The dataset contains 36733 instances of 11 sensor measures aggregated over one hour (by means of average or sum) from a gas turbine. The Dataset includes gas turbine parameters (such as Turbine Inlet Temperature and Compressor Discharge pressure) in addition to the ambient variables.

Problem statement: predicting turbine energy yield (TEY) using ambient variables as features.

Attribute Information:

The explanations of sensor measurements and their brief statistics are given below.

Variable (Abbr.) Unit Min Max Mean
Ambient temperature (AT) C â€“6.23 37.10 17.71
Ambient pressure (AP) mbar 985.85 1036.56 1013.07
Ambient humidity (AH) (%) 24.08 100.20 77.87
Air filter difference pressure (AFDP) mbar 2.09 7.61 3.93
Gas turbine exhaust pressure (GTEP) mbar 17.70 40.72 25.56
Turbine inlet temperature (TIT) C 1000.85 1100.89 1081.43
Turbine after temperature (TAT) C 511.04 550.61 546.16
Compressor discharge pressure (CDP) mbar 9.85 15.16 12.06
Turbine energy yield (TEY) MWH 100.02 179.50 133.51
Carbon monoxide (CO) mg/m3 0.00 44.10 2.37
Nitrogen oxides (NOx) mg/m3 25.90 119.91 65.29

In [1]:

```
import warnings
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import seaborn as sns



sns.set_style('darkgrid')

import plotly.express as px
import plotly.graph_objects as go
from plotly.subplots import make_subplots
import warnings
warnings.filterwarnings('ignore')
```

In [2]:

```
from keras.models import Sequential
from keras.layers import Dense
from keras.layers import Dropout
from keras.utils import np_utils
from keras.constraints import maxnorm
from sklearn.preprocessing import MinMaxScaler
from sklearn.metrics import mean_squared_error
from keras.wrappers.scikit_learn import KerasRegressor, KerasClassifier
from sklearn.model_selection import cross_val_score
from sklearn.model_selection import KFold
from sklearn.model_selection import train_test_split
from sklearn.feature_selection import SelectKBest
from sklearn.feature_selection import mutual_info_regression
from sklearn.preprocessing import StandardScaler
from sklearn.model_selection import GridSearchCV, KFold, RandomizedSearchCV
```

In [3]:

```
gas_turbines = pd.read_csv("gas_turbines.csv")
gas_turbines.head()
```

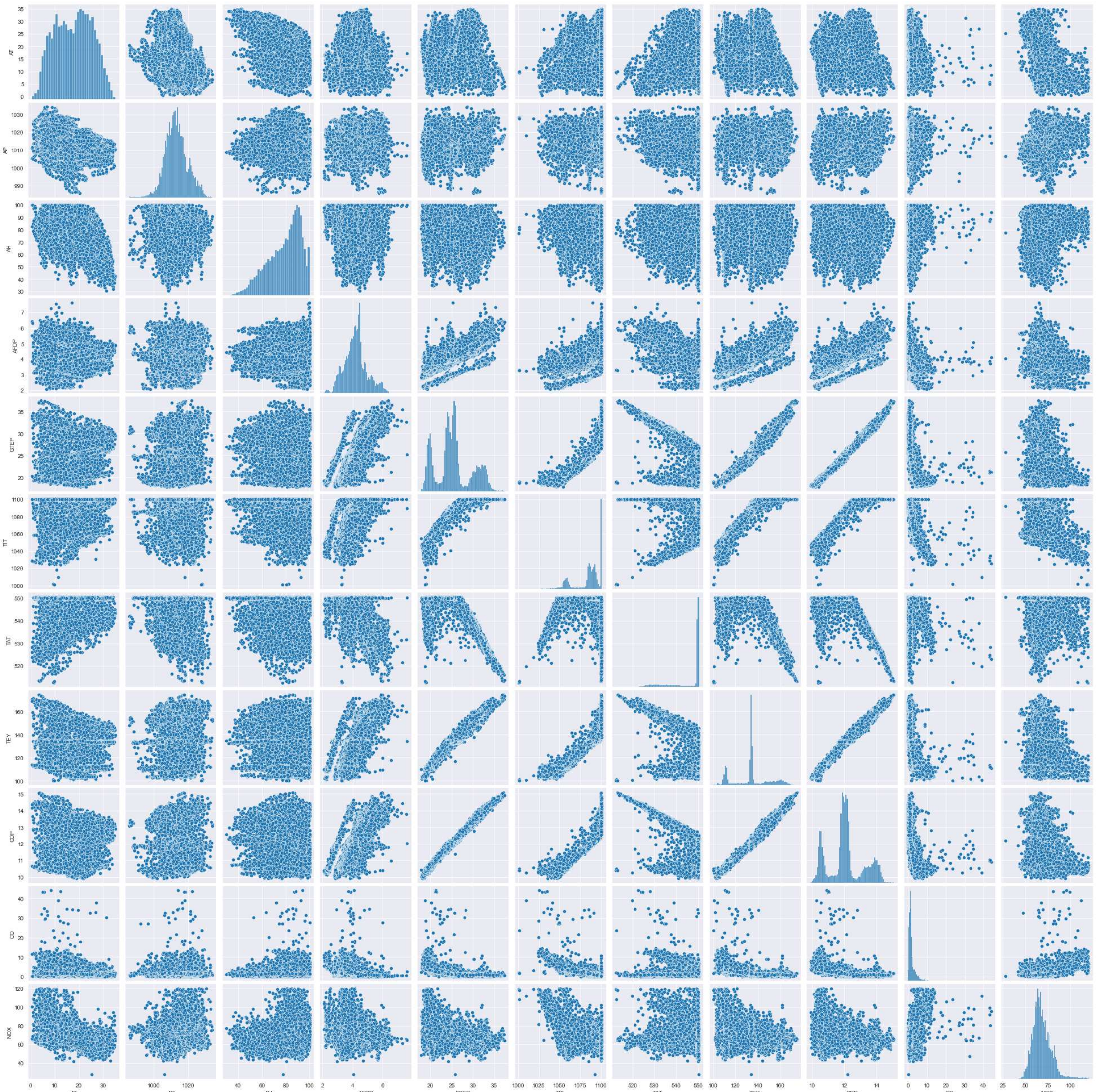
Out[3]:

	AT	AP	AH	AFDP	GTEP	TIT	TAT	TEY	CDP	CO	NOX
0	6.8594	1007.9	96.799	3.5000	19.663	1059.2	550.00	114.70	10.605	3.1547	82.722
1	6.7850	1008.4	97.118	3.4998	19.728	1059.3	550.00	114.72	10.598	3.2363	82.776
2	6.8977	1008.8	95.939	3.4824	19.779	1059.4	549.87	114.71	10.601	3.2012	82.468
3	7.0569	1009.2	95.249	3.4805	19.792	1059.6	549.99	114.72	10.606	3.1923	82.670
4	7.3978	1009.7	95.150	3.4976	19.765	1059.7	549.98	114.72	10.612	3.2484	82.311

In [4]:
```
gas_turbines.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 15039 entries, 0 to 15038
Data columns (total 11 columns):
 #   Column  Non-Null Count  Dtype  
---  ------  --------------  -----  
 0   AT      15039 non-null  float64
 1   AP      15039 non-null  float64
 2   AH      15039 non-null  float64
 3   AFDP    15039 non-null  float64
 4   GTEP    15039 non-null  float64
 5   TIT     15039 non-null  float64
 6   TAT     15039 non-null  float64
 7   TEY     15039 non-null  float64
 8   CDP     15039 non-null  float64
 9   CO      15039 non-null  float64
 10  NOX     15039 non-null  float64
dtypes: float64(11)
memory usage: 1.3 MB
```

In [5]:
```
sns.set_style('darkgrid')
sns.pairplot(gas_turbines)

plt.show()
```



In [6]:
```
"""color = ["g","y","r", "b","g","y","r", "b","g","y","r"]
for i,j in zip(gas_turbines.columns.values,color):
    f, axes = plt.subplots(figsize=(10,8))
    sns.regplot(x = 'TEY', y = i, data = gas_turbines,color = j, scatter_kws={'alpha':0.3})
    axes.set_xlabel('TEY', fontsize = 14)
    axes.set_ylabel(i, fontsize=14)
    plt.show()"""
```

Out[6]:
```
'color = ["g","y","r", "b","g","y","r", "b","g","y","r"]\nfor i,j in zip(gas_turbines.columns.values,colo
r):\n    f, axes = plt.subplots(figsize=(10,8))\n    sns.regplot(x = \'TEY\', y = i, data = gas_turbines,co
lor = j, scatter_kws={\'alpha\':0.3})\n    axes.set_xlabel(\'TEY\', fontsize = 14)\n    axes.set_ylabel(i,
fontsize=14)\n    plt.show()'
```

In [7]:

```
import seaborn as sns
import matplotlib.pyplot as pplt
#correlation matrix
corrmat = gas_turbines.corr()
f, ax = plt.subplots(figsize=(20, 10))
sns.heatmap(corrmat, vmax=.8, square=True, annot=True);
```

In [8]:

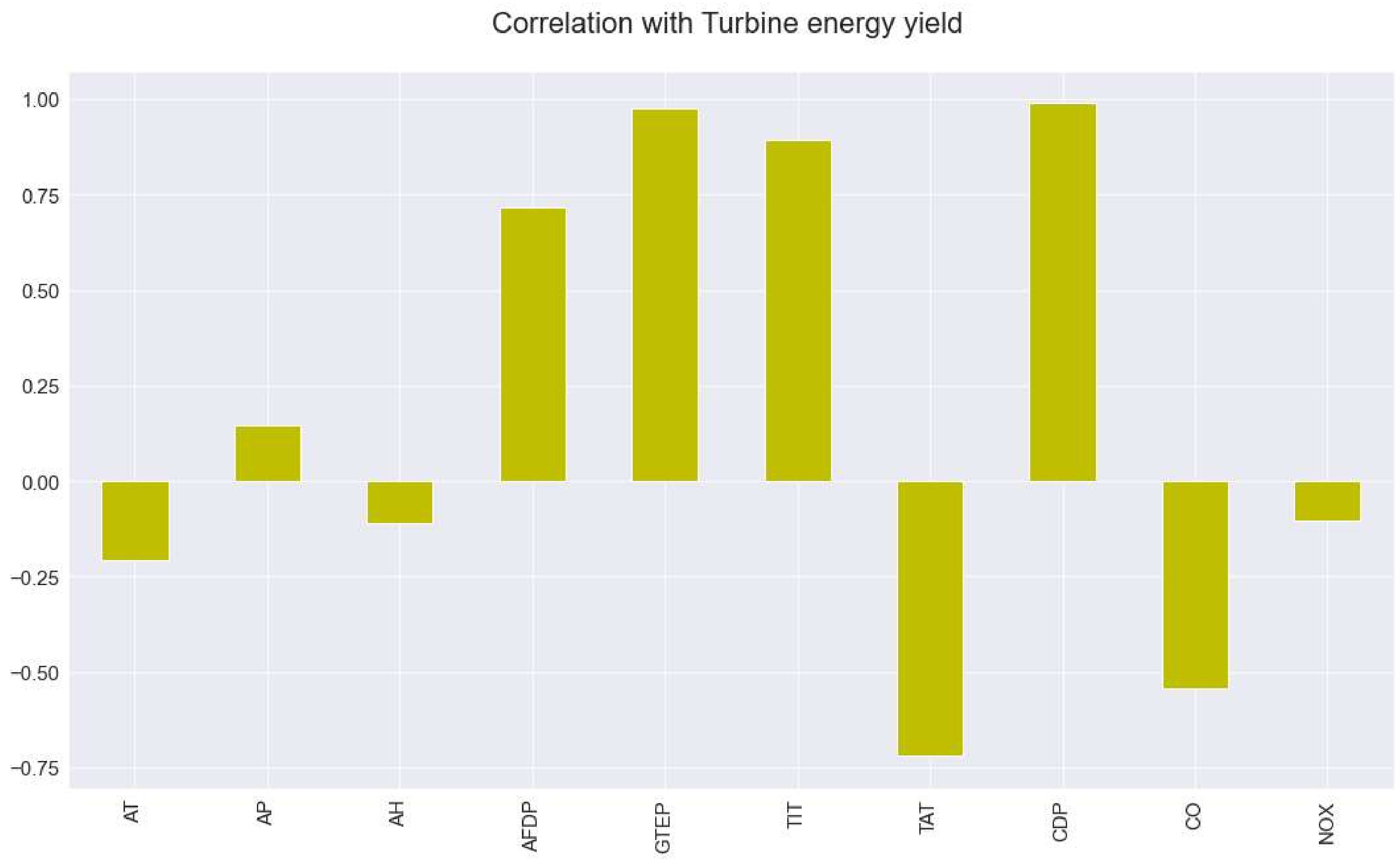
```
y = gas_turbines[gas_turbines.columns[7]]
X = gas_turbines[['AT', 'AP', 'AH', 'AFDP', 'GTEP', 'TIT', 'TAT', 'CDP', 'CO','NOX']]
```

In [9]:

```
# correlation with TEY

data2 = X.copy()

correlations = data2.corrwith(gas_turbines["TEY"])
correlations = correlations[correlations!=1]
positive_correlations = correlations[correlations >0].sort_values(ascending = False)
negative_correlations =correlations[correlations<0].sort_values(ascending = False)

correlations.plot.bar(
        figsize = (18, 10),
        fontsize = 15,
        color = 'y',
        rot = 90, grid = True)
plt.title('Correlation with Turbine energy yield \n',
horizontalalignment="center", fontstyle = "normal",
fontsize = "22", fontfamily = "sans-serif")
```

Out[9]:

```
Text(0.5, 1.0, 'Correlation with Turbine energy yield \n')
```



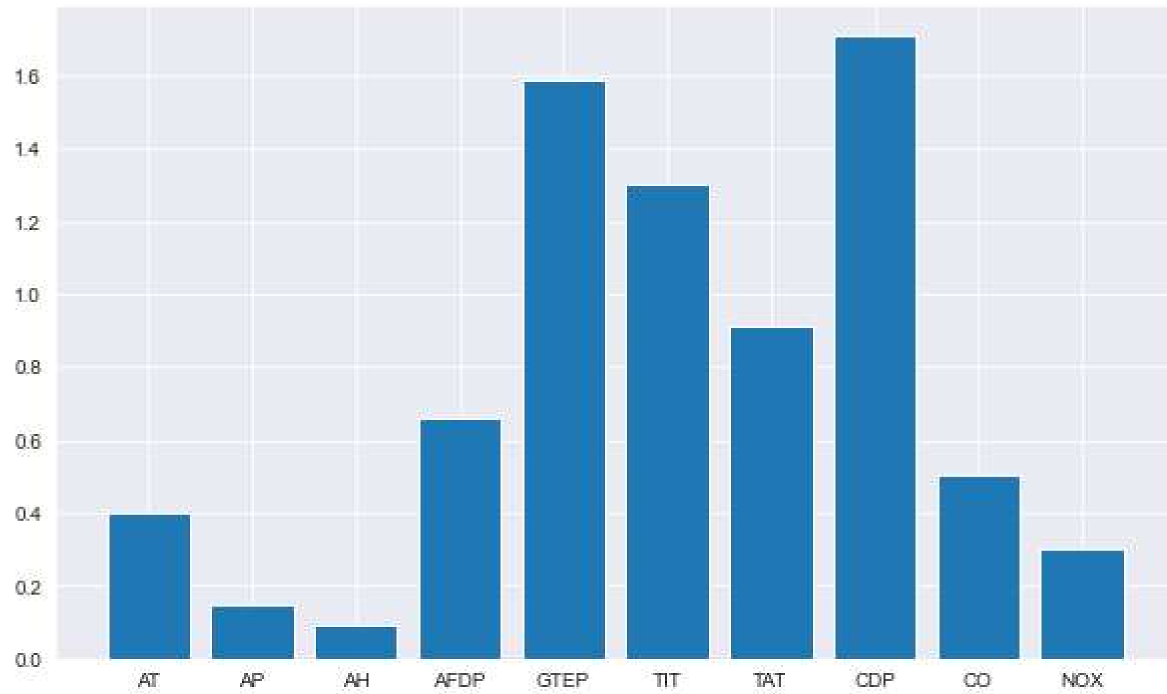
In [10]:

```
# split into train and test sets
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.33, random_state=1)
```

In [11]:

```
#feature selecton

def select_features(X_train, y_train, X_test):

    # configure to select all features
    features = SelectKBest(score_func=mutual_info_regression, k='all')

    # Relationships from training data
    features.fit(X_train, y_train)



    # transform train data
    X_train_f = features.transform(X_train)



    # transform test data
    X_test_f = features.transform(X_test)

    return X_train_f, X_test_f, features
```

In [12]:
```
X_train_f, X_test_f, features = select_features(X_train, y_train, X_test)
fig, axes = plt.subplots(figsize=(10, 6))
plt.bar([i for i in range(len(features.scores_))], features.scores_)
axes.set_xticks([0,1,2,3,4,5,6,7,8,9])
axes.set_xticklabels(X.columns.values)
plt.show()
```



In [13]:
```
y_copy = gas_turbines["TEY"]
from sklearn.preprocessing import StandardScaler
scaler=StandardScaler()
y_ = StandardScaler().fit_transform(y_copy.values.reshape(len(y_copy),1))[:,0]


X1 = gas_turbines.drop(['TEY','AT','AP','AH','CO','NOX'], axis = 1)
scaler.fit(X1)


#X_copy = X[['AFDP', 'GTEP', 'TIT', 'TAT', 'CDP']]
features_scaler=scaler.fit_transform(X1)
X_=pd.DataFrame(features_scaler,columns=X[['AFDP', 'GTEP', 'TIT', 'TAT', 'CDP']].columns)
X_.head()
```

Out[13]:

	AFDP	GTEP	TIT	TAT	CDP
0	-0.921232	-1.379101	-1.488376	0.585240	-1.357331
1	-0.921495	-1.363528	-1.482325	0.585240	-1.363676
2	-0.944385	-1.351309	-1.476275	0.568715	-1.360957
3	-0.946884	-1.348194	-1.464173	0.583969	-1.356424
4	-0.924389	-1.354663	-1.458123	0.582698	-1.350985

In [14]:
```
# Splitting data into test data and train data

from sklearn.model_selection import train_test_split

X_train, X_test, y_train, y_test = train_test_split(X1, y_, test_size=0.3, random_state=1)
```

In [15]:
```

print('Shape of x_train: ', X_train.shape)
print('Shape of x_test: ', X_test.shape)
print('Shape of y_train: ', y_train.shape)
print('Shape of y_test: ', y_test.shape)
```

```
Shape of x_train:  (10527, 5)
Shape of x_test:  (4512, 5)
Shape of y_train:  (10527,)
Shape of y_test:  (4512,)
```

In [16]:

```
model = Sequential()
model.add(Dense(28, input_dim=5, kernel_initializer='uniform', activation='tanh'))
model.add(Dense(50, kernel_initializer='uniform', activation='tanh'))
model.add(Dense(50, kernel_initializer='uniform', activation='tanh'))
model.add(Dense(1, kernel_initializer='uniform', activation='linear'))

# Compile model
model.compile(loss='mean_squared_error', optimizer='adam',
              metrics=['mean_squared_error', 'mean_absolute_error', 'mean_absolute_percentage_error', 'cosin
```

In [17]:

```
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
dense (Dense)                (None, 28)                168
_________________________________________________________________
dense_1 (Dense)              (None, 50)                1450
_________________________________________________________________
dense_2 (Dense)              (None, 50)                2550
_________________________________________________________________
dense_3 (Dense)              (None, 1)                 51
=================================================================
Total params: 4,219
Trainable params: 4,219
Non-trainable params: 0
_________________________________________________________________
```

In [18]:

```
# Fit the model
history = model.fit(X_train,y_train, epochs=500)
```

```
Epoch 1/500
329/329 [==============================] - 1s 1ms/step - loss: 0.6445 - mean_squared_error: 0.6445 - mea
n_absolute_error: 0.5400 - mean_absolute_percentage_error: 616.8769 - cosine_proximity: 0.2770
Epoch 2/500
329/329 [==============================] - 0s 1ms/step - loss: 0.0842 - mean_squared_error: 0.0842 - mea
n_absolute_error: 0.2336 - mean_absolute_percentage_error: 1140.4767 - cosine_proximity: 0.5508
Epoch 3/500
329/329 [==============================] - 1s 2ms/step - loss: 0.0682 - mean_squared_error: 0.0682 - mea
n_absolute_error: 0.2092 - mean_absolute_percentage_error: 1139.7822 - cosine_proximity: 0.5699
Epoch 4/500
329/329 [==============================] - 0s 1ms/step - loss: 0.0717 - mean_squared_error: 0.0717 - mea
n_absolute_error: 0.2150 - mean_absolute_percentage_error: 1303.7081 - cosine_proximity: 0.5729
Epoch 5/500
329/329 [==============================] - 1s 2ms/step - loss: 0.0811 - mean_squared_error: 0.0811 - mea
n_absolute_error: 0.2291 - mean_absolute_percentage_error: 1086.9312 - cosine_proximity: 0.5669
Epoch 6/500
329/329 [==============================] - 0s 1ms/step - loss: 0.0684 - mean_squared_error: 0.0684 - mea
n_absolute_error: 0.2102 - mean_absolute_percentage_error: 857.1329 - cosine_proximity: 0.5727
Epoch 7/500
```

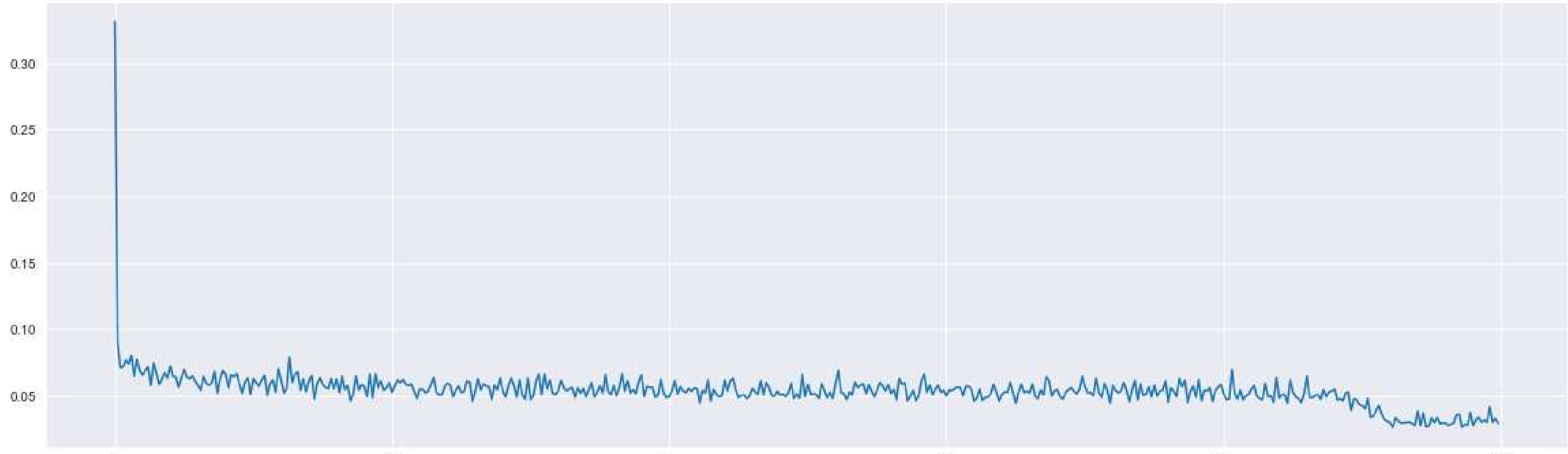
In [19]:

```
# model evaluation
scores = model.evaluate(X_test, y_test)
print((model.metrics_names[1]))
```

```
141/141 [==============================] - 1s 1ms/step - loss: 0.0299 - mean_squared_error: 0.0299 - mean_a
bsolute_error: 0.1292 - mean_absolute_percentage_error: 372.8955 - cosine_proximity: 0.7110
mean_squared_error
```

In [20]:

```
fig, axes = plt.subplots(figsize=(20, 6))
# plot metrics
plt.plot(history.history['mean_squared_error'])
"""plt.plot(history.history['mean_absolute_error'])
plt.plot(history.history['mean_absolute_percentage_error'])
plt.plot(history.history['cosine_proximity'])
"""
plt.show()
```



In [21]:

```
y2 = gas_turbines["TEY"]
data_c = gas_turbines.copy()
X2 = data_c.drop(['TEY','AT','AP','AH','CO','NOX'], axis = 1)

# Scaling all the features
scaler.fit(X2)
y2_ = StandardScaler().fit_transform(y2.values.reshape(len(y2),1))[:,0]



scaled_features=scaler.transform(X2)
data_head=pd.DataFrame(scaled_features,columns=X2.columns)
data_head.head()
```

Out[21]:

	AFDP	GTEP	TIT	TAT	CDP
0	-0.921232	-1.379101	-1.488376	0.585240	-1.357331
1	-0.921495	-1.363528	-1.482325	0.585240	-1.363676
2	-0.944385	-1.351309	-1.476275	0.568715	-1.360957
3	-0.946884	-1.348194	-1.464173	0.583969	-1.356424
4	-0.924389	-1.354663	-1.458123	0.582698	-1.350985

In [22]:

```
from sklearn.model_selection import train_test_split
from keras.optimizers import Adam


x_train, x_test, y_train, y_test = train_test_split(X2, gas_turbines["TEY"], test_size=0.3, random_state=42)
```

In [ ]:

```
def create_model(learning_rate,dropout_rate,activation_function,init,neuron1,neuron2):
    model = Sequential()
    model.add(Dense(neuron1,input_dim = 5,kernel_initializer = init,activation = activation_function))
    model.add(Dropout(dropout_rate))
    model.add(Dense(neuron2,input_dim = neuron1,kernel_initializer = init,activation = activation_function))
    model.add(Dropout(dropout_rate))
    model.add(Dense(1,activation = 'linear'))

    adam=Adam(learning_rate = learning_rate)
    model.compile(loss = 'mean_squared_error',optimizer = adam, metrics = ['mse'])
    return model

# Create the model

model = KerasClassifier(build_fn = create_model,verbose = 0)

# Define the grid search parameters

batch_size = [20,40]
epochs = [100,500]
learning_rate = [0.01,0.1]
dropout_rate = [0.1,0.2]
activation_function = ['softmax','relu','tanh','linear']
init = ['uniform','normal']
neuron1 = [4,8,16]
neuron2 = [2,4,8]

# Make a dictionary of the grid search parameters

param_grids = dict(batch_size = batch_size,epochs = epochs,learning_rate = learning_rate,dropout_rate = drop
                   activation_function = activation_function,init = init,neuron1 = neuron1,neuron2 = neuron2

# Build and fit the GridSearchCV

grid = GridSearchCV(estimator = model,param_grid = param_grids,cv = KFold(),verbose = 10, scoring='neg_mean_
grid_result = grid.fit(x_train, y_train)

# Summarize the results
print('Best : {}, using {}'.format(grid_result.best_score_,grid_result.best_params_))
```

```
Fitting 5 folds for each of 1152 candidates, totalling 5760 fits
[CV] activation_function=softmax, batch_size=20, dropout_rate=0.1, epochs=100, init=uniform, learning_ra
te=0.01, neuron1=4, neuron2=2

[Parallel(n_jobs=1)]: Using backend SequentialBackend with 1 concurrent workers.

[CV]  activation_function=softmax, batch_size=20, dropout_rate=0.1, epochs=100, init=uniform, learning_r
ate=0.01, neuron1=4, neuron2=2, score=-1426.468, total=  30.3s
[CV] activation_function=softmax, batch_size=20, dropout_rate=0.1, epochs=100, init=uniform, learning_ra
te=0.01, neuron1=4, neuron2=2

[Parallel(n_jobs=1)]: Done   1 out of   1 | elapsed:   30.2s remaining:    0.0s

[CV]  activation_function=softmax, batch_size=20, dropout_rate=0.1, epochs=100, init=uniform, learning_r
ate=0.01, neuron1=4, neuron2=2, score=-1388.876, total=  29.3s
[CV] activation_function=softmax, batch_size=20, dropout_rate=0.1, epochs=100, init=uniform, learning_ra
te=0.01, neuron1=4, neuron2=2

[Parallel(n_jobs=1)]: Done   2 out of   2 | elapsed:   59.6s remaining:    0.0s

[CV]  activation_function=softmax, batch_size=20, dropout_rate=0.1, epochs=100, init=uniform, learning_r
```

Reference: Keras classification and regression metrics
[https://machinelearningmastery.com/custom-metrics-deep-learning-keras-python/ (https://machinelearningmastery.com/custom-metrics-deep-learning-keras-python/)](https://machinelearningmastery.com/custom-metrics-deep-learning-keras-python/)