**Improve\_Hornsrev1\_Layout\_JRJ\_03\_03\_2025 code explanations**

In this document, it is explained, what the actual code is doing and how.

Hornsrev1 original layout is used with *Py\_wake* to calculate AEP in the different alternatives.

GitHub-Repository---Master-Thesis-Wind-farm-layout-optimization-with-group-random-search

The *Py\_wake* model used is the Bastankhah Gaussian, that combines the engineering wind farm model, “PropagateDownwind” with the” Bastankhah Gaussian Deficit” wake deficit model and the “Squared Sum” super position model.

The Bastankhah Gaussian Deficit model is implemented according to Bastankhah M and Porté-Agel F. “A new analytical model for wind-turbine wakes” J. Renew. Energy. 2014;70:116-23.

By applying mass and momentum conservation and assuming a self-similar Gaussian profile for the wake, a general expression for the velocity deficit is derived:

ΔU/U∞=C(x)e−x2/2σ2

The maximum velocity deficit at the center of the wake C(x) is defined by:

C(x)=1−(1−CT/(8(σ/d0)2))0.5

and the wake width (σ) is defined as:

σ/d0=k∗x/d0+ε

where k represents the wake expansion parameter and ε = 0.2 β, with β being a parameter function of the turbine’s CT.

Thus, the normalized velocity deficit can be calculated as:

ΔU/U∞=(1−(1−CT/(8(k∗x/d0+ε)^2)^0.5)×exp(−1/(2(k∗x/d0+ε)2{((z−zh)/d0)2+(y/d0)2})

Where CT is the turbine’s thrust coefficient, x the downstream distance, zH the turbine’s hub height, and y and z the spanwise and vertical coordinates, respectively.

The model is valid in the far wake only.

Interfaz de usuario gráfica

El contenido generado por IA puede ser incorrecto.

The area where the WT locations can move is defined with the most external positions of the actual layout, adding 25 additional meters on x and y coordinates.

In the beginning of the process, the maximum length of every new iteration, the number of Iterations (N) and the number of Generations (M) shall be fed in the interface by the user.

With this model, the code is calculating N iterations to improve the actual solution (normally 300 possible new solutions are analyzed on each successive Generation). At the end of every step, the best solution is elected to be the seed of a new generation of improved solutions. Later, all these N solutions are ordered from minimum to maximum AEP.

Oa a second step, a new generation is analyzed (N Generations are executed by the code). On each Generation, the best solution from the previous generation is used as a seed of new N solutions, generations with small variations on every WT position (80 turbines in the wind farm). A new set of N solutions is redefined.

Again, all the N solutions on each Generation are ordered from minimum to maximum AEP, electing again the last solution, as a seed of the next Generation.

On every Iteration, all the WT are reallocated; all of them. The approach of the code is to shift all the WT positions to get improvements on AEP, making a high number of new slightly modified solutions, searching for small improvements.

To accelerate the process and avoid it being slow, a fitness function is used to evaluate solutions that will have best AEP. Although the wake effects are taken into account by the *Py\_wake* model, the fitness function is penalizing solutions with distance between WT less than 5 time the WT Radius.

The calculations need a huge amount of time, as 80 WT are worked out at the same time.

The Wind Rose on Hornsrev1 can be found in the next chart. Other winds could be used in the model, but it will be implemented in the next steps. In this first draft only Hornsrev1 site has been used.

The site object has a few plot functions to visualize its properties, mainly the wind resource given by the wind rose and the probability functions.

Gráfico, Gráfico radial

El contenido generado por IA puede ser incorrecto.

Gráfico, Gráfico radial

El contenido generado por IA puede ser incorrecto.

Gráfico, Histograma

El contenido generado por IA puede ser incorrecto.

Plotting probability density function for the four sectors studied ±45 degrees.

If **include\_wd\_distribution=true**, the wind speed probability distributions are multiplied by the wind direction probability.

The sector size is set to 360 / len(wd). This only makes sense if the wd array is evenly distributed

Gráfico, Histograma

El contenido generado por IA puede ser incorrecto.

The new iteration positions on each WT are plotted on the following chart. Original positions are plotted in blue, the final ones in red, and the intermediate ones are plotted yellow.

Imagen que contiene Patrón de fondo

El contenido generado por IA puede ser incorrecto.

In the next chart only the original layout (blue) and the last one are plotted (black).

Gráfico, Gráfico de dispersión

El contenido generado por IA puede ser incorrecto.

The AEP improvements of every Generation is plotted next.

Gráfico, Gráfico de dispersión

El contenido generado por IA puede ser incorrecto.

And in the last chart an evolutive chart of the AEP Energy Generation (GWh) is plotted.

Gráfico, Gráfico de dispersión

El contenido generado por IA puede ser incorrecto.

**SOLUTION “Improve\_Hornsrev1\_Layout\_JRJ\_03\_03\_2025.py”**

In the solution below, a run of the code 03\_03\_2025 has been executed, with 10 m maximum iteration length, 300 iterations and 15 Generations.

The original layout AEP is 664.334531 GWh. The successive best solutions of each Generation are:

* Solution 0: 664.338804 GWh
* Solution 1: 664.351801 GWh
* Solution 2: 664.391400 GWh
* Solution 3: 664.436800 GWh
* Solution 4: 664.463822 GWh
* Solution 5: 664.516122 GWh
* Solution 6: 664.537318 GWh
* Solution 7: 664.582709 GWh
* Solution 8: 664.643282 GWh
* Solution 9: 664.672880 GWh
* Solution 10: 664.735165 GWh
* Solution 11: 664.776305 GWh
* Solution 12: 664.861690 GWh
* Solution 13: 664.907590 GWh
* Solution 14: 664.946755 GWh
* Solution 15: 665.010669 GWh

The improvements means 0,676138 GWh (676,138 MWh) a +0,102% AEP improvements from the original layout AEP.

Python 3.12.7 | packaged by Anaconda, Inc. | (main, Oct 4 2024, 13:17:27) [MSC v.1929 64 bit (AMD64)]

Type "copyright", "credits" or "license" for more information.

IPython 8.27.0 -- An enhanced Interactive Python.

runfile('C:/Users/jrjim/Downloads/Improve\_Hornsrev1\_Layout\_JRJ\_03\_03\_2025.py', wdir='C:/Users/jrjim/Downloads')

Original AEP: 664.334531 GWh

Enter Iteration Lenght in meters: 10

Enter Number of Iterations on each Generation: 300

Enter Number of Genetic Generations: 15

Best solution on reference layout randomized Generation 0:

(array([423982.67113123, 424033.49241831, 424115.26259266, 424186.06059932,

424256.51209799, 424313.53378322, 424390.50588399, 424445.34658179,

424539.67029227, 424604.17734849, 424674.01525329, 424742.06743324,

424806.34197608, 424868.49136867, 424945.10015521, 425014.3619007 ,

425101.76741107, 425159.83024577, 425223.51339319, 425293.03232987,

425365.1447315 , 425441.07125529, 425500.30450838, 425571.99932653,

425654.24510978, 425718.39666722, 425798.61206878, 425868.62865214,

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426217.07261962, 426287.08635732, 426357.3613491 , 426426.75501863,

426485.84953633, 426558.48685359, 426631.22374213, 426696.93579062,

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427045.19402039, 427108.54274377, 427174.23998534, 427243.02178662,

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427614.68097413, 427684.7018924 , 427750.77166518, 427804.8344915 ,

427901.24930571, 427953.7775239 , 428028.71445418, 428094.48491649,

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6150335.37602587, 6149770.65726047, 6149226.61597406,

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6149786.08542625, 6149221.87206772, 6148670.59647015,

6148117.03764713, 6147555.65162283, 6151454.66752006,

6150899.49857847, 6150329.92046465, 6149777.95401353,

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6148671.32442731, 6148120.31969073, 6147553.69972401,

6151450.41165278, 6150889.6620949 , 6150338.62724097,

6149772.23420516, 6149226.31388613, 6148676.02549216,

6148116.84092135, 6147551.00761422]))

aep\_best\_sol on reference layout randomized Generation 0: 664.3388040951618

Best solution on Genetic Generation 1:

([423991.8260432351, 424025.25345431775, 424124.0610390488, 424181.9843287292, 424247.23340025963, 424314.75305611634, 424390.7327216625, 424441.43013141316, 424537.36176561867, 424603.9672281092, 424677.05865110847, 424748.3923133859, 424806.99452319863, 424871.7117487193, 424946.2838887257, 425016.0274885347, 425098.6596182639, 425167.588540492, 425232.0030223073, 425291.46709012607, 425358.42666103365, 425432.5103980578, 425492.6948364708, 425568.19361439935, 425658.9293789817, 425718.5933327418, 425799.9985525962, 425874.66788421647, 425934.9486455086, 425990.71162358753, 426064.3487898482, 426141.0957929206, 426224.77683604317, 426291.8196913967, 426354.1855507818, 426427.3221407952, 426480.54523456306, 426567.37855650537, 426623.42902130826, 426696.4685379955, 426769.4265326887, 426838.31135136297, 426910.9256472812, 426975.3665033051, 427045.4552275323, 427115.7033524758, 427170.1829961763, 427242.01026051404, 427331.14426105947, 427395.8488529001, 427468.8283128039, 427542.0690104177, 427604.78313728585, 427681.3783359119, 427751.78138707206, 427795.32511509716, 427898.6129534614, 427952.9684483068, 428032.9707499204, 428100.9798890697, 428165.29386933154, 428220.31767189276, 428305.66380999866, 428370.09736830357, 428460.0639855684, 428514.19013203727, 428598.3407978764, 428659.4245841505, 428731.6352907262, 428805.2516002705, 428877.8791442728, 428946.6176816451, 429020.03335851856, 429088.24426397245, 429169.6390751551, 429219.0599727154, 429295.63541366823, 429368.5014514623, 429433.17479951313, 429492.1472139], [6151434.047799555, 6150900.503233136, 6150340.253092464, 6149783.724867985, 6149226.810643809, 6148683.618895342, 6148115.954504977, 6147548.49083353, 6151454.018706201, 6150889.357667375, 6150339.701226503, 6149762.578192613, 6149230.048365602, 6148677.123129976, 6148113.218320611, 6147556.469821458, 6151450.996975156, 6150885.904211025, 6150329.129043444, 6149778.580966334, 6149229.717645928, 6148673.090995744, 6148110.639835352, 6147539.124949887, 6151450.319160535, 6150896.0671860045, 6150316.967705715, 6149782.606120377, 6149216.925556288, 6148676.471184383, 6148107.46079999, 6147548.098795566, 6151445.314529584, 6150895.412072738, 6150335.748639137, 6149768.428384263, 6149212.49681266, 6148664.65564046, 6148104.473052117, 6147555.092766075, 6151438.163514761, 6150890.726398672, 6150335.01637136, 6149776.8813721975, 6149217.5061852, 6148670.57319016, 6148113.13013426, 6147548.434511669, 6151445.453791403, 6150898.0213962495, 6150332.033827741, 6149783.151045463, 6149217.041046095, 6148664.024597261, 6148115.481531486, 6147549.604298674, 6151457.743852526, 6150892.9203961985, 6150337.021206127, 6149762.902131205, 6149212.959943766, 6148652.846884789, 6148110.027689094, 6147542.711402514, 6151455.922946272, 6150895.149046282, 6150345.643627785, 6149786.186738692, 6149223.342879276, 6148666.129710384, 6148126.454521048, 6147546.039571617, 6151453.659576682, 6150885.751631932, 6150330.32339592, 6149773.771381682, 6149219.810625875, 6148683.220589824, 6148111.707483825, 6147558.48989373])

aep\_best\_sol on Genetic Generation 1: 664.3518006314465

Best solution on Genetic Generation 2:

([423985.4119723842, 424034.02980720665, 424116.58836732985, 424183.76646853646, 424248.1783074226, 424306.340447168, 424381.9069684101, 424440.67390272976, 424541.2524739351, 424595.7614152194, 424670.86059300666, 424738.4054094066, 424800.29037005454, 424867.74618451274, 424945.7307281686, 425017.83348498796, 425093.8461877099, 425175.2686277551, 425228.52597731573, 425281.8910758535, 425361.2418478628, 425436.63480377034, 425501.4926130195, 425577.2551094769, 425649.84632138815, 425719.0241334873, 425791.0765989139, 425867.2419211468, 425935.05365073937, 425995.36390364694, 426065.31464683806, 426132.2871940228, 426233.07993432146, 426290.10804735695, 426363.4260334545, 426421.9668148187, 426484.63888415444, 426574.06625881995, 426624.4740324337, 426693.6472875774, 426768.9951655325, 426838.25403271726, 426913.43638128217, 426974.50030843576, 427055.2196587042, 427120.7786644316, 427174.5834535064, 427245.1778937634, 427331.42423009244, 427398.1714061301, 427462.28666067426, 427532.6093940145, 427595.73535380204, 427676.0747176738, 427744.6353934305, 427785.54818268336, 427898.5915815811, 427957.698534957, 428029.4200832144, 428095.8859942476, 428164.4112596752, 428213.27428262384, 428313.91158816335, 428378.2775702579, 428458.1363648129, 428512.79095685907, 428604.7029776283, 428651.6386055174, 428731.56166947505, 428799.06979208713, 428874.61107601185, 428950.12190303404, 429015.13288191013, 429083.63791534636, 429173.16852399404, 429229.0083750064, 429302.8740180364, 429363.23410003644, 429434.1785451709, 429491.8124816479], [6151441.300665073, 6150906.524901482, 6150345.650933893, 6149773.949928069, 6149228.022487261, 6148677.5568159465, 6148109.19199416, 6147550.305041343, 6151444.779716687, 6150889.683467924, 6150331.490381044, 6149759.512910873, 6149228.028524261, 6148686.112671281, 6148118.266169998, 6147546.97215954, 6151456.498021146, 6150890.328144925, 6150329.299230497, 6149787.320761866, 6149229.362937964, 6148681.774080909, 6148106.202124558, 6147541.879090949, 6151446.339258955, 6150903.689649373, 6150322.78905245, 6149776.603136319, 6149209.502914976, 6148672.655424735, 6148103.75549359, 6147547.366640282, 6151452.894611463, 6150893.59420073, 6150330.075543343, 6149761.627849367, 6149222.1450882675, 6148659.598271367, 6148100.467024832, 6147554.754989925, 6151433.938240424, 6150886.634923574, 6150334.308147037, 6149781.967758766, 6149208.537279198, 6148661.829900331, 6148119.840467379, 6147549.1246051, 6151452.895608356, 6150894.787523692, 6150334.714287134, 6149789.107000998, 6149220.212055038, 6148672.307993252, 6148124.053405634, 6147540.914798216, 6151460.396959822, 6150889.948213546, 6150334.78000078, 6149768.47463623, 6149219.991711074, 6148648.4172740625, 6148106.258498954, 6147541.759289611, 6151464.026517926, 6150903.248206353, 6150345.1308215875, 6149784.537350672, 6149216.748583212, 6148673.412233868, 6148120.43694418, 6147541.947419263, 6151457.398584487, 6150889.232600314, 6150339.322062476, 6149777.5030033365, 6149221.157329977, 6148678.261092345, 6148104.628066433, 6147565.18865943])

aep\_best\_sol on Genetic Generation 2: 664.3913995105816

Best solution on Genetic Generation 3:

([423988.67977342906, 424033.2707938018, 424112.01100648614, 424174.3989097095, 424239.20551900147, 424302.89405974554, 424380.4308964529, 424447.59635033214, 424548.86305038125, 424595.3254259762, 424674.3588828599, 424746.1806352567, 424791.43211142777, 424864.6476084605, 424946.1091792252, 425019.7144910259, 425088.3198277982, 425176.23580535647, 425234.65415134025, 425276.81771039724, 425367.3582569628, 425446.335797044, 425501.21556960366, 425575.3937414132, 425646.478548442, 425728.9409081941, 425790.70325234474, 425865.2948548355, 425928.54378629714, 426004.31714334316, 426070.6519389516, 426140.6764646234, 426229.6531373167, 426290.2377513605, 426369.5129177318, 426423.7488266732, 426492.44194847037, 426579.04288773716, 426620.7610172088, 426695.0007951159, 426767.10336144763, 426847.82032789977, 426915.88109139533, 426966.78822656017, 427053.43430119916, 427118.8122047889, 427182.2482233777, 427248.7541194091, 427338.7002542412, 427401.67816735886, 427469.89441530843, 427525.0512474915, 427601.7229300719, 427670.55744743557, 427734.69860387145, 427780.53875017026, 427908.5075920206, 427954.5394297811, 428027.38492399734, 428098.34632284986, 428164.52127667086, 428211.5584277098, 428317.20505440066, 428378.2223723958, 428453.04014205973, 428506.75757278455, 428610.42711119127, 428660.3611326185, 428724.8373100608, 428796.16993412015, 428869.09879025957, 428944.25661294616, 429018.9195278513, 429087.11179159296, 429176.94392855186, 429235.06192544714, 429311.76128794305, 429358.6907784752, 429443.49104960926, 429493.3794422425], [6151450.4259277955, 6150914.4106035195, 6150350.997794693, 6149765.009986199, 6149234.784521088, 6148670.2848556135, 6148105.398538506, 6147550.094306573, 6151439.853720292, 6150892.725145824, 6150334.417941325, 6149760.667835683, 6149230.020261112, 6148680.1789381225, 6148114.633638392, 6147544.713573004, 6151446.562868534, 6150900.121057487, 6150335.4019250795, 6149778.355610307, 6149221.7691066265, 6148674.723479511, 6148101.87155639, 6147547.884072535, 6151455.324472785, 6150909.612298212, 6150327.48763565, 6149770.60072283, 6149215.216183195, 6148665.383324327, 6148096.5120109655, 6147546.539345116, 6151459.50416431, 6150889.374459629, 6150322.480321014, 6149751.902668182, 6149226.377460753, 6148661.953364612, 6148097.403137764, 6147558.161262928, 6151442.911809382, 6150883.990719201, 6150328.991365766, 6149782.061109565, 6149203.856431558, 6148654.782091014, 6148110.608861848, 6147552.51332634, 6151447.304419332, 6150891.66593145, 6150343.446270766, 6149787.036385012, 6149220.9428938115, 6148662.471946263, 6148126.545363625, 6147535.746532708, 6151467.881721096, 6150892.337798662, 6150325.1533682775, 6149760.440045859, 6149215.443705078, 6148641.980453341, 6148110.5647391835, 6147534.291768018, 6151470.263478461, 6150910.730698224, 6150342.509664758, 6149781.818543117, 6149224.418929876, 6148671.3927266225, 6148127.371967196, 6147543.004768146, 6151462.164926161, 6150889.188312755, 6150339.210261744, 6149773.139853248, 6149226.32581902, 6148687.156933664, 6148097.691309855, 6147560.838892296])

aep\_best\_sol on Genetic Generation 3: 664.4368000559413

Best solution on Genetic Generation 4:

([423986.48276592616, 424023.3791332881, 424114.52433444967, 424165.58604929183, 424243.9401610828, 424305.1378787831, 424386.2586465468, 424452.909236157, 424544.9582567363, 424596.88249247894, 424664.4773470285, 424756.1662587596, 424791.18099878955, 424855.170648257, 424937.225458128, 425012.50210612844, 425080.42204682186, 425174.7929694925, 425227.9945690019, 425276.52850711107, 425376.12246393005, 425449.18045719044, 425496.22229787754, 425582.5289125784, 425640.42296822806, 425725.7400078148, 425796.69104512566, 425861.2030993568, 425919.4901157678, 426002.65014045325, 426065.0413247299, 426138.79098990705, 426228.0784957453, 426290.85442920396, 426378.5854218655, 426423.48131962813, 426486.18704275263, 426579.8927656029, 426627.42036444123, 426704.046567395, 426766.60243148677, 426846.9574691563, 426917.40176580276, 426967.52825768985, 427046.2464110007, 427121.3005905932, 427186.18593888654, 427243.22538704926, 427334.7195301464, 427408.5975385353, 427467.88235900784, 427531.16138434235, 427600.16388946644, 427679.5648106746, 427738.6807465221, 427778.55885619787, 427907.1059963217, 427948.3325177508, 428029.53219265444, 428107.09446728823, 428171.7446375302, 428209.83114669385, 428315.3918698596, 428385.5475923635, 428449.9351871431, 428501.5268383679, 428606.0411472457, 428655.78975036804, 428728.1263886947, 428804.0218791708, 428874.1252238686, 428953.13915486954, 429008.949795962, 429082.5075413974, 429171.91222127265, 429244.5191816568, 429320.8904461075, 429368.05109300686, 429452.9003545972, 429501.66546047124], [6151453.434712807, 6150905.151403873, 6150359.953606964, 6149771.6902133, 6149237.418394345, 6148666.913559544, 6148104.5391756585, 6147546.774919183, 6151434.848327426, 6150892.553353305, 6150331.824746096, 6149767.383492722, 6149222.211425594, 6148670.925129527, 6148118.083969266, 6147540.19597346, 6151456.312770337, 6150899.268406312, 6150329.513210012, 6149784.042706833, 6149212.043119926, 6148672.034569199, 6148100.033377104, 6147551.093417927, 6151455.137903888, 6150904.388052258, 6150332.397152081, 6149774.657137741, 6149215.940125215, 6148671.223428235, 6148088.138910966, 6147551.646053415, 6151464.329882169, 6150891.2362635005, 6150312.612638865, 6149754.238350594, 6149224.127081105, 6148652.7431244105, 6148094.0189511245, 6147555.348842574, 6151450.005219521, 6150884.280305099, 6150327.63531237, 6149779.008449532, 6149210.369016182, 6148657.120542391, 6148100.925857581, 6147554.611311077, 6151449.663539998, 6150890.751874454, 6150335.099478918, 6149791.964891345, 6149217.229455598, 6148661.313113153, 6148118.447242398, 6147539.012485406, 6151469.418212854, 6150900.8046957115, 6150329.340354107, 6149763.55364237, 6149218.911260782, 6148633.177350813, 6148101.058478744, 6147534.177214974, 6151470.750584722, 6150915.282087078, 6150350.840225956, 6149782.5416752715, 6149234.255944167, 6148664.555439294, 6148121.3971120315, 6147550.899939738, 6151457.236855909, 6150886.38839523, 6150345.625617572, 6149767.619414696, 6149223.197337303, 6148695.380389587, 6148102.619587043, 6147559.349024854])

aep\_best\_sol on Genetic Generation 4: 664.463822240382

Best solution on Genetic Generation 5:

([423995.4402806174, 424025.6831683524, 424117.8420924946, 424170.06980969047, 424236.146880694, 424296.7384789671, 424386.9273356306, 424448.4645083637, 424537.849841141, 424590.27817396144, 424658.77151517523, 424746.8057140926, 424785.5613044797, 424858.17029792664, 424930.9218532691, 425019.68384921, 425085.33352102025, 425177.93702086725, 425232.8934911029, 425279.2160945406, 425368.67306453316, 425440.92484940594, 425505.47912686586, 425573.46140975633, 425639.4482939986, 425733.4478724969, 425805.2241197912, 425855.9913930593, 425927.1686198065, 426008.58557118254, 426056.2487661507, 426146.8159358055, 426221.06926514185, 426281.7422340173, 426378.99264533, 426423.9171377352, 426494.4116047647, 426570.08519485913, 426626.1299900246, 426705.03683653555, 426776.05205046193, 426849.8495914787, 426913.9932173683, 426967.68090286216, 427054.00950022606, 427121.0089806149, 427184.9952190902, 427244.2925181477, 427325.036348871, 427407.8288228546, 427470.23547974357, 427533.62277131557, 427600.52644425427, 427681.8768186805, 427740.1714369029, 427781.45049325767, 427904.26764992374, 427956.73692675127, 428027.5990985355, 428111.9730286745, 428168.66342033126, 428218.47387761885, 428307.75118546875, 428384.16440240573, 428457.13278527884, 428497.98431534995, 428603.3136314909, 428658.2105568372, 428729.4787930805, 428801.8961178702, 428876.46214801044, 428944.63402618, 429017.0751568504, 429090.9182303358, 429170.5610854787, 429244.2862233798, 429311.6600373794, 429366.61714102543, 429462.7120821088, 429507.82697295316], [6151444.895198176, 6150902.5730816815, 6150356.589871803, 6149778.473212831, 6149246.55823266, 6148672.077679864, 6148108.200210591, 6147552.721906032, 6151437.723296859, 6150892.6336674215, 6150339.122663728, 6149764.464595393, 6149226.317002282, 6148665.677332781, 6148116.829774601, 6147535.868217707, 6151456.042363351, 6150900.491634295, 6150337.731963371, 6149784.698554, 6149220.916856404, 6148678.768936462, 6148105.338205959, 6147543.4365076395, 6151463.815420041, 6150898.1794067845, 6150332.6290011, 6149773.337943541, 6149222.2781398315, 6148679.162880502, 6148088.244516857, 6147554.464334646, 6151463.292737153, 6150888.641403195, 6150315.10427221, 6149762.180631672, 6149220.529182164, 6148647.328691499, 6148088.1509817, 6147546.099515362, 6151447.245658748, 6150875.759883076, 6150333.006360651, 6149781.586680686, 6149220.220286472, 6148654.209383634, 6148096.390560772, 6147547.168553944, 6151458.957598475, 6150887.501358841, 6150343.700075586, 6149785.614691879, 6149207.24825374, 6148655.599991868, 6148127.441236882, 6147538.651348258, 6151470.319361918, 6150897.0795725975, 6150333.012646125, 6149758.823680262, 6149212.970868563, 6148638.605479958, 6148091.075435243, 6147537.429876126, 6151471.10763339, 6150921.738816785, 6150349.93826035, 6149773.106075934, 6149239.962161795, 6148667.964267143, 6148122.484925063, 6147555.865314852, 6151448.236332492, 6150888.5917247115, 6150345.435665761, 6149777.191374659, 6149213.279312979, 6148697.81544985, 6148110.113108685, 6147566.734312629])

aep\_best\_sol on Genetic Generation 5: 664.5161218960061

Best solution on Genetic Generation 6:

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aep\_best\_sol on Genetic Generation 6: 664.5373175415051

Best solution on Genetic Generation 7:

([423996.9002692296, 424032.92620557436, 424108.8355910837, 424169.40170344984, 424221.7385800313, 424284.86931731005, 424383.7394777338, 424439.44462912215, 424523.90604511235, 424580.6096713282, 424661.3406616936, 424736.4025449133, 424769.40563858754, 424862.0767878635, 424923.76784638537, 425012.66815121094, 425085.160058396, 425181.98419963254, 425225.4143698872, 425277.0224978747, 425369.1736822308, 425442.9710764166, 425489.22403509595, 425577.4408959015, 425623.5507833752, 425731.9165835265, 425814.0897969896, 425867.4353246553, 425924.7287962817, 425999.3370805196, 426068.17052325845, 426161.2582946248, 426227.8925029787, 426291.8337077695, 426376.11074452754, 426433.1617446668, 426498.524345785, 426567.0474287684, 426632.1266179142, 426712.94379260676, 426766.28484885494, 426841.3570443763, 426905.29216725664, 426958.69690904254, 427041.61693752307, 427116.42390366516, 427200.07872108166, 427244.267360406, 427324.9638650143, 427398.5527621954, 427477.7005916673, 427525.24056328274, 427598.1239193902, 427682.2442477513, 427744.5189775998, 427769.6613935957, 427912.7100712126, 427960.33535452426, 428024.4672333006, 428100.746972403, 428156.79903184343, 428218.76971364656, 428306.2310762191, 428385.6473939936, 428455.45847369137, 428513.27751083765, 428609.4619442775, 428671.859922721, 428743.7043103706, 428799.02053801145, 428861.87222808134, 428939.7899243111, 429009.6138567151, 429104.09489535686, 429171.1113463264, 429246.1983376481, 429311.6435133266, 429364.49858713883, 429472.7287250894, 429505.6140559973], [6151452.430760842, 6150890.941620896, 6150346.472979964, 6149777.578684084, 6149228.557626803, 6148666.741390991, 6148115.670620743, 6147549.369531986, 6151435.56716087, 6150890.151790892, 6150330.586589666, 6149763.837112119, 6149241.324292694, 6148655.2726585055, 6148118.871856151, 6147544.106747364, 6151461.480142819, 6150889.010038975, 6150330.949966773, 6149790.485540205, 6149231.826432117, 6148678.100017188, 6148104.9250874035, 6147538.219025098, 6151460.410052877, 6150899.635137676, 6150328.701234751, 6149775.752086674, 6149216.314872033, 6148670.972861458, 6148073.3504142575, 6147536.147640785, 6151466.645365147, 6150900.847530317, 6150310.548607813, 6149758.937018819, 6149210.736378202, 6148634.902510354, 6148084.311181392, 6147561.895385798, 6151459.636238523, 6150878.070370696, 6150330.899800876, 6149776.228226115, 6149212.506543713, 6148648.31595933, 6148107.433437234, 6147551.120098667, 6151462.68295581, 6150885.61431706, 6150344.104839207, 6149783.601709839, 6149203.909503212, 6148646.709422405, 6148120.660708404, 6147533.601431463, 6151467.778871411, 6150909.037981732, 6150319.655626105, 6149760.360819342, 6149201.781372483, 6148652.769735247, 6148097.700038866, 6147542.23228775, 6151460.515338031, 6150930.151321228, 6150351.891640643, 6149761.858352872, 6149240.2622239385, 6148661.504468664, 6148118.971145205, 6147547.190197367, 6151441.513635026, 6150888.751156992, 6150352.907175679, 6149783.440041686, 6149211.305204391, 6148697.300845191, 6148114.910149992, 6147572.219653209])

aep\_best\_sol on Genetic Generation 7: 664.5827093909176

Best solution on Genetic Generation 8:

([423989.5900196294, 424030.6147734845, 424108.7685078581, 424160.7903307354, 424224.2536215006, 424280.8864096601, 424384.69624244486, 424437.8972319164, 424524.6148760309, 424589.82966636866, 424668.07750918425, 424732.0211479645, 424773.1187854697, 424858.645655606, 424926.8116071125, 425012.758806355, 425089.5290333853, 425174.58948742057, 425223.311066043, 425281.64131849696, 425365.51970178494, 425444.3666470636, 425481.50206981995, 425584.480837424, 425621.361384755, 425732.8090932568, 425817.74282190145, 425871.4653698456, 425928.19497063826, 425990.6229822589, 426071.5493912901, 426162.847208381, 426222.4315374038, 426300.93347443565, 426375.86656927573, 426425.30909434945, 426496.26752635185, 426575.99675544165, 426635.7429438785, 426703.58880886575, 426768.3159641363, 426843.5669922095, 426902.51226566813, 426962.90143955225, 427045.9725170592, 427122.8830344433, 427200.65885688394, 427242.9088509533, 427334.8029444428, 427393.6931600666, 427469.64393544587, 427516.2222487192, 427590.66095065937, 427678.25798599137, 427739.5446101002, 427777.1578254183, 427920.44318002084, 427969.0660992705, 428027.9844585864, 428097.4665121173, 428158.3653693213, 428223.2774066944, 428312.9128030798, 428376.0471700185, 428458.23213676293, 428522.7982219358, 428610.3603060943, 428679.5535486252, 428733.72178952274, 428793.2190237342, 428867.2720919941, 428948.4640916702, 429016.80828767497, 429109.73338921944, 429179.5338966601, 429248.63941685884, 429318.5299979156, 429370.5329269729, 429481.91112168133, 429509.37757677666], [6151450.62122009, 6150881.978547429, 6150343.5034436565, 6149768.791231578, 6149225.085538389, 6148658.215455456, 6148123.319245014, 6147554.375564088, 6151438.258976639, 6150895.707213563, 6150331.603081162, 6149772.562726333, 6149248.785969236, 6148660.427111847, 6148114.459311461, 6147549.055222948, 6151466.487390281, 6150897.8290855605, 6150339.055501297, 6149790.915859779, 6149223.604342973, 6148675.802597626, 6148109.255525808, 6147537.040573384, 6151463.7253302485, 6150895.129712228, 6150328.847642682, 6149769.839094637, 6149221.7339763, 6148669.608679553, 6148073.671226616, 6147537.733225186, 6151470.875021111, 6150891.356100416, 6150306.304374023, 6149757.9407096505, 6149205.808785101, 6148627.558255688, 6148083.898720034, 6147566.581442104, 6151452.301659215, 6150879.571511523, 6150332.376052158, 6149781.344211192, 6149210.360836048, 6148639.950581834, 6148109.455098866, 6147549.83154095, 6151470.803748133, 6150890.004100254, 6150338.477807315, 6149778.159406316, 6149204.766644943, 6148639.163491677, 6148112.8381484635, 6147538.499818165, 6151458.225043599, 6150917.639202282, 6150325.172532765, 6149751.209761933, 6149197.578935572, 6148645.158018543, 6148100.830588923, 6147546.236683632, 6151459.062146589, 6150939.754560671, 6150349.281789815, 6149771.832095702, 6149234.5596357705, 6148668.283183402, 6148118.857494571, 6147554.1667541275, 6151439.1345012635, 6150888.204600705, 6150345.364335233, 6149788.562655024, 6149212.866950907, 6148698.610176955, 6148120.521746273, 6147570.384070889])

aep\_best\_sol on Genetic Generation 8: 664.6432822695476

Best solution on Genetic Generation 9:

([423998.6753413523, 424037.15181709174, 424106.52017980895, 424150.93499410927, 424221.18314363895, 424283.76714552194, 424382.81558200676, 424432.77212689223, 424526.6907593259, 424592.94830231485, 424661.6031148026, 424725.7109665719, 424766.4253975429, 424860.6584707182, 424919.50547502085, 425021.57133951737, 425094.5321709911, 425178.2854472359, 425222.4707070556, 425285.54891017877, 425366.3667515605, 425436.6282528538, 425487.4495801571, 425582.71925899177, 425622.38552080916, 425726.24975779187, 425817.33345104574, 425873.9033135306, 425923.1833973045, 425992.38032378495, 426067.1052047312, 426161.86839979194, 426217.49024049554, 426303.74337608105, 426380.96407737135, 426415.82543450437, 426496.2266319065, 426567.59827865503, 426640.8838064322, 426702.93753043225, 426760.9915308997, 426840.3107716358, 426905.5051822935, 426967.52967363485, 427044.55180161225, 427115.3364866947, 427208.45717690117, 427249.8942392937, 427325.01086070173, 427393.8742735802, 427463.7371778977, 427515.4164786013, 427585.79763992724, 427684.89459895925, 427734.62170843675, 427768.544432704, 427927.849013976, 427967.4126716699, 428029.1533817558, 428106.49694302276, 428157.92698417197, 428221.01296917564, 428315.6228361086, 428370.42657673213, 428462.2547697268, 428525.8471346131, 428603.3560589961, 428676.4772636139, 428731.050543453, 428802.49827892694, 428857.9898492547, 428942.8030010191, 429022.0476471524, 429114.75121971074, 429170.87969325745, 429257.80006465514, 429316.7392310691, 429379.8840529663, 429471.9988816667, 429513.72742791363], [6151452.478634712, 6150883.639296907, 6150349.85718927, 6149768.588148334, 6149230.840157147, 6148664.01139912, 6148113.947140562, 6147547.080921251, 6151436.833762396, 6150895.014187553, 6150329.846635643, 6149770.5172045, 6149243.943101139, 6148662.158162713, 6148118.098375249, 6147551.233328441, 6151465.619166272, 6150898.397747733, 6150330.871831265, 6149786.729306998, 6149232.529696559, 6148675.012561366, 6148115.740798543, 6147538.689421482, 6151462.762836961, 6150893.79621521, 6150320.5356387645, 6149768.858289165, 6149222.3292491, 6148659.98092596, 6148068.530403125, 6147535.7099334225, 6151468.214766579, 6150900.5774936145, 6150304.217531059, 6149765.238520534, 6149208.708502626, 6148627.0955121275, 6148081.645054753, 6147559.0469440855, 6151459.546604543, 6150883.904707877, 6150324.415594356, 6149772.279523997, 6149214.586648037, 6148635.923420945, 6148104.547867883, 6147541.524493454, 6151470.840135887, 6150887.7397630755, 6150329.359538208, 6149782.335022414, 6149202.897834113, 6148643.2439480685, 6148113.295378712, 6147546.290908344, 6151454.271478074, 6150925.799017482, 6150327.578018061, 6149746.540720305, 6149196.905603562, 6148643.5668191165, 6148105.019368785, 6147541.289588119, 6151450.479504477, 6150929.909143697, 6150341.511130776, 6149767.226097887, 6149232.735340343, 6148661.163400081, 6148109.219700152, 6147561.745553642, 6151439.444997963, 6150891.831953149, 6150340.502055251, 6149783.104072417, 6149203.411297828, 6148691.080719305, 6148119.773127483, 6147565.841980441])

aep\_best\_sol on Genetic Generation 9: 664.6728802682214

Best solution on Genetic Generation 10:

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aep\_best\_sol on Genetic Generation 10: 664.7351654317062

Best solution on Genetic Generation 11:

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aep\_best\_sol on Genetic Generation 11: 664.7763051566801

Best solution on Genetic Generation 12:

([423983.5240785791, 424035.5186445008, 424098.7340808605, 424146.39156581816, 424219.7102103005, 424280.8517539747, 424370.4051955838, 424430.1082288316, 424512.4175659372, 424586.9183757454, 424675.65297950356, 424723.7724982551, 424786.1730262659, 424847.486061839, 424922.90977027954, 425008.99158176314, 425080.8739342012, 425188.68752813555, 425226.6170932945, 425292.79817272647, 425354.0894208832, 425441.9360832808, 425506.0515730719, 425589.48446785647, 425606.7343516209, 425722.67520861723, 425808.35802946996, 425875.8803497439, 425925.43250965816, 425997.0730328104, 426047.7912602138, 426169.354097452, 426222.4795547936, 426295.45760744764, 426372.23810292105, 426412.2015886208, 426499.996758422, 426563.4214837631, 426636.1645153723, 426696.91880200524, 426770.5624206247, 426845.4868558046, 426910.94459722436, 426966.2182474324, 427038.7563405408, 427104.311515873, 427223.8570922546, 427242.23674466275, 427303.1217446808, 427397.02136882144, 427463.9094089013, 427523.1162856868, 427597.3566481263, 427664.72960410424, 427731.8074419118, 427775.20141060144, 427929.47637491405, 427970.73144692864, 428041.59591812885, 428114.2742704415, 428144.7670698354, 428222.3836372201, 428305.6904872153, 428370.05821610923, 428481.61022632825, 428534.44764685194, 428611.0090775379, 428670.4595761466, 428734.7688610873, 428789.78064795176, 428863.21496849257, 428916.2688601042, 429028.14554228197, 429121.4354101491, 429188.92258254805, 429272.6067484899, 429323.6483660882, 429386.17660330306, 429493.35234924225, 429503.2977767665], [6151442.205032089, 6150879.022684755, 6150359.643182545, 6149763.264932459, 6149235.043990023, 6148663.146742219, 6148103.948710826, 6147531.32915591, 6151447.418176501, 6150903.565875801, 6150339.345041534, 6149767.09007545, 6149242.452145151, 6148672.295556264, 6148122.462177623, 6147558.758671024, 6151463.576964841, 6150906.382555935, 6150313.158568991, 6149788.690288193, 6149242.927122431, 6148671.941689555, 6148104.519425956, 6147535.758833855, 6151468.86791825, 6150902.206277149, 6150316.154551924, 6149774.758235523, 6149212.709062676, 6148664.161041436, 6148071.366704075, 6147534.792871848, 6151465.100555796, 6150891.590352121, 6150310.749801101, 6149758.512767456, 6149205.569458484, 6148625.024054407, 6148097.360692972, 6147551.855699474, 6151451.377981717, 6150881.33681507, 6150334.265448535, 6149757.9487559665, 6149201.816954181, 6148635.501266266, 6148117.24126208, 6147533.675874867, 6151466.057534819, 6150892.912729172, 6150329.371738695, 6149774.589387187, 6149208.443354198, 6148650.621640612, 6148089.359121111, 6147539.54382263, 6151464.772873481, 6150932.641823093, 6150331.16128309, 6149756.022906892, 6149207.449104435, 6148643.0105105275, 6148097.930635917, 6147535.036916229, 6151445.376147123, 6150942.183458387, 6150324.377806991, 6149766.734672861, 6149244.593996652, 6148663.915773132, 6148099.378382226, 6147542.659810156, 6151442.75016392, 6150889.43112016, 6150339.188399553, 6149792.260382436, 6149187.840138337, 6148680.717259663, 6148112.519362526, 6147556.546140096])

aep\_best\_sol on Genetic Generation 12: 664.8616898680448

Best solution on Genetic Generation 13:

([423977.27662794816, 424030.19424254826, 424093.2605491645, 424137.49916210235, 424220.70467676286, 424283.0315727737, 424371.97719712777, 424435.7932940342, 424513.96343209286, 424594.01916301117, 424671.84011841775, 424714.2433729363, 424793.1979702235, 424843.6607779417, 424922.2398592333, 425000.18330815603, 425086.5006030659, 425181.2994586056, 425229.56564693915, 425301.44025553705, 425359.8782356244, 425434.41560142755, 425498.88622536307, 425586.2052296023, 425602.11996737856, 425719.25145521015, 425804.14941826643, 425873.65176438424, 425928.2281238443, 425990.6194173272, 426050.2669057658, 426162.7399593807, 426226.81155175134, 426285.95510163, 426370.0789313153, 426405.62191341456, 426509.8022418003, 426571.1729726374, 426631.6222729628, 426701.91006009246, 426773.8479160969, 426848.6633606485, 426916.4635389231, 426964.13476125646, 427040.52760248486, 427111.5159692763, 427218.3717117244, 427245.9095079714, 427311.6057012918, 427399.0758067657, 427462.6617406991, 427527.4666454671, 427589.90324790904, 427658.4141839251, 427723.71586188086, 427782.15210945363, 427928.4830176552, 427967.80078003404, 428040.9929474143, 428121.1953910226, 428147.87911596487, 428218.9077084564, 428297.226018576, 428375.6783138666, 428480.6405249224, 428537.2539803955, 428619.07853949803, 428675.5143210444, 428731.4723293498, 428792.32848865294, 428872.5410596295, 428914.24258775724, 429036.1885833582, 429126.73083636584, 429197.7460226924, 429280.44904016436, 429327.02874092234, 429393.53490607964, 429502.0931497663, 429495.02428948646], [6151442.646029624, 6150877.303511139, 6150368.011220934, 6149772.310680998, 6149227.931947399, 6148656.680902502, 6148106.271558807, 6147534.992232895, 6151444.0150073, 6150895.820923777, 6150340.4529177565, 6149773.536335365, 6149233.435477932, 6148676.628394538, 6148119.594652791, 6147554.393320101, 6151455.857052667, 6150913.729325378, 6150308.877207544, 6149798.217576542, 6149240.426662233, 6148668.864204768, 6148107.18930875, 6147534.801811205, 6151464.916563278, 6150908.569559483, 6150325.2809135225, 6149780.3039591145, 6149216.829888249, 6148658.961332808, 6148068.42325356, 6147541.488194482, 6151467.784848295, 6150886.874941534, 6150311.867007483, 6149753.685365671, 6149206.21288966, 6148632.536715595, 6148099.69951745, 6147552.206167191, 6151457.825431808, 6150875.740017985, 6150334.260297052, 6149763.769584751, 6149195.8907620115, 6148638.853236968, 6148108.1007782025, 6147531.960048321, 6151462.048737133, 6150900.760151499, 6150323.016188285, 6149769.657912098, 6149199.193846303, 6148647.948828245, 6148096.547542448, 6147539.080661768, 6151464.728907413, 6150937.615094869, 6150322.821398373, 6149754.592553608, 6149213.758613465, 6148638.589988219, 6148105.316857126, 6147541.176923556, 6151448.4716142155, 6150944.108324505, 6150322.096195639, 6149759.993359915, 6149254.507854847, 6148665.785894463, 6148109.17160786, 6147550.195976752, 6151447.4391108705, 6150895.352609517, 6150348.888048131, 6149797.912649009, 6149180.284724417, 6148678.769205995, 6148104.228090486, 6147548.332668231])

aep\_best\_sol on Genetic Generation 13: 664.9075898335572

Best solution on Genetic Generation 14:

([423967.7890837364, 424038.007754639, 424095.16767041764, 424130.84868412017, 424212.24719767726, 424283.34832842427, 424369.5109621724, 424431.91249892587, 424507.13238197705, 424596.58782360115, 424678.0743352116, 424720.4179766647, 424800.3794858974, 424839.27889088, 424912.4898195317, 424998.0661078466, 425093.415422981, 425174.294832263, 425230.6892762553, 425301.4148429764, 425354.1093868408, 425426.12126287277, 425493.4604946403, 425578.5202442832, 425609.1469474398, 425717.5066155395, 425797.468222823, 425868.00807189837, 425924.33163949987, 425997.1775579416, 426041.5988262251, 426161.187610581, 426233.7580598471, 426281.3177738721, 426365.95885248075, 426403.399790468, 426505.7373565248, 426562.9457097947, 426636.746194184, 426695.90784075443, 426771.81116219476, 426846.85061227356, 426925.6352559773, 426970.0962155526, 427040.0327078642, 427117.37534218945, 427224.1310789786, 427241.5390413368, 427320.92202374135, 427401.777794057, 427461.2532986601, 427528.686559243, 427593.031416678, 427654.1366030907, 427728.4995335641, 427782.31898797327, 427926.96995195234, 427968.2300995028, 428037.5818135072, 428112.0283445131, 428157.3265319284, 428216.99759397644, 428287.30699576845, 428381.7111651948, 428484.4098222206, 428536.6450990447, 428624.8039350634, 428685.48126088915, 428741.1649827092, 428787.842976287, 428877.22206807154, 428913.84348507953, 429033.9156983465, 429136.1713857465, 429200.7288968037, 429273.9551414434, 429326.98138887173, 429400.3223006253, 429506.57188181183, 429491.0253033735], [6151446.84999944, 6150872.107404206, 6150366.075295787, 6149779.886945175, 6149223.954758728, 6148648.978670189, 6148112.667611957, 6147542.948368551, 6151452.077242476, 6150902.312020264, 6150338.839717632, 6149766.0841552485, 6149235.776640099, 6148678.377675319, 6148116.112691712, 6147553.509186995, 6151465.633082135, 6150909.930309038, 6150312.770991279, 6149794.415991524, 6149243.981475199, 6148677.250681934, 6148107.2804473825, 6147541.505720791, 6151466.631979593, 6150902.48920611, 6150327.277845131, 6149786.6397153735, 6149224.189755431, 6148666.176498919, 6148069.235973014, 6147534.222208277, 6151471.753633145, 6150878.388899593, 6150304.254073341, 6149763.498501622, 6149211.551406002, 6148631.43892993, 6148108.199338391, 6147546.925609592, 6151451.250366885, 6150878.2367989775, 6150334.074839017, 6149770.978081712, 6149188.512966297, 6148631.622670164, 6148112.2884276435, 6147531.590270237, 6151460.620150899, 6150898.401484371, 6150316.26151578, 6149764.465162489, 6149206.4868286485, 6148641.330742613, 6148098.905367324, 6147541.439215261, 6151471.950902337, 6150944.676583224, 6150317.792183714, 6149756.095741503, 6149212.913434724, 6148641.419751382, 6148109.775164994, 6147538.407753258, 6151449.514152716, 6150935.603815576, 6150327.248217051, 6149760.612281196, 6149246.895005827, 6148656.87525664, 6148116.905649318, 6147555.689159157, 6151446.553019913, 6150889.244806562, 6150342.061999678, 6149793.97670336, 6149171.66368065, 6148688.622221242, 6148100.151723149, 6147540.401647058])

aep\_best\_sol on Genetic Generation 14: 664.9467549489113

Best solution on Genetic Generation 15:

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aep\_best\_sol on Genetic Generation 15: 665.0106690298023

finalsolution

([423958.5252344358, 424040.4532615847, 424098.5194902548, 424129.6709944254, 424207.3844525066, 424276.03197608766, 424366.2085592622, 424425.12682528194, 424515.1099257942, 424602.8295675369, 424686.39853289886, 424725.28860570997, 424796.5323696371, 424842.15965493035, 424920.21784177126, 425006.3179307481, 425085.35871993843, 425174.47973999655, 425235.0313310428, 425295.631158745, 425349.89317967836, 425435.79707231786, 425490.247731018, 425570.1287136105, 425616.5227307094, 425708.6186326206, 425802.97954906966, 425868.1104588299, 425931.095905262, 425990.3965215107, 426044.1252160752, 426159.97558036045, 426225.1306360848, 426286.29728983843, 426359.95048272714, 426408.9118946966, 426505.185113897, 426556.9300380175, 426630.19688197295, 426693.8685358372, 426780.80296327604, 426849.7827258153, 426917.77665666497, 426979.27812466136, 427046.07040891703, 427110.7515959477, 427228.5707397193, 427245.93582600396, 427317.13046545675, 427407.9874290029, 427461.2250039913, 427522.93915656256, 427585.104226659, 427662.6769527432, 427721.0423466561, 427782.0806077428, 427936.70908936963, 427958.750181841, 428032.4454363915, 428113.00829124736, 428154.80992133525, 428226.3186238184, 428296.07765105984, 428385.0432756177, 428482.2722083052, 428530.8408211386, 428627.07931682037, 428690.245758558, 428743.9469852995, 428789.09838391165, 428880.8323033658, 428923.05966891994, 429042.1022384649, 429144.9919948301, 429202.5249614397, 429271.8288404402, 429335.59751147014, 429407.5799621772, 429515.55777262803, 429487.3197253095], [6151456.300209728, 6150869.945034268, 6150360.852923496, 6149787.283200412, 6149220.990204547, 6148645.848681843, 6148115.262058972, 6147541.964065897, 6151460.496583287, 6150898.956601605, 6150344.091725377, 6149773.466983143, 6149232.479689574, 6148681.920952189, 6148108.830218303, 6147549.522742202, 6151458.512447242, 6150910.3465136215, 6150320.882469611, 6149796.663387094, 6149244.995327744, 6148668.358990271, 6148100.490030599, 6147538.868841612, 6151464.755692268, 6150896.304942122, 6150324.951966092, 6149782.372605586, 6149223.285816008, 6148665.498501055, 6148073.569996844, 6147535.365287849, 6151466.112868512, 6150877.56635095, 6150302.753157617, 6149766.741884259, 6149207.604312824, 6148638.112916806, 6148101.224598619, 6147546.4400969315, 6151446.879195505, 6150883.197576151, 6150341.066208647, 6149780.229026985, 6149191.955245643, 6148638.537931976, 6148115.071916939, 6147536.279409818, 6151466.422055891, 6150895.131271722, 6150321.041401472, 6149762.899023778, 6149209.158349722, 6148650.209303979, 6148094.879169567, 6147534.828179588, 6151463.772977873, 6150947.893138869, 6150319.164860734, 6149763.374707045, 6149210.441107638, 6148641.562858843, 6148112.762066682, 6147531.900409854, 6151439.809234382, 6150931.3393024495, 6150326.837067257, 6149753.407389798, 6149242.296964241, 6148651.511804162, 6148114.044832395, 6147560.124264302, 6151451.8908550395, 6150898.717661681, 6150340.347778075, 6149788.609036659, 6149176.8512910195, 6148681.358872941, 6148090.406892453, 6147536.925971404])

aep\_ref: 664.3345305655693

aep\_max: 665.0106690298023

**CODE “Improve\_Hornsrev1\_Layout\_JRJ\_03\_03\_2025.py”**

# Juan R Jimenez DTU Wind Energy Master

# Master Thesis Wind farm layout optimization with group random search

# Install PyWake if needed

import py\_wake

import numpy as np

import matplotlib.pyplot as plt

import random as rnd

#importing the properties of Hornsrev1, which are already stored in PyWake

from py\_wake.examples.data.hornsrev1 import V80

from py\_wake.examples.data.hornsrev1 import Hornsrev1Site

from py\_wake.examples.data.hornsrev1 import wt\_x, wt\_y

# BastankhahGaussian combines the engineering wind farm model, `PropagateDownwind` with

# the `BastankhahGaussianDeficit` wake deficit model and the `SquaredSum` super position model

from py\_wake.literature.gaussian\_models import Bastankhah\_PorteAgel\_2014

# After we import the objects we instatiate them:

site = Hornsrev1Site()

wt = V80()

windFarmModel = Bastankhah\_PorteAgel\_2014(site, wt, k=0.0324555)

site.plot\_wd\_distribution(n\_wd=12)

posit\_x\_max = 429492 + 25

posit\_y\_max = 6151447 + 25

posit\_x\_min = 423974 - 25

posit\_y\_min = 6147556 - 25

# Original AEP

aep\_ref = windFarmModel(wt\_x,wt\_y).aep().sum()

aep\_max = 0

print ('Original AEP: %f GWh'%aep\_ref)

# Define the problem constants

WT\_Num = 80

farm\_widht = posit\_x\_max - posit\_x\_min

Farm\_height = posit\_y\_max - posit\_y\_min

WT\_Rad = 40

# Gen\_Num = 10

def Data\_Imputs ():

global Iter\_Lenght

global Iter\_Num

global Gen\_Num

Iter\_Lenght = int(input ("Enter Iteration Lenght in meters: "))

Iter\_Num = int(input ("Enter Number of Iterations on each Generation: "))

Gen\_Num = int(input ("Enter Number of Genetic Generations: "))

return Iter\_Lenght

return Iter\_Num

return Gen\_Num

def fitness(s):

penalty = 0

# Calculate the total energy output and penalize overlapping turbines

for i in range(0,(WT\_Num-1)):

x1,y1 = s[0][i], s[1][i]

for j in range(i+1,(WT\_Num-1)):

x2,y2 = s[0][j], s[1][j]

distance = np.sqrt((x2 - x1)\*\*2 + (y2 - y1)\*\*2)

if distance > 5 \* WT\_Rad:

penalty += 0

else:

penalty += -(distance - 5 \* WT\_Rad)

optim\_func = float(windFarmModel(s[0],s[1]).aep().sum()) - penalty # Simplified energy calculation

return optim\_func

# Generate Solutions

def all\_elements\_greater\_than(lst, value):

return all(x > value for x in lst)

def all\_elements\_smaller\_than(lst, value):

return all(x < value for x in lst)

def list\_randon\_values(lst, val\_max, val\_min):

lst\_rnd = []

for x in lst:

lst\_rnd\_val = 0

good\_lst\_rnd\_val = False

while good\_lst\_rnd\_val == False:

lst\_rnd\_val = (x + (Iter\_Lenght \* rnd.uniform(-1,1)))

if (lst\_rnd\_val < val\_max) and (lst\_rnd\_val > val\_min):

good\_lst\_rnd\_val = True

lst\_rnd.append(lst\_rnd\_val)

return lst\_rnd

Data\_Imputs ()

solutions = []

for s in range(Iter\_Num):

x\_rnd = []

y\_rnd = []

x\_sol = wt\_x

x\_rnd = list\_randon\_values(x\_sol, posit\_x\_max, posit\_x\_min)

x\_sol = np.array(x\_rnd)

y\_sol = wt\_y

y\_rnd = list\_randon\_values(y\_sol, posit\_y\_max, posit\_y\_min)

y\_sol = np.array(y\_rnd)

solutions.append( (x\_sol,y\_sol) )

rankedsolutions = []

for s in solutions:

rankedsolutions.append( (fitness(s),s) )

rankedsolutions.sort(key=lambda a: a[0])

bestsolution = rankedsolutions[(Iter\_Num-1)]

bestsolution = ( (bestsolution[1][0],bestsolution[1][1]) )

print("Best solution on reference layout randomized Generation 0:")

print(bestsolution)

x\_best\_sol,y\_best\_sol = (bestsolution[0],bestsolution[1])

aep\_best\_sol = float(windFarmModel(x\_best\_sol,y\_best\_sol).aep().sum())

print("aep\_best\_sol on reference layout randomized Generation 0:",aep\_best\_sol)

global Gen

Gen = []

NewGen\_i\_best = []

aep\_best\_sol\_i = []

Delta\_aep\_best\_sol\_i = []

for i in range(1,Gen\_Num+1):

Gen.append(i)

NewGen = []

for \_ in range(Iter\_Num):

new\_gen\_x = []

new\_gen\_y = []

for s in bestsolution:

new\_gen\_x = bestsolution[0]

new\_gen\_x\_rnd = []

new\_gen\_x\_rnd = list\_randon\_values(new\_gen\_x, posit\_x\_max , posit\_x\_min)

for s in bestsolution:

new\_gen\_y = bestsolution[1]

new\_gen\_y\_rnd = []

new\_gen\_y\_rnd = list\_randon\_values(new\_gen\_y, posit\_y\_max, posit\_y\_min)

x\_sol = new\_gen\_x\_rnd

y\_sol = new\_gen\_y\_rnd

NewGen.append( (x\_sol,y\_sol) )

solutions = NewGen

rankedsolutions = []

for s in solutions:

rankedsolutions.append( (fitness(s),s) )

rankedsolutions.sort(key=lambda a: a[0])

bestsolution = rankedsolutions[(Iter\_Num-1)]

bestsolution = ( (bestsolution[1][0],bestsolution[1][1]) )

print(f"Best solution on Genetic Generation {i}:")

print(bestsolution)

x\_best\_sol,y\_best\_sol = (bestsolution[0],bestsolution[1])

NewGen\_i\_best.append( (x\_best\_sol,y\_best\_sol) )

aep\_best\_sol = float(windFarmModel(x\_best\_sol,y\_best\_sol).aep().sum())

aep\_best\_sol\_i.append(aep\_best\_sol)

print(f"aep\_best\_sol on Genetic Generation {i}:",aep\_best\_sol)

aep\_best\_sol\_prev = aep\_ref

for s in aep\_best\_sol\_i:

Delta\_aep\_best\_sol\_i\_elem = s - aep\_best\_sol\_prev

aep\_best\_sol\_prev = s

Delta\_aep\_best\_sol\_i.append(Delta\_aep\_best\_sol\_i\_elem)

Delta\_aep\_best\_sol\_i

finalsolution = []

finalsolution = bestsolution

print("finalsolution")

print(finalsolution)

x\_max,y\_max = (finalsolution[0],finalsolution[1])

aep\_ref = float(windFarmModel(wt\_x,wt\_y).aep().sum())

print("aep\_ref:",aep\_ref)

aep\_max = float(windFarmModel(x\_max,y\_max).aep().sum())

print("aep\_max:",aep\_max)

plt.figure()

plt.title('Original blue and evolutions of Generation Layouts yellow')

plt.plot(wt\_x, wt\_y,'b.')

for s in NewGen\_i\_best:

plt.plot(s[0], s[1],'y.')

plt.plot(x\_max, y\_max, 'r.')

plt.xlabel('Evolution of positions x [m]')

plt.ylabel('Evolution of positions y [m]')

plt.show()

plt.figure()

plt.title('Original blue and Final black Layouts')

plt.plot(wt\_x, wt\_y,'b.')

wt.plot(x\_max, y\_max)

plt.xlabel('x [m]')

plt.ylabel('y [m]')

plt.show()

plt.figure()

plt.title('Evolution of improvement throught genetic evolutions')

plt.plot(Gen, aep\_best\_sol\_i, 'r.')

plt.xlabel('Genetic Generation i')

plt.ylabel('Best aep Generation i GWh')

plt.show()

plt.figure()

plt.title('Evolution of diferencial improvement throught genetic evolutions')

plt.plot(Gen, Delta\_aep\_best\_sol\_i, 'r.')

plt.xlabel('Genetic Generation i')

plt.ylabel('Best Delta aep Generation i GWh')

plt.show()