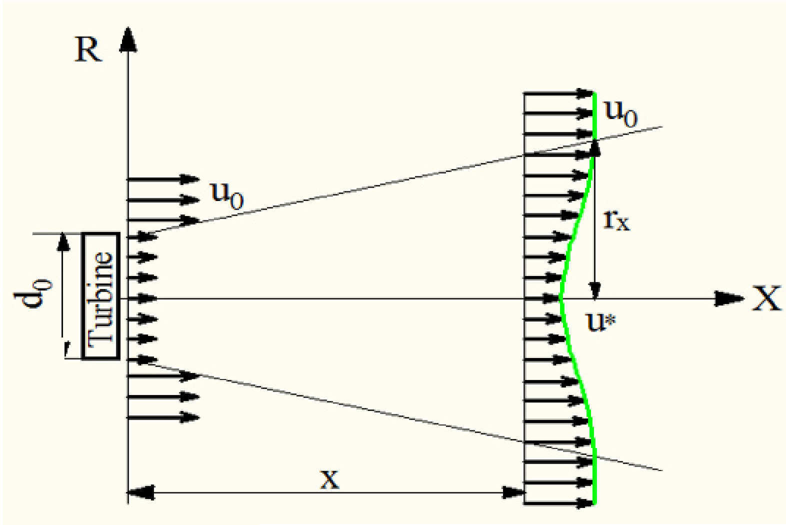

**Optimized Layout and Wind Turbine Power**
**( with Decommissioning Strategy)**
**(Conventional)**

**Results of Optimized Layouts**

| | Convention strategy | Decommissioning strategy | |
|---|---|---|---|
| **Number of wind turbine** | 40 | 40 | |
| **Service years** | 2×20 | 40 | |
| **Energy yield (Gw·h)** | $2\times7.55\times10^3$ | $13.18\times10^3$ | |
| **Total cost (MHKD)** | $2\times8.96\times10^3$ | $13.47\times10^3$ | **24.83%** |
| **COE (HKD/Kw·h)** | 1.19 | **1.02** | **13.94%** |

# Study on wind turbine wake model




**Jenson:** $$\frac{\Delta u}{u_0} = \left(1-\sqrt{1-C_T}\right) \Big/ \left(1+\frac{2kx}{d_0}\right)^2$$

**Jenson-Gaussian:** $$u = A\left(\frac{1}{\sigma\sqrt{2\pi}} \cdot e^{\frac{-r^2}{2\sigma^2}}\right) + B$$

**Three assumptions:**

1. **The same radius:** $2.58\sigma = r_x$

2. **When r=rx :** $A\left(\frac{1}{\sigma\sqrt{2\pi}} \cdot e^{\frac{-(\pm r_x)^2}{2\sigma^2}}\right) + B = u_0$

3. **The same mass flux:** $\int_{-r_x}^{r_x} \left( A\left(\frac{1}{\sigma\sqrt{2\pi}} \cdot e^{\frac{-(y)^2}{2\sigma^2}}\right) + B \right) dx = u^* \cdot 2r_x$

$$\begin{cases} u^* = u_0\left[1-2a/(1+kx/r_1)^2\right] \\ u = u_0 - (u_0 - u^*)\dfrac{5.16}{\sqrt{2\pi}} \cdot e^{\frac{-r^2}{2\cdot\left(r_x/2.58\right)^2}} \end{cases}$$

# Turbine wake model development

## Improved Wake Model: new development

*Wake decay constant k was effected by ambient turbulence level o that the turbine induces turbulence!*

*Before modified k, turbulence model should be improved.*

Frandsen et al's model, 1996

$$I_{wake} = \sqrt{K_n \frac{C_T}{(x/D)^2} + I_0^2}$$

Tian et al.'s model, 2015

$$I_{wake} = K_n \frac{C_T}{x/D} + I_0$$

*Iwake is determined by the $I_0$, $C_T$ and $x/D$.*

**Proposed turbulence model:**

$$I_{wake} = \left( K_n \frac{C_T}{(x/D)^{0.5}} + I_0^{0.5} \right)^2$$

# Turbine wake model development

## Improved Jenson-Gaussian Wake Model: Development

Using this equation to calculate *kwake*: $$k_{wake} = k\frac{I_{wake}}{I_0}$$

Replacing wake decay constant *k* in the Jenson-Gaussian wake model using *kwake*

**Improved Jenson-Gaussian wake model:**

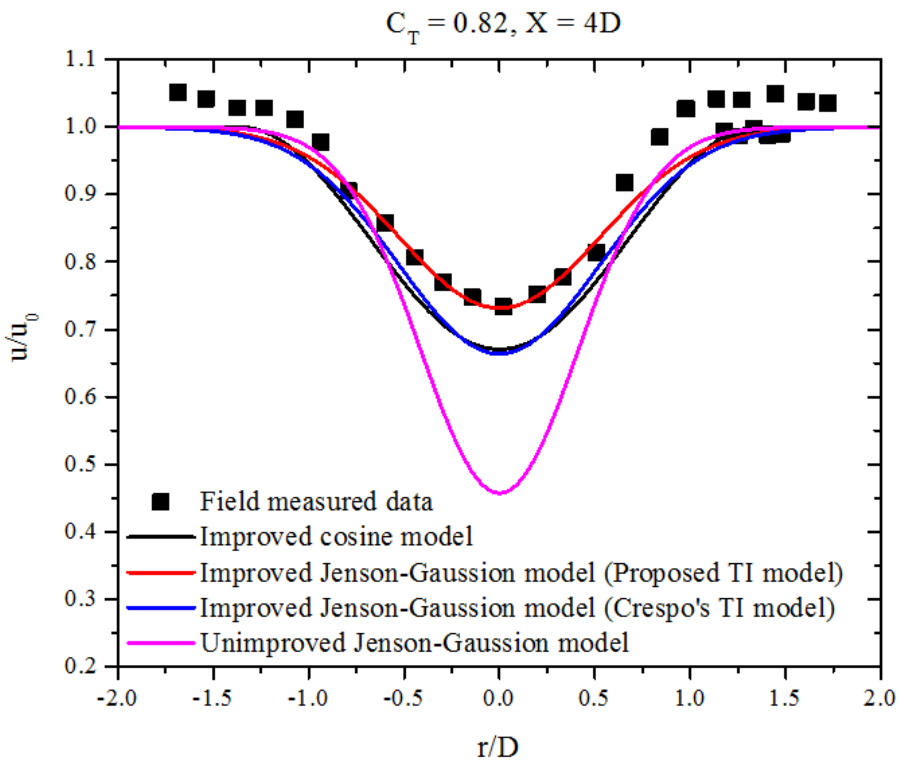
$$\begin{cases} u^* = u_0\left[1 - 2a/(1 + k_{wake}x/r_1)^2\right] \\ u = u_0 - (u_0 - u^*)\dfrac{5.16}{\sqrt{2\pi}} \cdot e^{\frac{-r^2}{2\left(r_x/2.58\right)^2}} \end{cases}$$

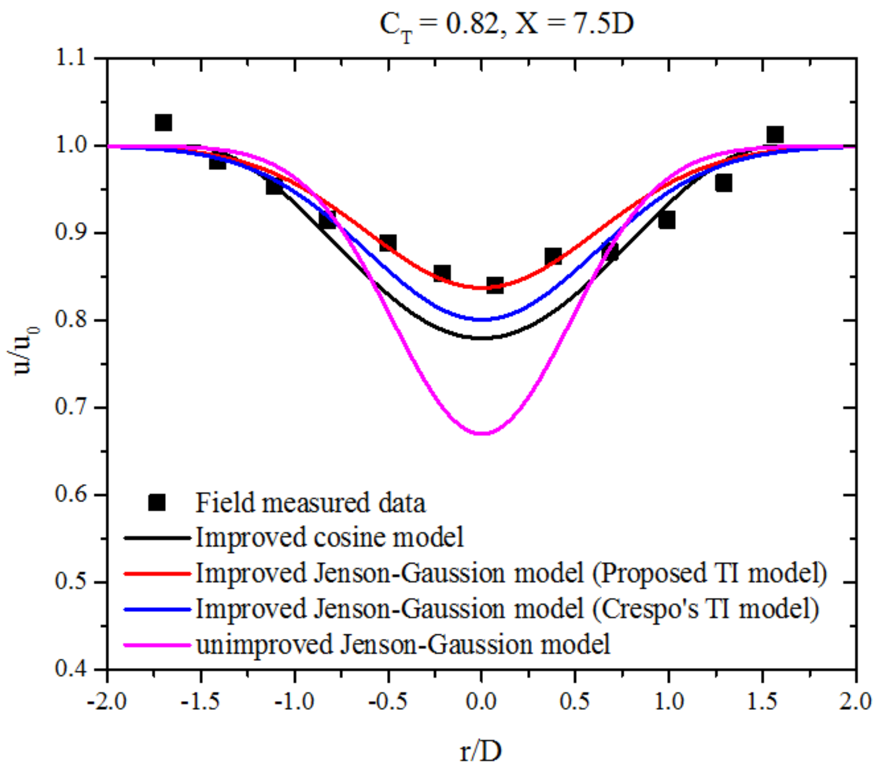
# Turbine wake model development

## Improved Jenson-Gaussian Wake Model: Validation

*With previous models and data from field experiment (Taylor's study of Nibe site).*

*Two turbines, 45m hub height , 40 diameters, wind speed of 8.55m/s.*




**'Qualified' good performance is obtained by the improved Jenson-Gaussian wake model !**

# Turbine wake model development

## Analytical Wake Model for Multiple Turbines in Row:

**superposition**

Wake model of single turbine:

$$\begin{cases} u^* = u_0\left[1 - 2a/(1 + k_{wake}x/r_1)^2\right] \\ u = u_0 - b \cdot \exp\left[\dfrac{-(r - r_c)^2}{2s_w^2}\right] \end{cases}$$

$$b = (u_0 - u^*)\frac{5.16}{\sqrt{2\pi}}$$

$$s_w = {r_x}/{2.58}$$

Wake model of two turbines:

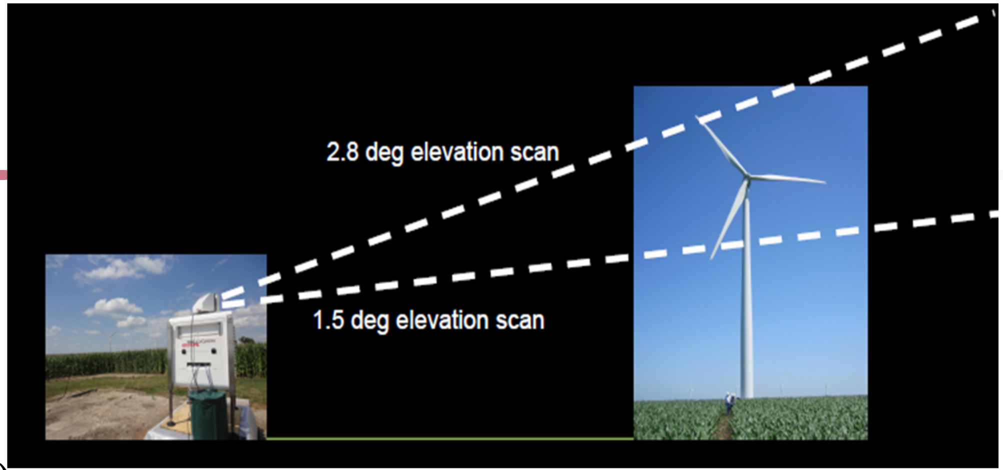
$$\begin{cases} u^* = u_0\left[1 - 2a/(1 + k_{wake}x/r_1)^2\right] \\ u = u_0 - b_1\left\{\exp\left[\dfrac{-(r - r_{c1})^2}{2s_{w1}^2}\right]\right\} - b_2\left\{\exp\left[\dfrac{-(r - r_{c2})^2}{2s_{w2}^2}\right]\right\} \end{cases}$$

Wake model of multiple turbines:

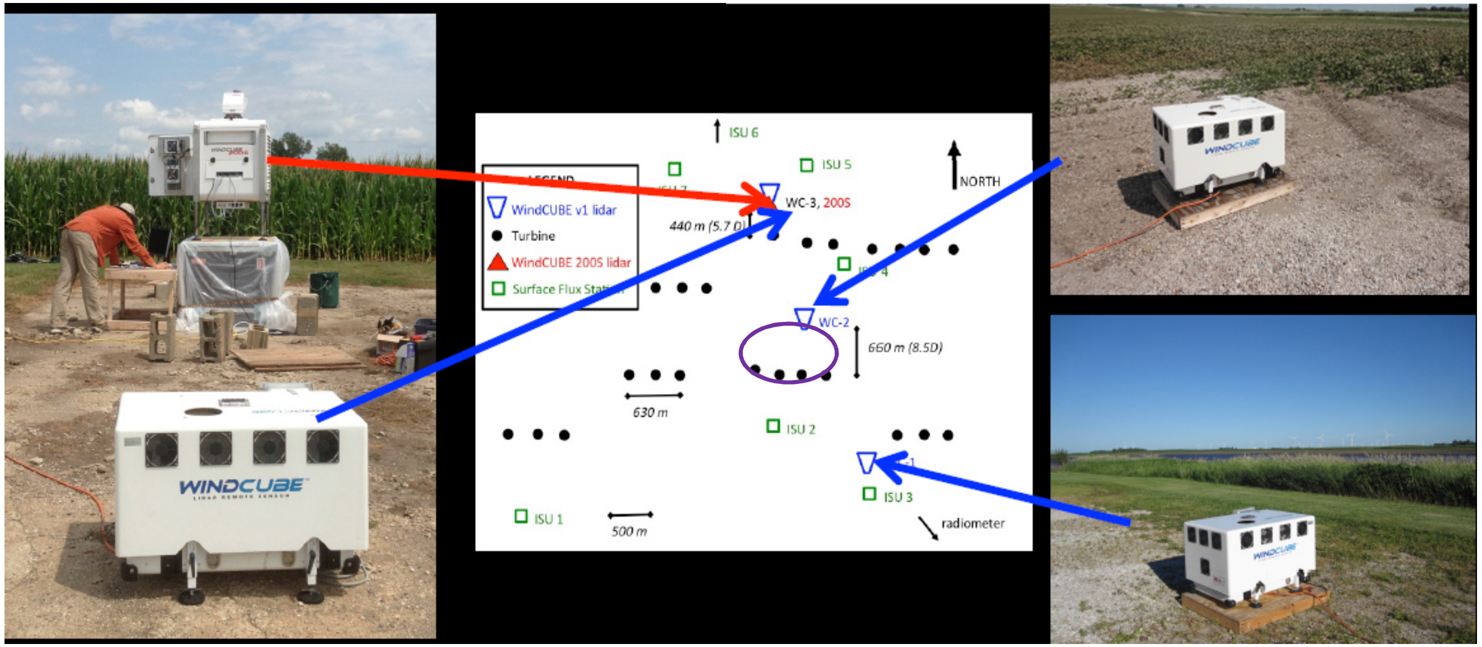
$$\begin{cases} u^* = u_0\left[1 - 2a/(1 + k_{wake}x/r_1)^2\right] \\ u = u_0 - b_1\left\{\exp\left[\dfrac{-(r - r_{c1})^2}{2s_{w1}^2}\right]\right\} - \ldots - b_n\left\{\exp\left[\dfrac{-(r - r_{cn})^2}{2s_{wn}^2}\right]\right\} \end{cases}$$

# Field experiment

## CWEX-13 Field Experiment:




- 300 MW of GE 1.5 XLE
  (80m hub height, 80m D)
- Three profiling lidars (WindCUBEv1)
  - WS and WD at 1 Hz; 40m to 220m above the surface; 29 June – 5 Sept, 2013
- One scanning lidar (WindCUBE 200S)
  - Line-of-sight (LOS) velocities from six elevations of PPI scans



# Field experiment & findings

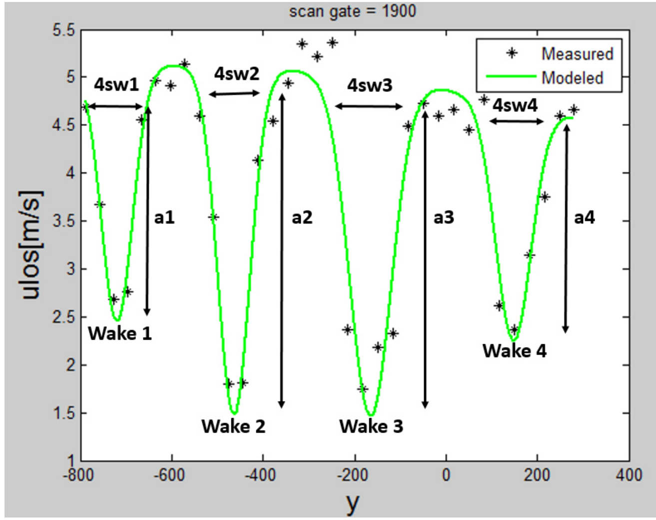
## Validation for the Multiple Wakes of Turbines in Row

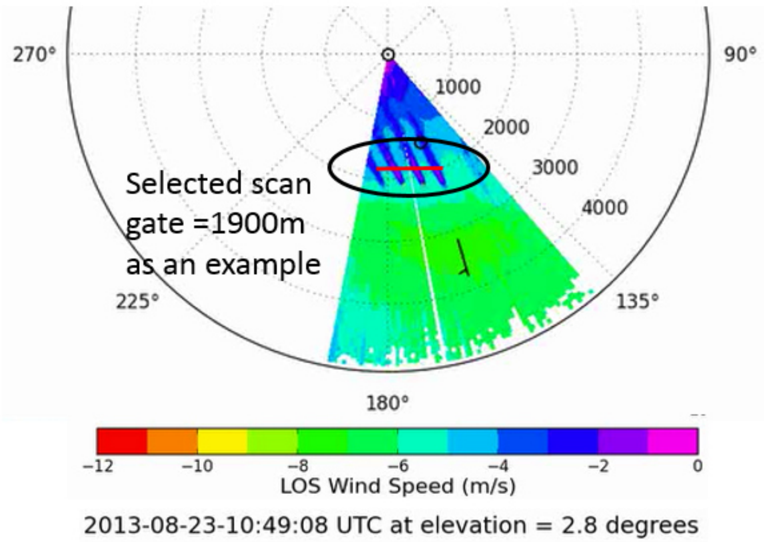
## Fitting and Validation

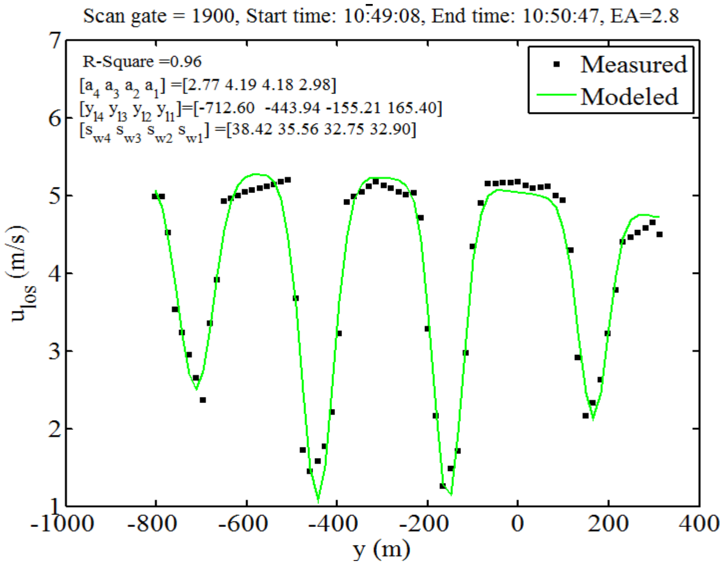

**Divided wind turbine into two styles**

Velocity deficit: $\mathrm{VD} = \frac{u-(u-a)}{u} \times 100\% = \frac{a}{u} \times 100\%$

Wake width: $w = 4s_w$



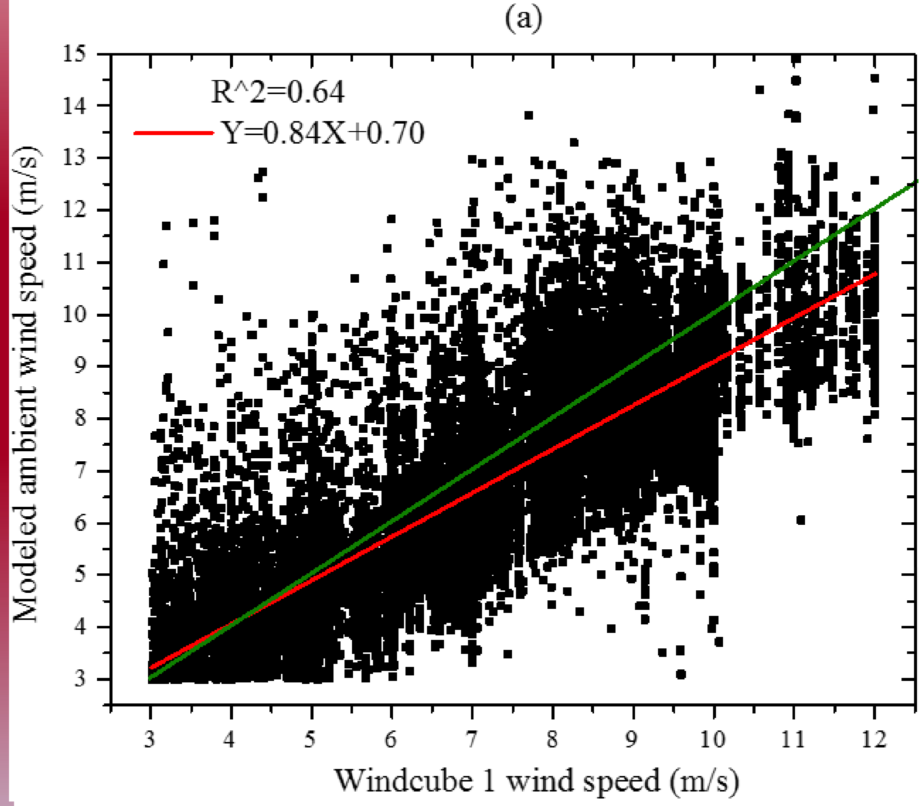



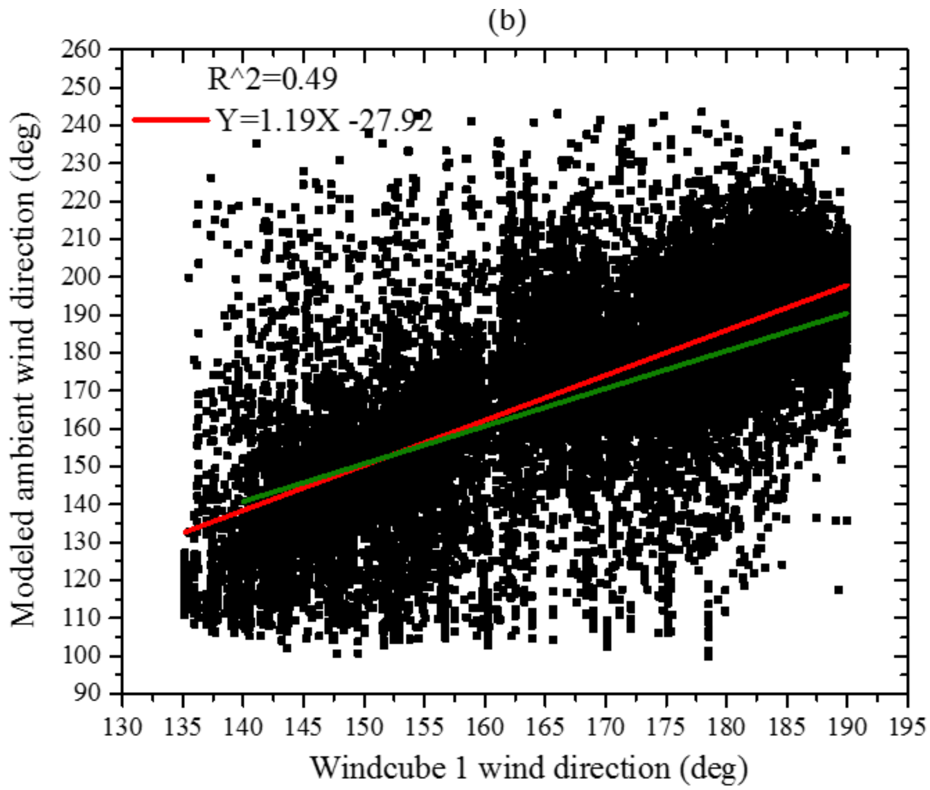



# Field experiment & findings

## Multiple Wakes' Characteristics under Different Atmospheric Conditions

## Comparisons between measured data and modeled

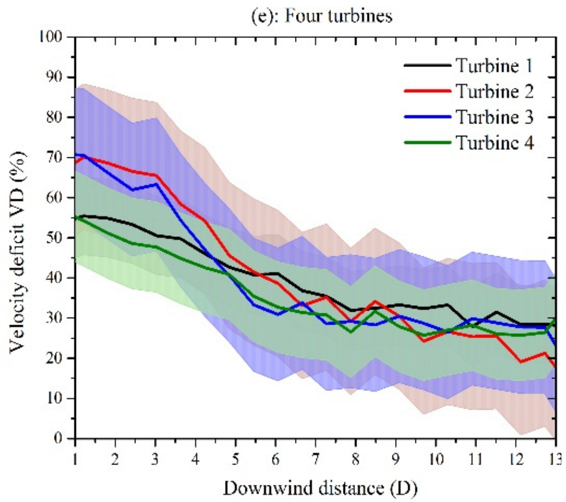


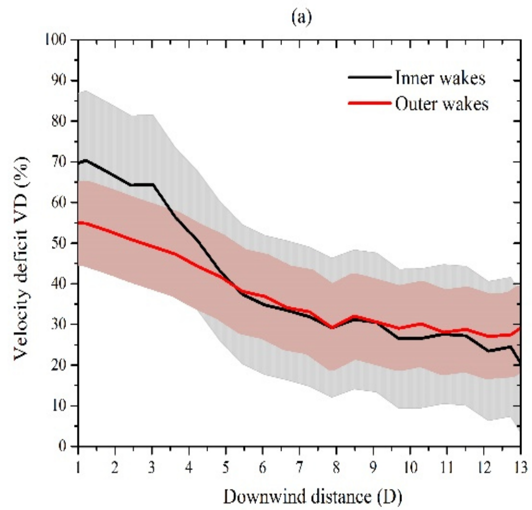



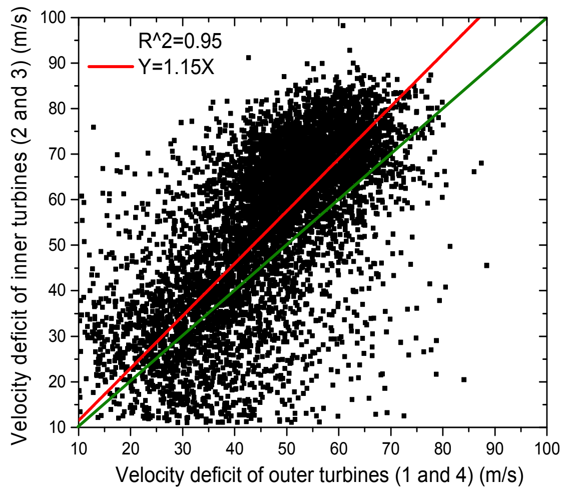
# Field experiment & findings

## Multiple Wakes' Characteristics under Different (ACs)

### - Velocity deficit



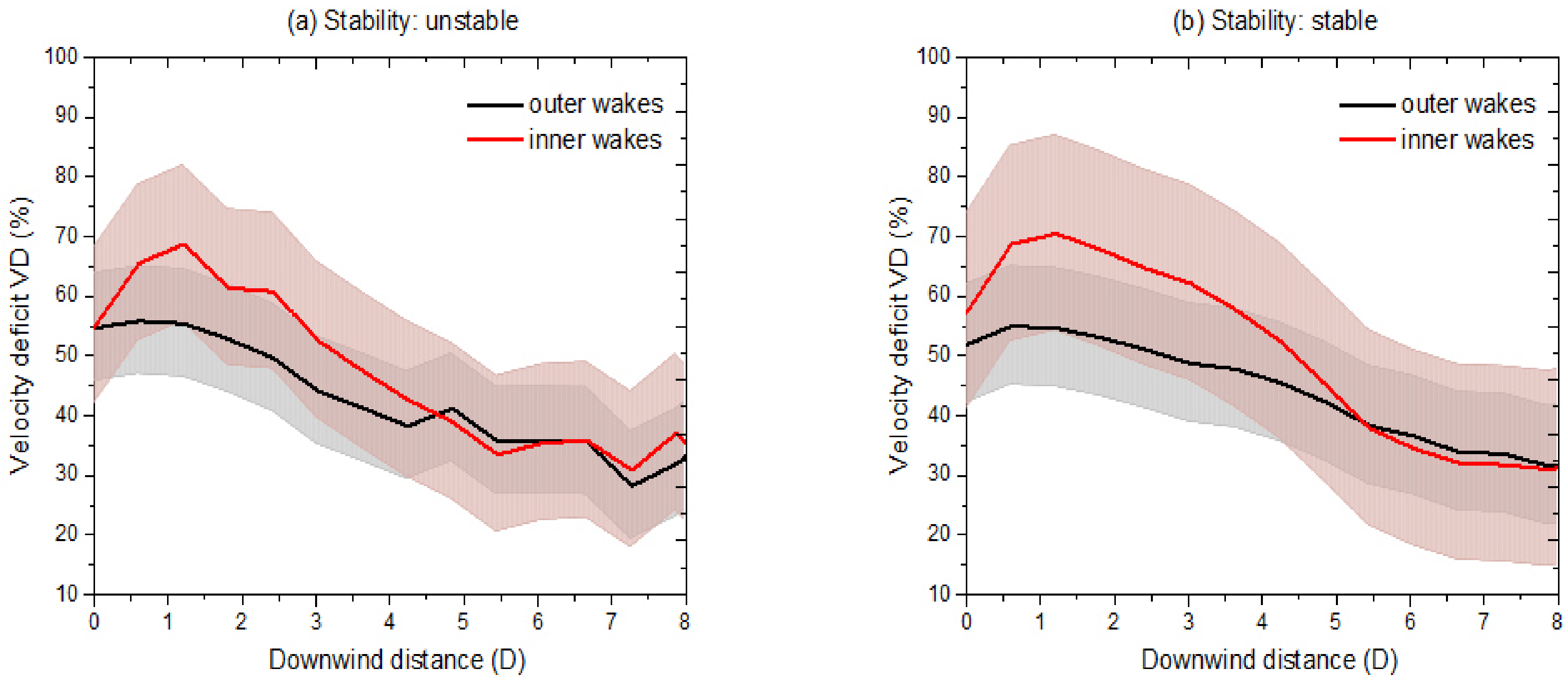

**Summarizes:**

- **Velocity deficit, 55% for outer turbine and 70% for inner ones.**
- **No differences after the downwind distance of 5D.**
- **The VD of the inner one is 1.15-fold of VD caused by the outer turbine.**
- **Wakes from the outer turbines erode faster than that from the inner ones.**

# Field experiment & findings

## Multiple Wakes' Characteristics under Different ACs

### - Velocity deficit under different atmospheric stabilities



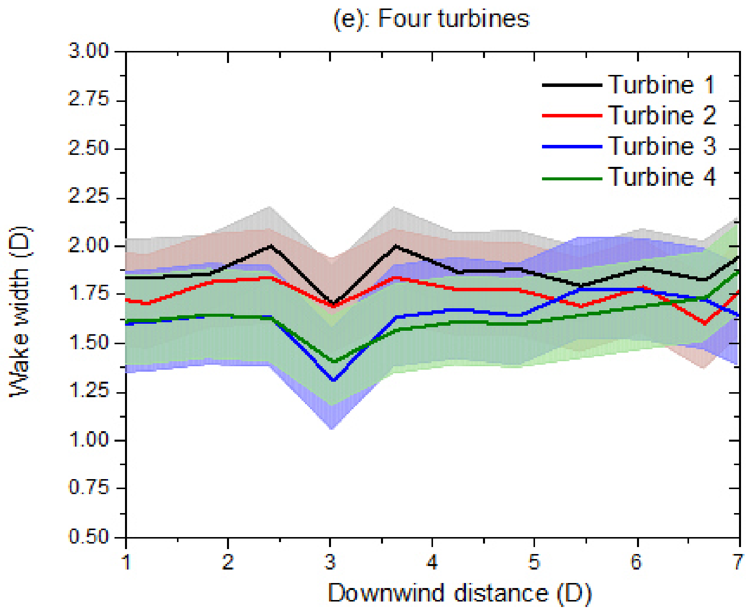

**Summarizes:**

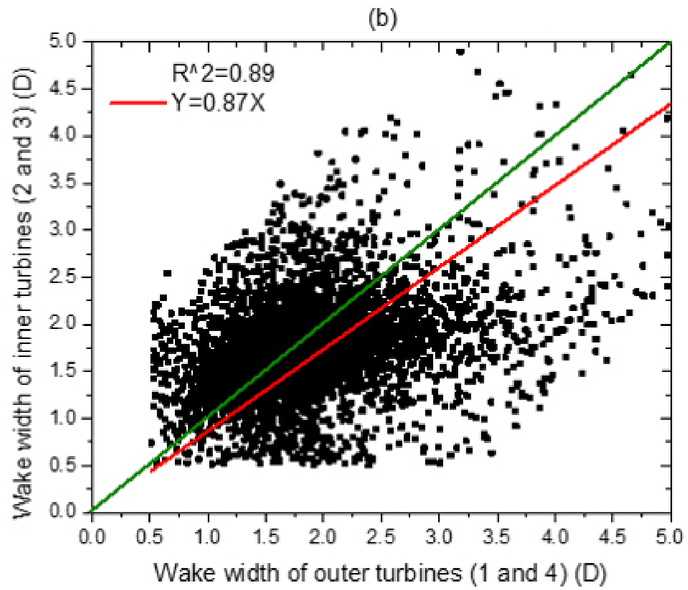
**Few influence of the atmospheric stabilities on the velocity deficit can be observed. Still the inner wakes have bigger velocity deficit than that of the outer wakes in both stable and unstable conditions.**

# 4. Field experiment & findings

## Multiple Wakes' Characteristics under Different ACs

### - Wake width



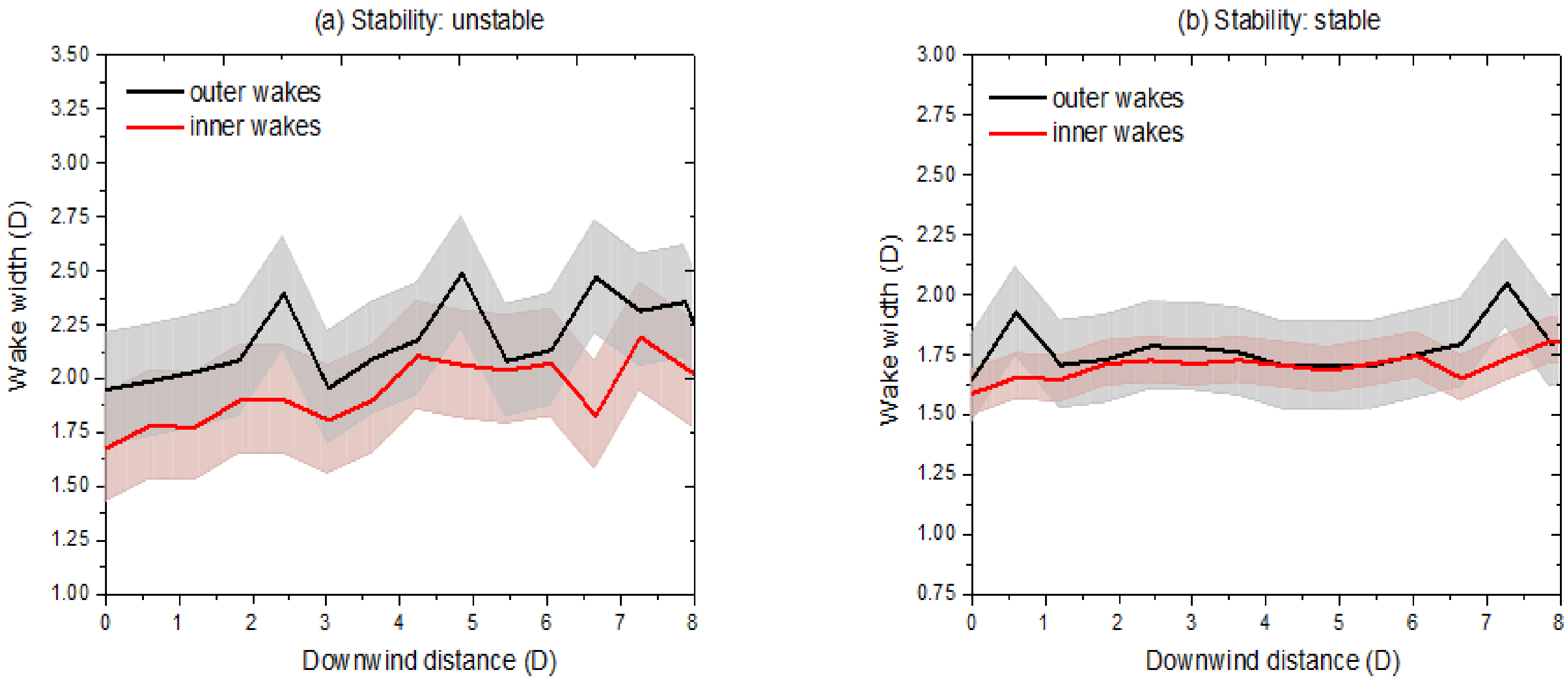

**Summarizes:**

- **Wake width, in the range of 1.5D-2.0D.**
- **The WW of the inner one is 0.87-fold of WW caused by the outer turbine.**

# 4. Field experiment & findings

## Multiple Wakes' Characteristics under Different ACs

### - Wake width under different atmospheric stability



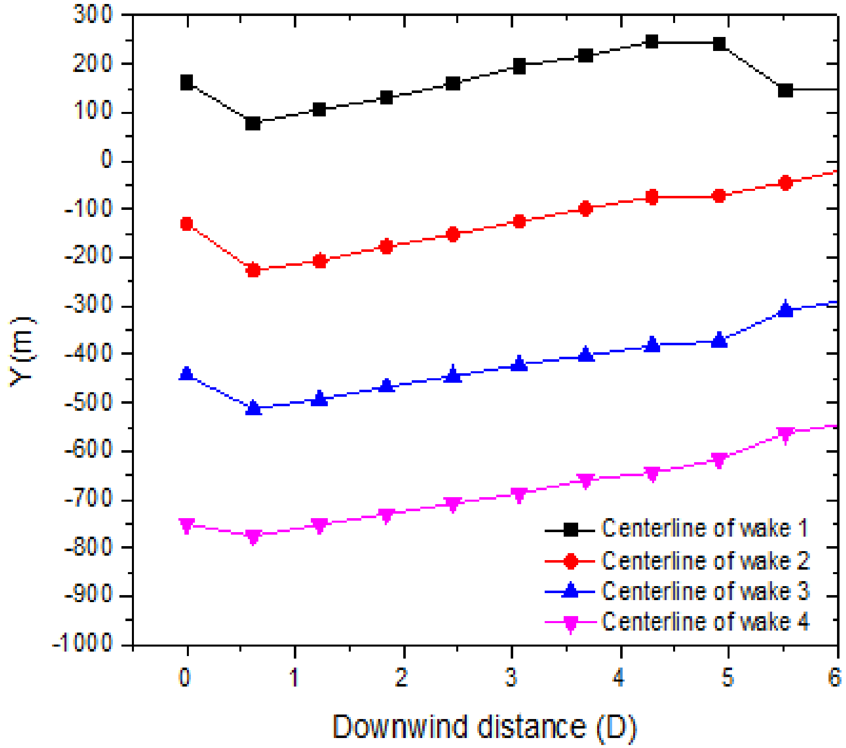

**Summarizes:**

**The outer wakes expand more than the inner wakes under unstable atmospheric conditions while there is no significant difference between the widths under stable conditions.**

# 4. Field experiment & findings

## Multiple Wakes' Characteristics under Different ACs

### - Wake centerline




**Summarizes:**

**Night on August 23 from 10:26:00 to 12:09:33 UTC, the wind direction was in the range 153 º-160º. The centerlines have the same trend after the row of turbines.**

# Study on wind turbine layout optimization

## 1. Basic Models for the Optimization Program Development

*Optimal layout pattern can increase power generation and reduce COE.*

Wake model: $u_i = u_0 \times [1 - \sqrt{\sum_{i=1}^{N} (1 - u/u_0)^2}]$

Power generation: $P = C_p(\lambda, \beta)\rho A u^3 / 2$

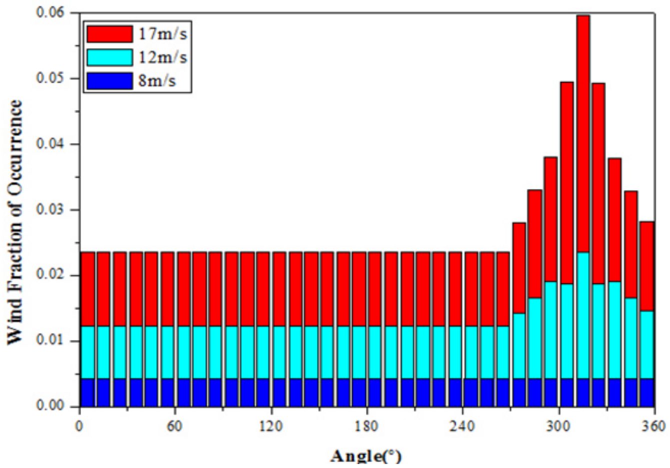
Cost model: $\mathrm{COST} = N \times [\frac{2}{3} + \frac{1}{2} e^{-0.00174 N^2}]$

Wind farm efficiency: $\eta_{WF} = \sum_{1}^{N} 0.3 \times u_i^3 / N \times (0.3 \times u_0^3)$

| Wind farm site | |
|---|---|
| square region: | 2km*2km |
| The ground roughness $z_0$ | 0.3m |
| **Wind turbine properties** | |
| Hub height | 60m |
| Rotor radius | 40m |
| Thrust coefficient | 0.88 |

Wind Conditions:

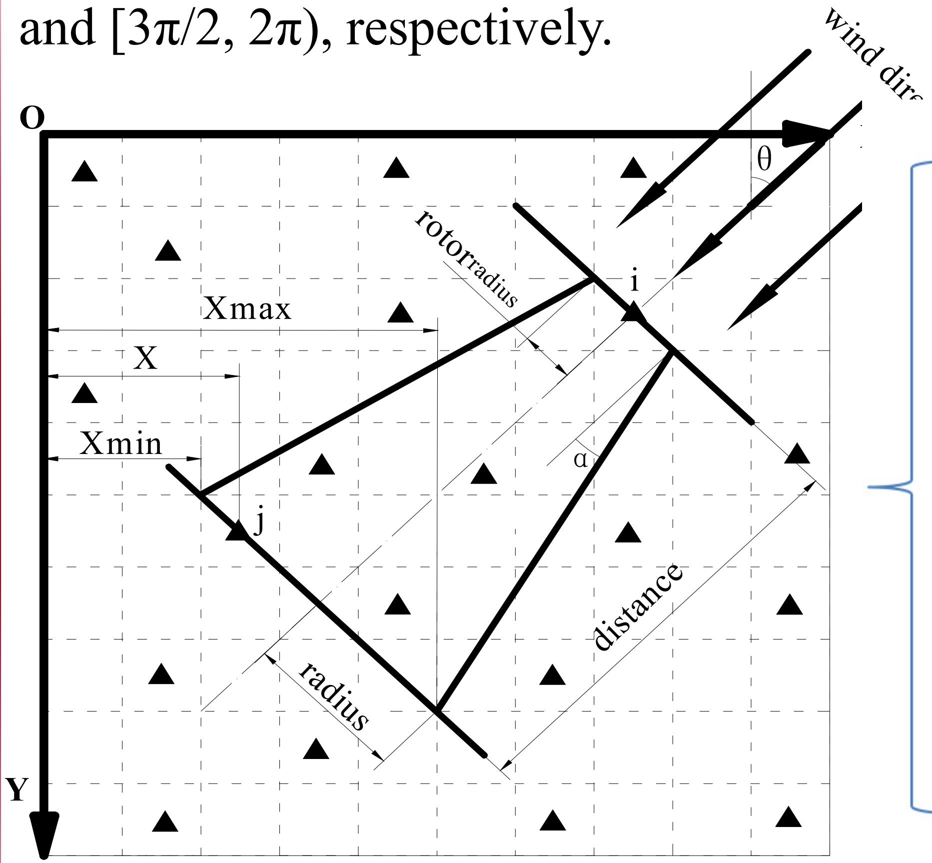
| Case NO. | Case description | Wind speed(m/s) | Wind Direction |
|---|---|---|---|
| 1 | Constant Wind Speed; Fixed Wind Direction | 12 | Fixed 0° |
| 2 | Constant Wind Speed; Variable Wind Direction | 12 | equal probability 0-360° |
| 3 | Variable Wind Direction; Variable Wind Direction | 8,12,17 | Seen from the following Figure |



# 5. Turbine layout optimization program development

## 2. Velocity calculation based on wake effect

Calculate the velocity deficit when the WD in the range of [0, π/2), [π/2, π), [π, 3π/2) and [3π/2, 2π), respectively.




$$distance = \frac{\left|\tan(\pi-\theta)*x - y + y_i - \tan(\pi-\theta)*x_i\right|}{\sqrt{(\tan(\pi-\theta))^2+1}}$$

$$radius = rotor_{radius} + \alpha * distance$$

$$X_{min} = x_i - distance*\cos\left(\frac{\pi}{2}-\theta\right) - radius*\sin\theta$$

$$X_{max} = x_i - distance*\cos\left(\frac{\pi}{2}-\theta\right) + radius*\sin\theta$$

$$u_j^i = u_0 * \frac{2a*r_d^2}{(r_d+\alpha x)^2} = u_i * \frac{2a*rotor_{dradius}^2}{(rotor_{radius}+\alpha*distance)^2}$$

$$= u_i \frac{2a*rotor_{dradius}^2}{\left(rotor_{radius} + \alpha*\left(\frac{\left|\tan(\pi-\theta)*x - y + y_i - \tan(\pi-\theta)*x_i\right|}{\sqrt{(\tan(\pi-\theta))^2+1}}\right)\right)^2}$$

$$u_j = u_0 - \sum_{i=i}^{N} u_j^i$$

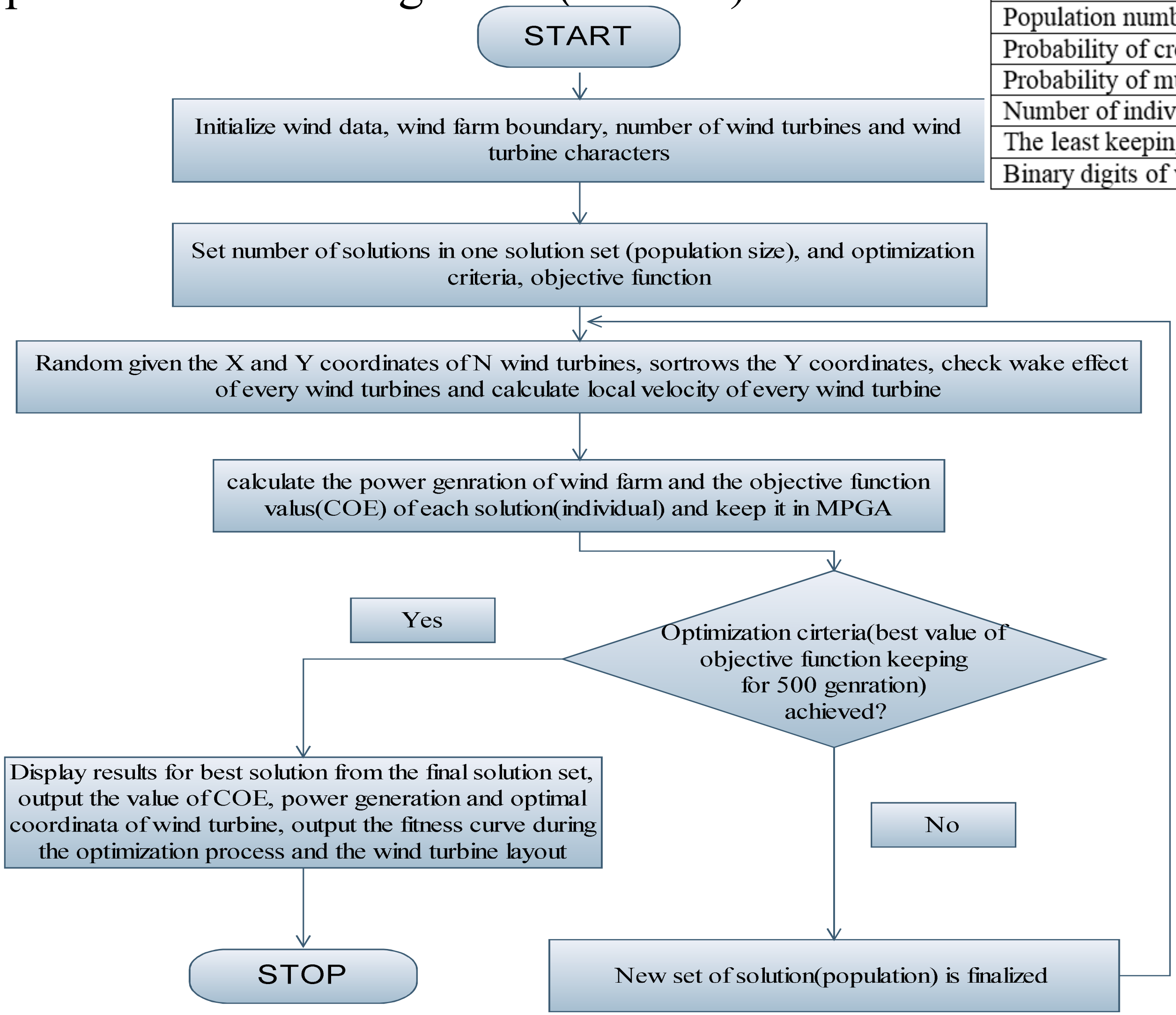
**Two steps: 1. Check wake number and 2, calculate velocity**

# 5. Turbine layout optimization program development

## 3. Program design

Multiple Population Genetic Algorithm( MPGA) is used

| Parameters | Value |
|---|---|
| Population number | 10 |
| Probability of crossover | 0.7-0.9 |
| Probability of mutation | 0.001-0.05 |
| Number of individual | 40 |
| The least keeping generations | 500 |
| Binary digits of variable | 20 |



# 6. Determination of the optimal layout pattern and power potential in Hong Kong offshore

**6. Three layout patterns: Scattered, aligned and staggered**

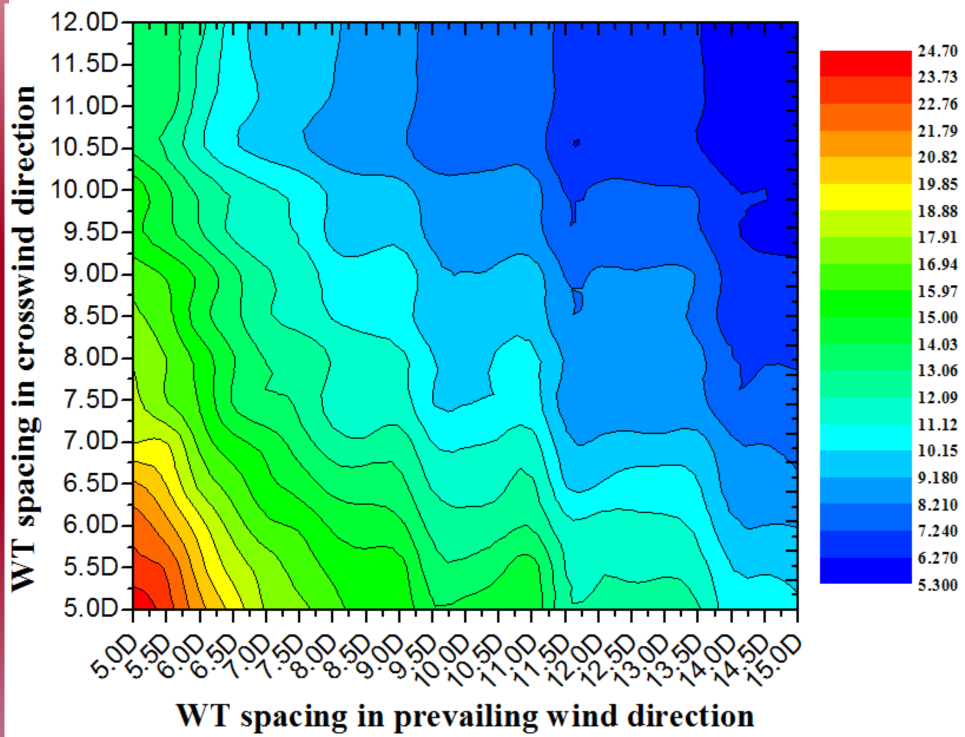
- From the aspect of engineering, turbines are recommended to be installed in arrays.
- 7D -12D in prevailing wind direction (PWD) and 5D-10D in crosswind direction (CWD) (Huang et al. 2012).
- No recommendations about Hong Kong offshore.


North Carolina offshore wind farm

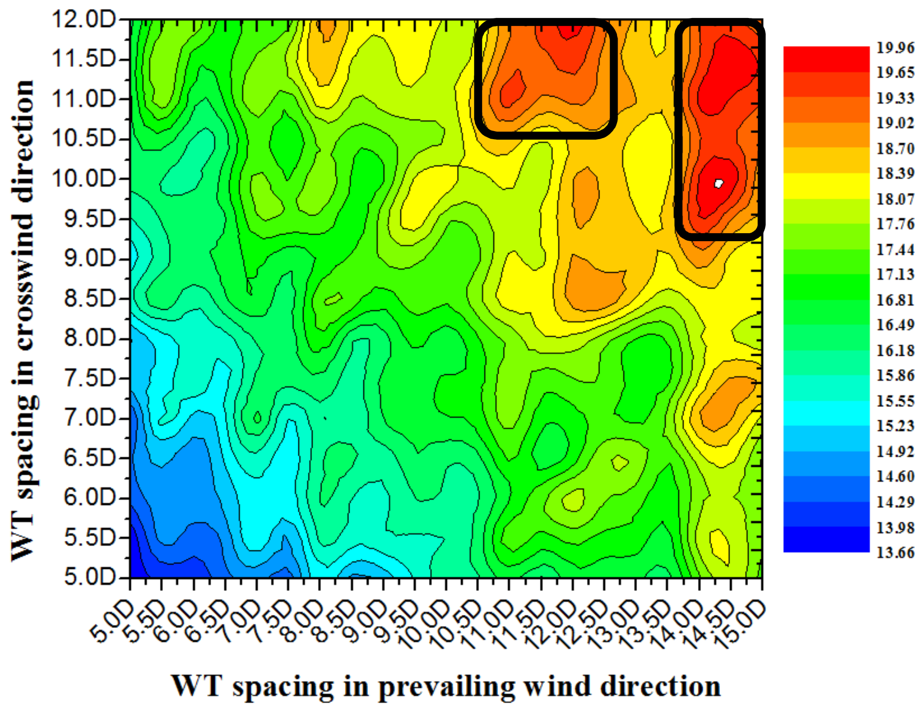
# 6. Determination of the optimal layout pattern and power potential in Hong Kong offshore

## 6. Results for Aligned and Staggered WF Configurations

### 6.1 Energy Generation : Aligned




AEG ( × $10^8$ kWh)

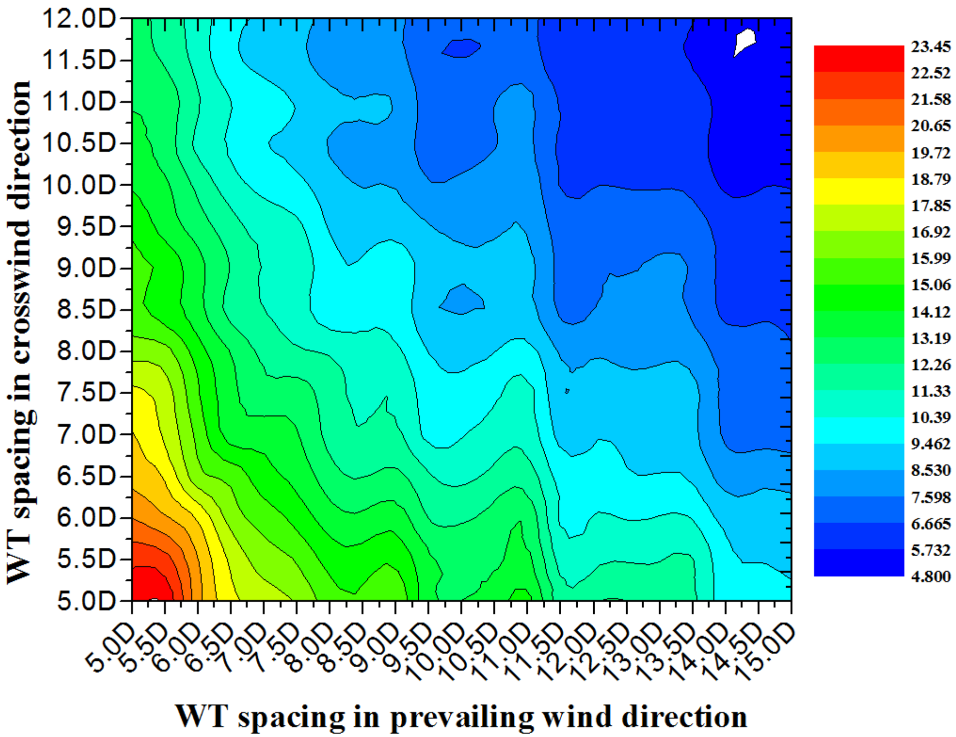



AEG per Turbine ( × $10^6$ kWh)

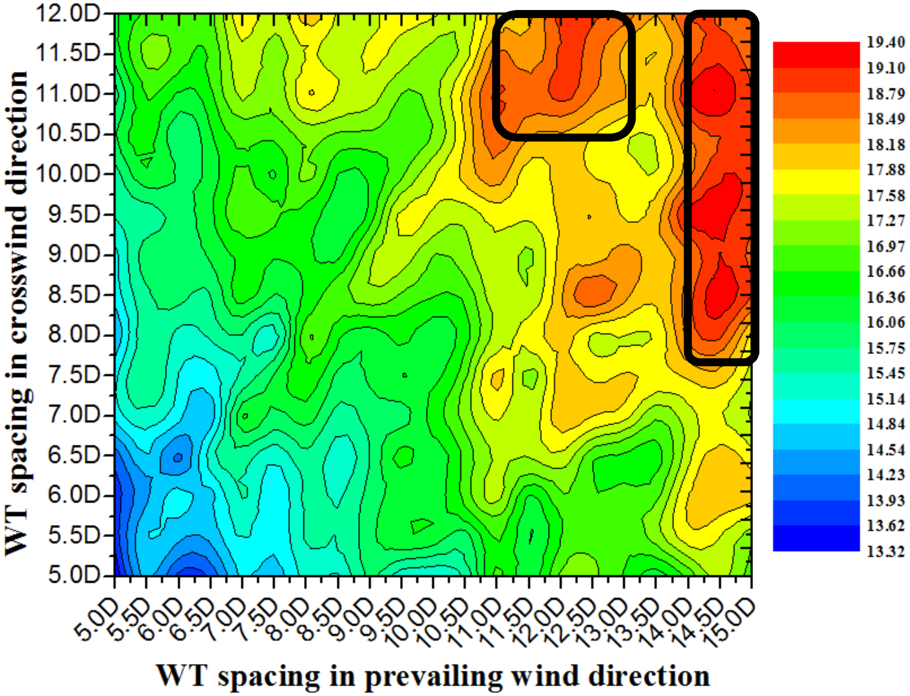
# 6. Determination of the optimal layout pattern and power potential in Hong Kong offshore

## 6. Results for Aligned and Staggered WF Configurations

### 6.3 Energy Generation : Staggered



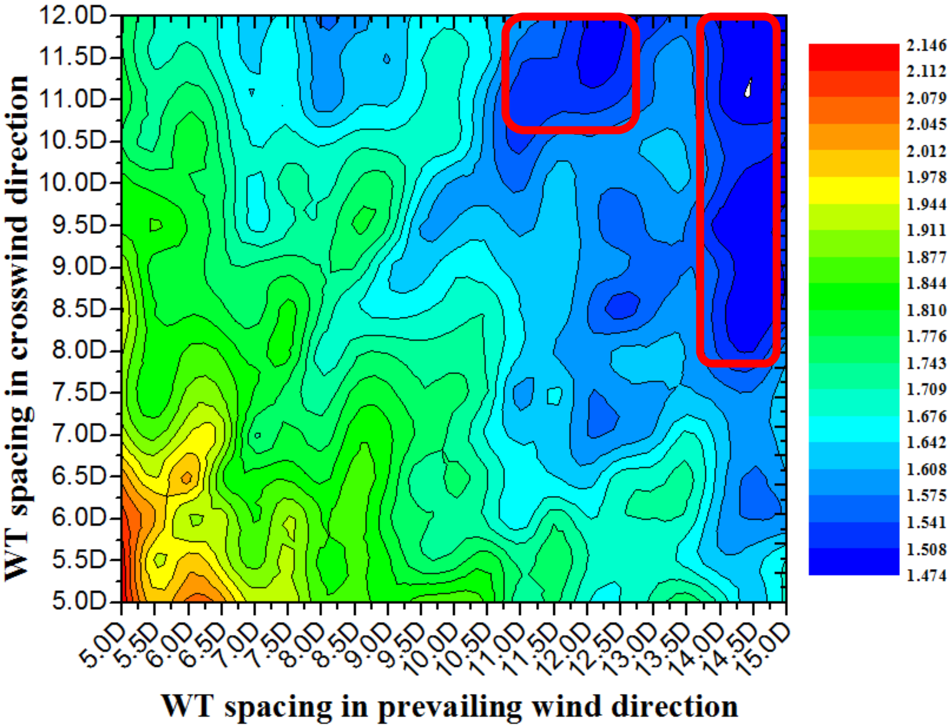

AEG ( × $10^8$ kWh)



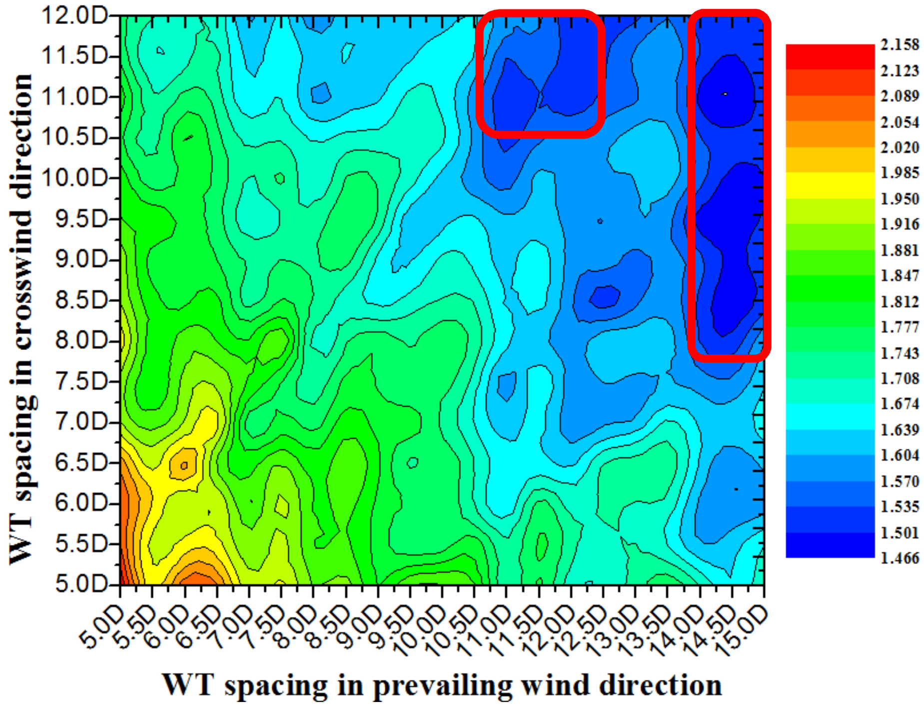

AEG per Turbine ( × $10^6$ kWh)

## 6. Results for Aligned and Staggered WF Configurations

### 6.4 Results of COE




Aligned (HKD/kWh)
1.5-2.1 HKD/kWh

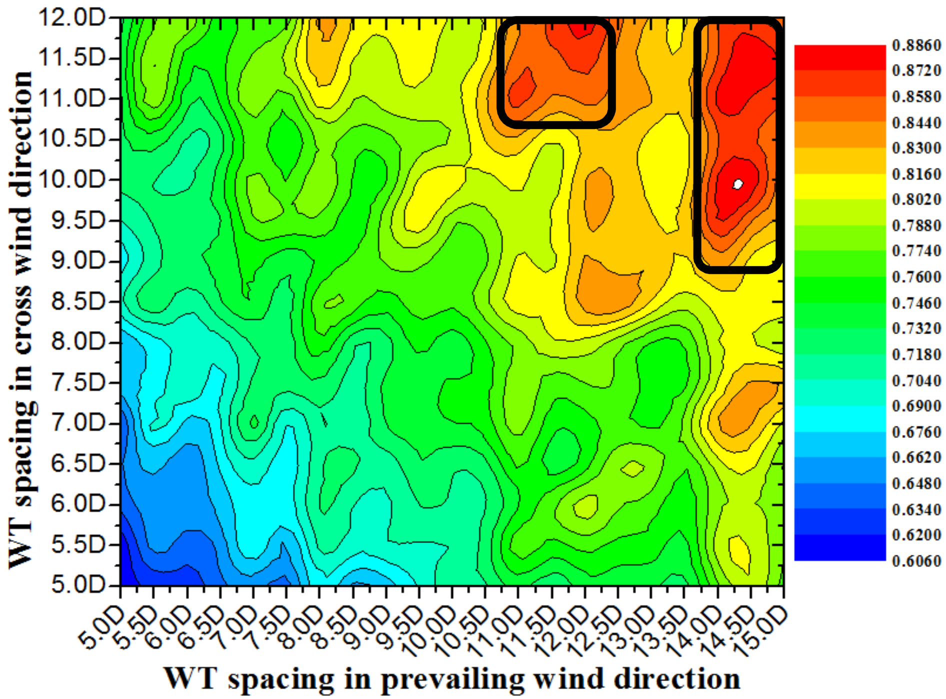



Staggered (HKD/kWh)
1.5-2.2 HKD/kWh

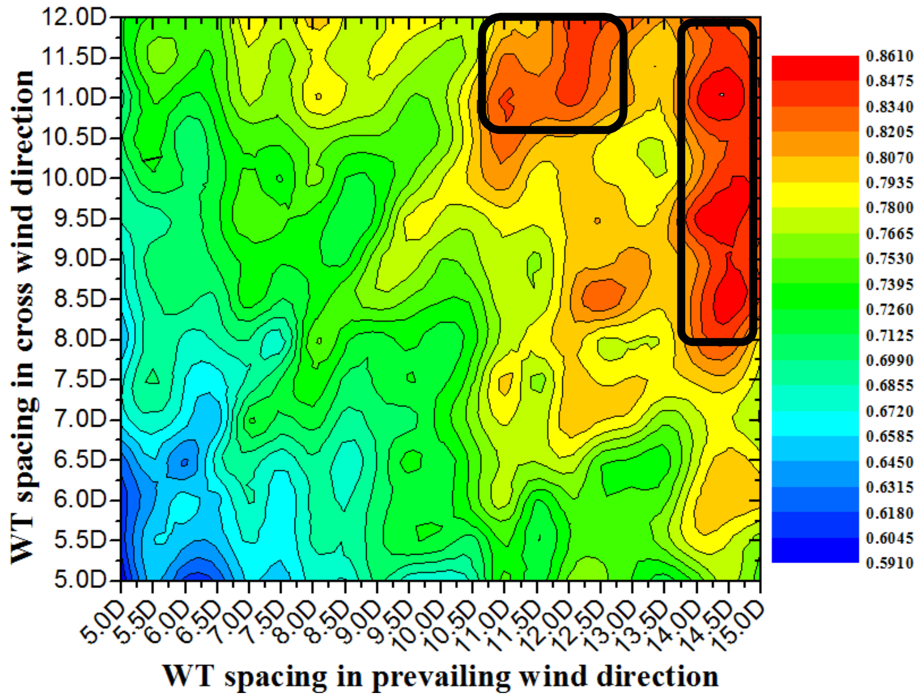
# 6. Determination of the optimal layout pattern and power potential in Hong Kong offshore

## 6. Results for Aligned and Staggered WF Configurations

### 6.5 Results of Wind farm efficiency



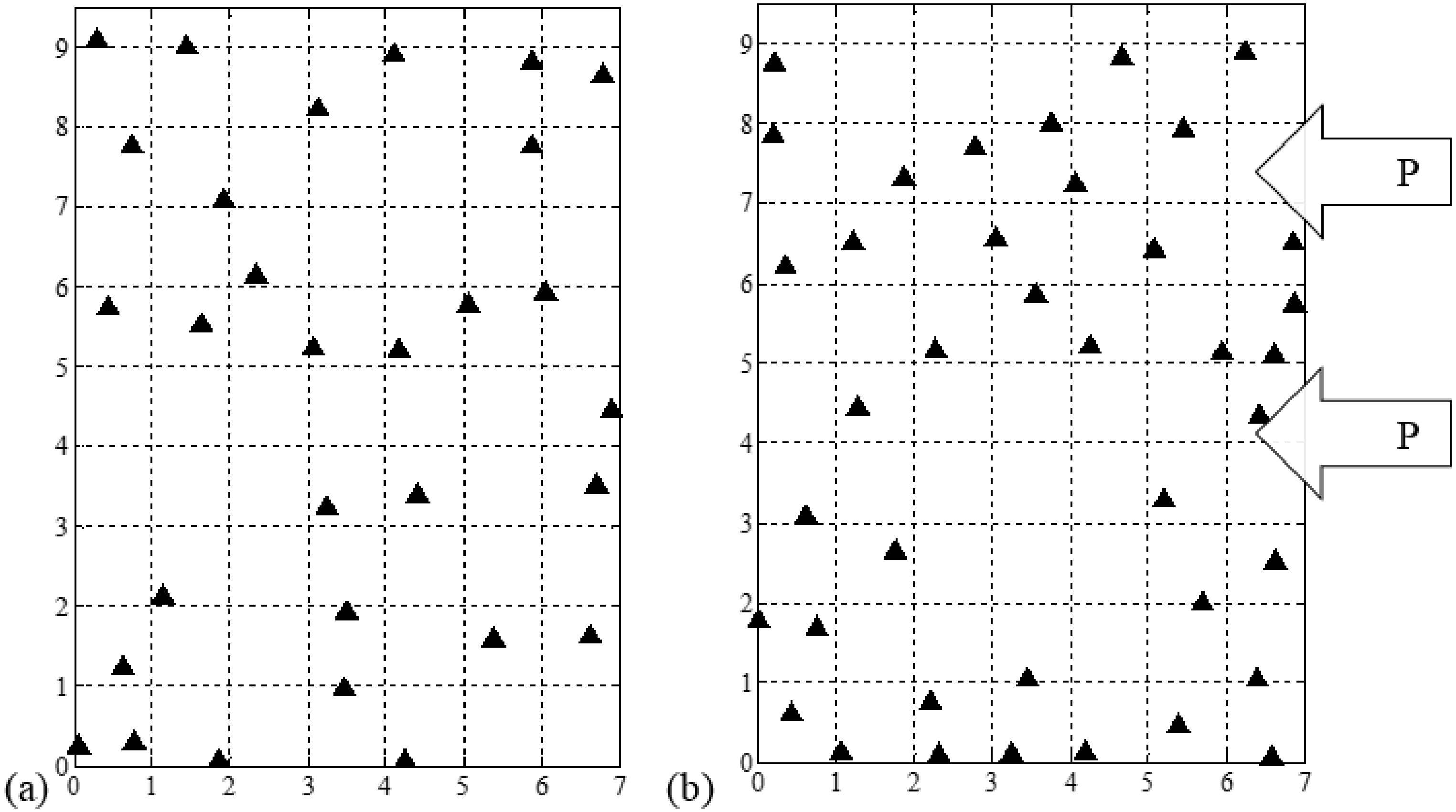

Aligned (HKD/KWh)




Staggered (HKD/KWh)

# 6. Determination of the optimal layout pattern and power potential in Hong Kong offshore

## 6.6 Optimal Turbine Number for Scattered WF Configurations




Wind turbine numbers in scattered wind farm

# Conclusions

- Wind power develops fast and offshore wind power can provide meaningful power supply to coastal urban areas for renewable energy applications.
- The annual offshore wind power generation could be $40.8 \times 10^8$ kWh in Hong Kong, which accounts for 32.9% of the local annual electricity consumption in 2012.
- The developed 2-dimensional wake model is a new development in this professional area.
- The MPGA optimization program has been successfully developed and validated, which is a useful tool in wind farm micro-siting and power generation prediction.
- Decommissioning costs should be included for life-cycle cost analysis.

Thanks

Q & A