Exploring the solar and wind energy generation landscape and future in the Philippines

Summary: In the past decade, the Philippines has increased its wind and solar energy generation capacity and enacted legislation to encourage the construction of new capacity.

The research project aims to investigate the present and projected future progress of the Philippines in transitioning its energy generation to green sources, specifically for wind and solar power generation. This will be accomplished by analyzing current power plant locations vs potential renewable energy capacity per location, and by clustering of countries based on installed capacity, gdp, and population.

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Section 1

Sub-question: Are current solar and wind power plants in the country being predominantly built in areas of high solar and wind power potential?

Powerplants superimposed on heatmap of Philippine regions according to Solar Potential per administrative boundary up to Provincial Level

In [1]:
```
import pandas as pd
import matplotlib.pyplot as plt
import geopandas as gpd
import xlsxwriter
from shapely.geometry import Point, Polygon
import seaborn as sns
from mpl_toolkits.mplot3d import Axes3D
import numpy as np
from sklearn.neighbors import KNeighborsRegressor
from sklearn.metrics import mean_squared_error
from sklearn.model_selection import GridSearchCV
from math import sqrt
```

In [2]:
```
# taken from https://data.humdata.org/dataset/cod-ab-phl
fp = ".\Data\Shapefiles\Philippines\phl_admbnda_adm2_psa_namria_20200529.shp"
map_df = gpd.read_file(fp)
map_df.columns
map_df = map_df[['ADM2_EN', 'geometry']]
```

In [3]:
```
# PowerPlants
powerplantsfp = '.\Data\PowerPlants\global_power_plant_database.csv'
powerplants = pd.read_csv(powerplantsfp)
powerplants = powerplants[powerplants.country_long == 'Philippines']
powerplants.capacity_mw = pd.to_numeric(powerplants.capacity_mw, errors='coerce')
```

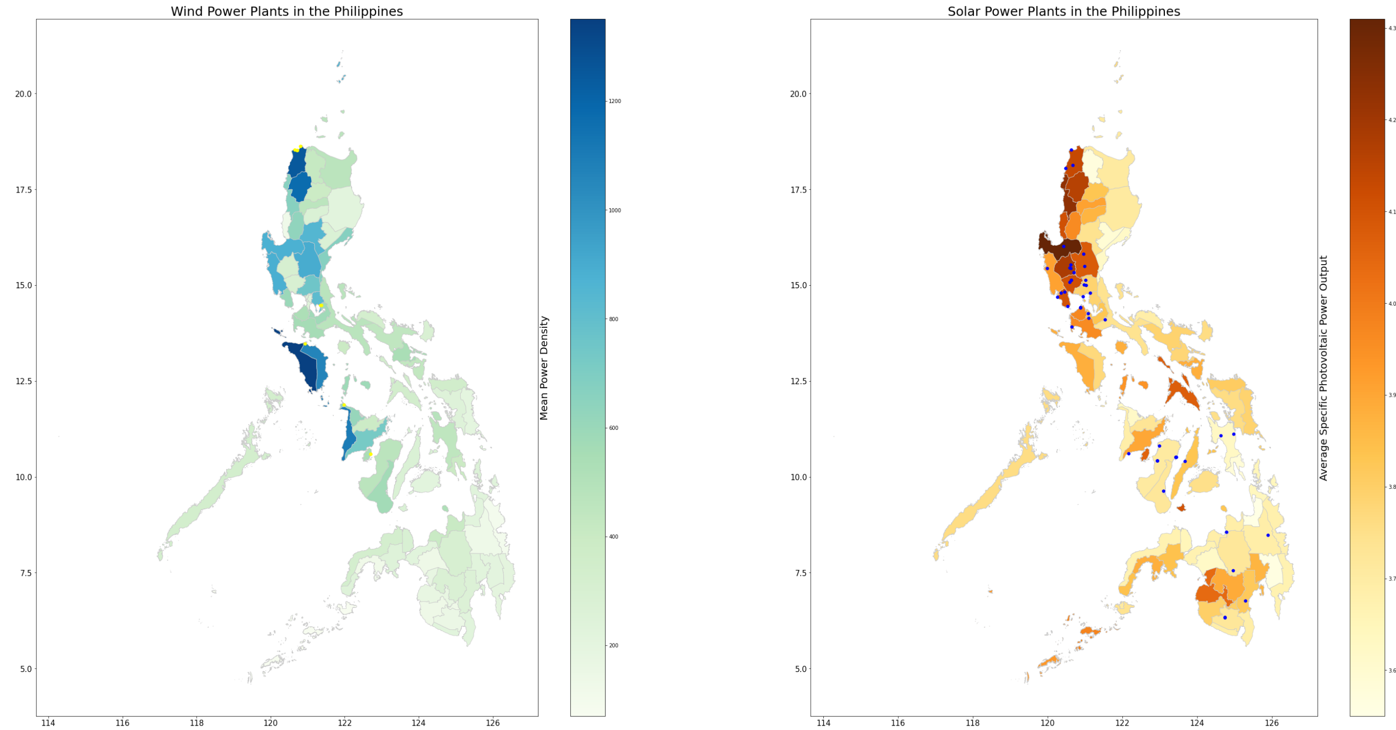
```
crs = {'init':'epsg:4326'}

solar_powerplants = powerplants[powerplants.primary_fuel == 'Solar']
solargeometry=[Point(xy) for xy in zip(solar_powerplants["longitude"], solar_powerplants
geodata_solar=gpd.GeoDataFrame(solar_powerplants,crs=crs, geometry=solargeometry)

wind_powerplants = powerplants[powerplants.primary_fuel == 'Wind']
windgeometry=[Point(xy) for xy in zip(wind_powerplants["longitude"], wind_powerplants["l
geodata_wind=gpd.GeoDataFrame(wind_powerplants,crs=crs, geometry=windgeometry)

# create figure and axes for Matplotlib
fig, (ax1,ax2) = plt.subplots(1,2, figsize=(50, 25))

# Data for Wind Potential Heatmap
datafp = '.\Data\WindPotential\Philippine_regions_windpotential.csv'
wind_potential_data = gpd.read_file(datafp)
wind_potential_data = wind_potential_data[["ADM2_EN", "mean_power_density"]]
wind_potential_data.mean_power_density = pd.to_numeric(wind_potential_data.mean_power_de

merged_wind = map_df.set_index("ADM2_EN").join(wind_potential_data.set_index("ADM2_EN"))
variable_wind = "mean_power_density"

# Data for Solar Potential Heatmap
datafp = '.\Data\SolarPotential\Philippine_regions_pvpotential.csv'
solar_potential_data = gpd.read_file(datafp)
solar_potential_data = solar_potential_data[["ADM2_EN", "avg_specific_pv_output"]]
solar_potential_data.avg_specific_pv_output = pd.to_numeric(solar_potential_data.avg_spe

merged_solar = map_df.set_index("ADM2_EN").join(solar_potential_data.set_index("ADM2_EN"
variable_solar = "avg_specific_pv_output"

# Modifying Axes
#ax1.axis("off")
ax1.set_title("Wind Power Plants in the Philippines", fontdict = {"fontsize": "25", "fon
ax1.tick_params(labelsize=15)
ax1.yaxis.set_label_position('right')
ax1.set_ylabel("Mean Power Density", fontsize = 20)
#ax1.figure.axes[1].tick_params(labelsize=30)
#ax1.annotate("Source: Global Wind Map, 2022",xy=(0.1, .08), xycoords="figure fraction",

#ax2.axis("off")
ax2.set_title("Solar Power Plants in the Philippines", fontdict = {"fontsize": "25", "fo
ax1.figure.axes[1].tick_params(labelsize=15)
ax2.yaxis.set_label_position('right')
ax2.set_ylabel("Average Specific Photovoltaic Power Output", fontsize = 20)
#ax2.annotate("Source: Global Solar Map, 2022",xy=(0.1, .1), xycoords="figure fraction",


# Plotting
merged_wind.plot(column=variable_wind, cmap="GnBu", linewidth=0.8, ax=ax1, edgecolor="0.
geodata_wind.plot(ax=ax1, color='yellow', markersize=30)
merged_solar.plot(column=variable_solar, cmap="YlOrBr", linewidth=0.8, ax=ax2, edgecolor
geodata_solar.plot(ax=ax2, color='blue', markersize=30)
```

```
C:\Users\rayno\AppData\Local\Temp\ipykernel_10100\1994217374.py:3: DtypeWarning: Columns
(10) have mixed types. Specify dtype option on import or set low_memory=False.
  powerplants = pd.read_csv(powerplantsfp)
C:\Users\rayno\AppData\Local\Temp\ipykernel_10100\1994217374.py:5: SettingWithCopyWarnin
g:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_
guide/indexing.html#returning-a-view-versus-a-copy
  powerplants.capacity_mw = pd.to_numeric(powerplants.capacity_mw, errors='coerce')
```

```
c:\Program Files\Python310\lib\site-packages\pyproj\crs\crs.py:130: FutureWarning: '+init=<authority>:<code>' syntax is deprecated. '<authority>:<code>' is the preferred initialization method. When making the change, be mindful of axis order changes: https://pyproj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6
  in_crs_string = _prepare_from_proj_string(in_crs_string)
c:\Program Files\Python310\lib\site-packages\pyproj\crs\crs.py:130: FutureWarning: '+init=<authority>:<code>' syntax is deprecated. '<authority>:<code>' is the preferred initialization method. When making the change, be mindful of axis order changes: https://pyproj4.github.io/pyproj/stable/gotchas.html#axis-order-changes-in-proj-6
  in_crs_string = _prepare_from_proj_string(in_crs_string)
```

Out[3]:

```
<AxesSubplot:title={'center':'Solar Power Plants in the Philippines'}, ylabel='Average Specific Photovoltaic Power Output'>
```



The above map shows the locations of solar and wind powerplants respectively, superimposed with a heatmap of the potential solar (average specific photovoltaic output) and wind (mean power density) power generation with a provincial resolution. Average Specific Photovoltaic Power output represents the amount of power generated per unit of the installed PV capacity over the long-term, and it is measured in kilowatthours per installed kilowatt-peak of the system capacity (kWh/kWp). Mean Power Density is the mean annual power available per square meter of swept area of a turbine, and is calculated for different heights above ground. Calculation of wind power density includes the effect of wind velocity and air density.

In [4]:

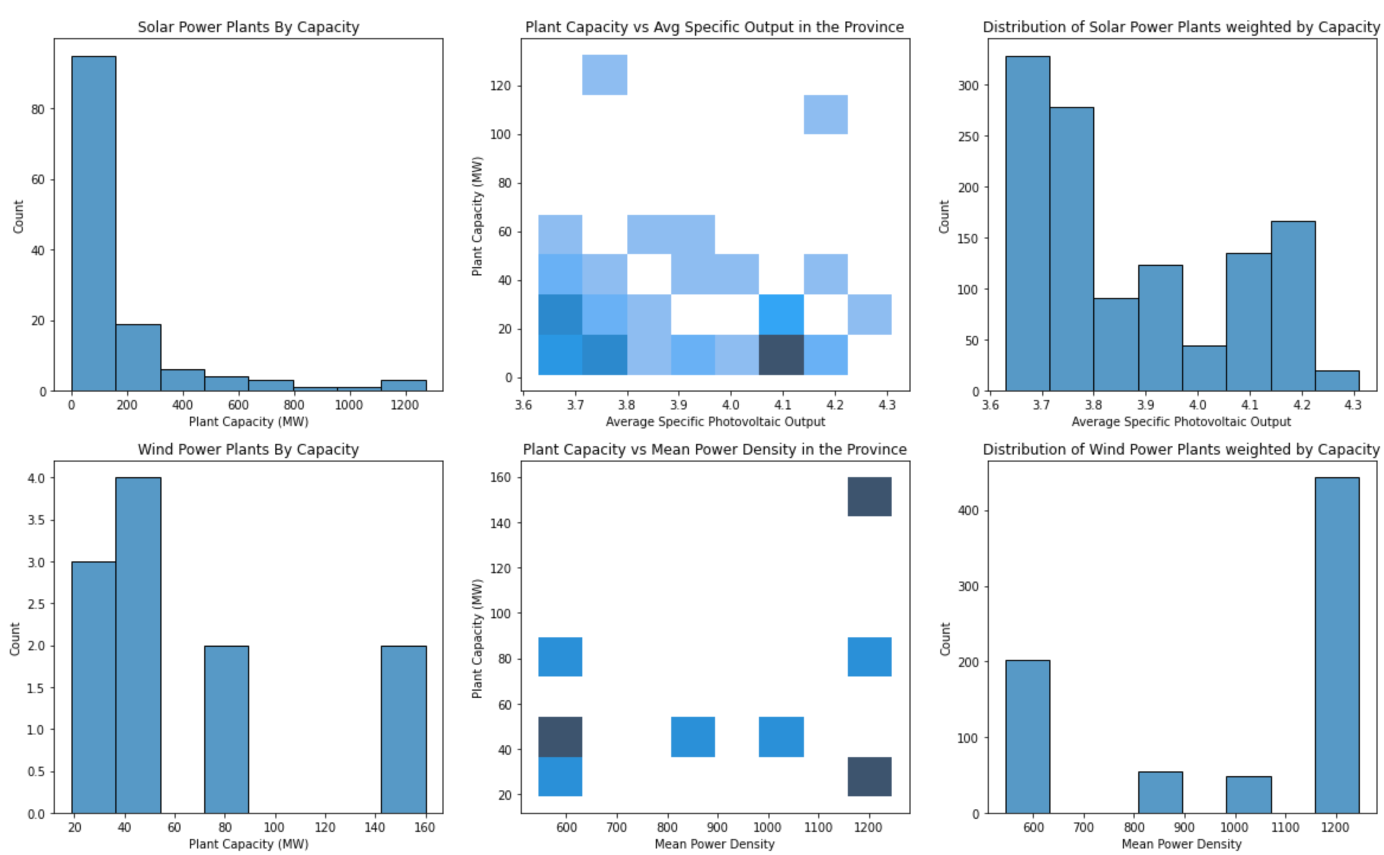
```python
#Solar Powerplants analyses
geodata_solar[variable_solar] = None
for index, entry in geodata_solar.iterrows():
    a = merged_solar.geometry.contains(entry['geometry'])
    a = a[a == True]
    geodata_solar[variable_solar][index] = merged_solar.loc[a.index.array[0]][variable_s

fig, ((h1,h2,h3), (h4,h5,h6)) = plt.subplots(2,3, figsize=(20, 12))
sns.histplot(x='capacity_mw', data=powerplants, ax=h1,bins=8)
h1.set_title("Solar Power Plants By Capacity")
h1.set_xlabel("Plant Capacity (MW)")
sns.histplot(x=variable_solar, data=geodata_solar,y="capacity_mw",  bins=8, ax=h2)
h2.set_title("Plant Capacity vs Avg Specific Output in the Province")
h2.set_xlabel("Average Specific Photovoltaic Output")
h2.set_ylabel("Plant Capacity (MW)")
sns.histplot(x=variable_solar, data=geodata_solar, weights='capacity_mw', bins=8, ax=h3)
h3.set_title("Distribution of Solar Power Plants weighted by Capacity")
h3.set_xlabel("Average Specific Photovoltaic Output")
```

```
#Wind Powerplants analyses
geodata_wind[variable_wind] = None
for index, entry in geodata_wind.iterrows():
    a = merged_wind.geometry.contains(entry['geometry'])
    a = a[a == True]
    geodata_wind[variable_wind][index] = merged_wind.loc[a.index.array[0]][variable_wind

sns.histplot(x='capacity_mw', data=geodata_wind, ax=h4, bins=8)
h4.set_title("Wind Power Plants By Capacity")
h4.set_xlabel("Plant Capacity (MW)")
sns.histplot(x=variable_wind, data=geodata_wind, y="capacity_mw",  bins=8, ax=h5)
h5.set_title("Plant Capacity vs Mean Power Density in the Province")
h5.set_xlabel("Mean Power Density")
h5.set_ylabel("Plant Capacity (MW)")
sns.histplot(x=variable_wind,data=geodata_wind, weights='capacity_mw', bins=8, ax=h6)
h6.set_title("Distribution of Wind Power Plants weighted by Capacity")
h6.set_xlabel("Mean Power Density")
```

```
C:\Users\rayno\AppData\Local\Temp\ipykernel_10100\2665484102.py:6: SettingWithCopyWarnin
g:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_
guide/indexing.html#returning-a-view-versus-a-copy
  geodata_solar[variable_solar][index] = merged_solar.loc[a.index.array[0]][variable_sol
ar]
C:\Users\rayno\AppData\Local\Temp\ipykernel_10100\2665484102.py:25: SettingWithCopyWarni
ng:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_
guide/indexing.html#returning-a-view-versus-a-copy
  geodata_wind[variable_wind][index] = merged_wind.loc[a.index.array[0]][variable_wind]
```

Out[4]:

```
Text(0.5, 0, 'Mean Power Density')
```



The graphs "Solar Power Plants By Capacity" and "Wind Power Plans By Capacity" shows us a histogram of the currently operating wind and solar powerplants in the country. The distribution of "Solar Power Plants By

Capacity" is heavily right-skewed, indicating that a majority of the solar powerplants in the country produce less than 200 MW per plant. This presents a missing gap in the solar power plant development in the country in that it might be beneficial to build larger-scale powerplants to take advantage of reduced prices stemming from mass procurement and production.

The "Wind Power Plans By Capacity" graph also indicates a right-skewed distribution, leaning towards lower MW generation capacity per plant, with none generating more than 160 MW. This shows an opportunity that we could be building more wind powerplants with higher generation capacities to take advantage of the cost-reductions brought about by mass procurement and production.

The graphs in the center column of the above results are 2d histograms indicating the relationship between plant capacity and the solar or wind capacity of each region. The intersection of both signifies whether the wind/solar capacity of the province the plant is generated in and the MW capacity of the plant. As we can see on the graph for Solar Power Plants in the country, There is heavy investment in provinces with a solar potential of 4.1, with it being deeply highlighted, however a majority of these plants are low capacity (<20 MW). This indicates underinvestment in provinces with particularly high solar generation potential, and we must build more high capacity power plants in areas with more solat potential. Furthermore, there is also a concentration of investment in low-solar potential province with low-capacity power plants. This is perhaps a solution to intermittent electricity access in more remote areas of the country, although this indicates the need for a more robust and reliable power transmission network in the country

The graph "Plant Capacity vs Mean Power Density in the Province" indicates string investment in high-potential areas in both high and low-capacity powerplants, as indicated by two dark squares in the 1200 mean power density (MPW) column. Althugh, we also see heavy investment in the low wind potential locations with low plant capacities. This once again may be due the attempt in stabilizing local power supply and indicates the need for a more robust and reliable country-wide power transmission network so that plants investment can be concentrated into areas with more potential for both wind and solar, and the excess electricity can be easily transmitted to other parts of the country.

The final column of graphs "Distribution of Solar/Wind Power Plants weighted by Capacity" is another expression of the center column of graphs, where we weight the histogram by the MW of each power plant. As we can see, the distribution of solar powerplants, is bimodal and right-skewed, while the distribution of wind power plants is bimodal, and left-skewed.

Section 2

Sub-question: How much wind and solar energy is the Philippines projected to generate in the future? Can countries around the world be clustered based on solar and wind capacity, population, and GDP?

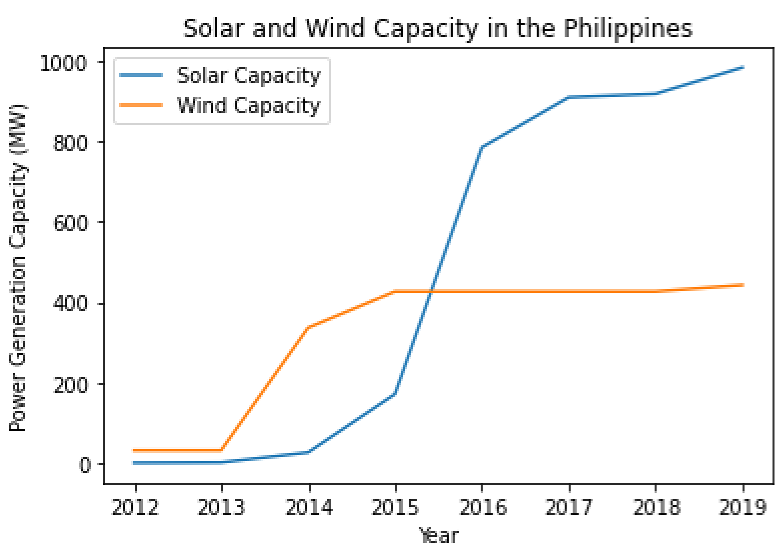
History of Wind and Solar Capacity in the Philippines

In [5]:
```
years = ["2012","2013","2014","2015","2016","2017","2018","2019"]
years_num = [2012,2013,2014,2015,2016,2017,2018,2019]

Installedfp = '.\Data\InstalledCapacity\RECAP_20220519-053554.csv'
Installed = pd.read_csv(Installedfp, encoding = "ISO-8859-1")

Installed[years] = Installed[years].apply(pd.to_numeric, errors='coerce')
#Installed = Installed[Installed.Technology == "Solar"]

Popfp = '.\Data\PopAndGDP\Population.csv'
Pop = pd.read_csv(Popfp, encoding = "utf-8")
```

```
Pop[years] = Pop[years].apply(pd.to_numeric, errors='coerce')

GDPfp = '.\Data\PopAndGDP\GDPPerCapita.csv'
GDP = pd.read_csv(GDPfp, encoding = "utf-8")
GDP[years] = GDP[years].apply(pd.to_numeric, errors='coerce')

dfs = []
for year in years:
    df = pd.merge(Installed[["Country",year]], GDP[["Country",year]], on=["Country"], ho
    df = pd.merge(df, Pop[["Country",year]], on=["Country"], how='inner')
    df = df.drop_duplicates()
    df.rename(columns={year+'_x':"Installed", year+'_y':"GDP", year:"Pop"}, inplace=True
    df[["Installed", "GDP", "Pop"]] = df[["Installed", "GDP", "Pop"]].apply(pd.to_numeri
    df = df.dropna(axis=0)
    df.Installed = df.Installed/df.Pop
    dfs.append(df)
    #print(year, df.shape)

Installed_solar = Installed[Installed.Technology == "Solar"]
Installed_wind = Installed[Installed.Technology == "Wind"]


plt.plot(years,np.array(Installed_solar[Installed_solar["Country"] == "Philippines"][yea
plt.plot(years,np.array(Installed_wind[Installed_wind["Country"] == "Philippines"][years
plt.title("Solar and Wind Capacity in the Philippines")
plt.xlabel("Year")
plt.ylabel("Power Generation Capacity (MW)")
plt.legend(loc='best')
```

Out[5]:

```
<matplotlib.legend.Legend at 0x1e27aa29150>
```



The above graph displyes the development of Philippine solar and wind capacity per year. Wind capacity experience heavy buildup between 2014 and 2016, and has since had slower, albeit powitive growth. In contrast, wind power generation has stalled out as around 400 MW since the year 2015. This elucidates that there is a lot more work that can be done in accelerating the growth of solar generation assets and the untapped potential for wind generation in the country.

Solar and Wind Generation and Consumption Projections

In [6]:

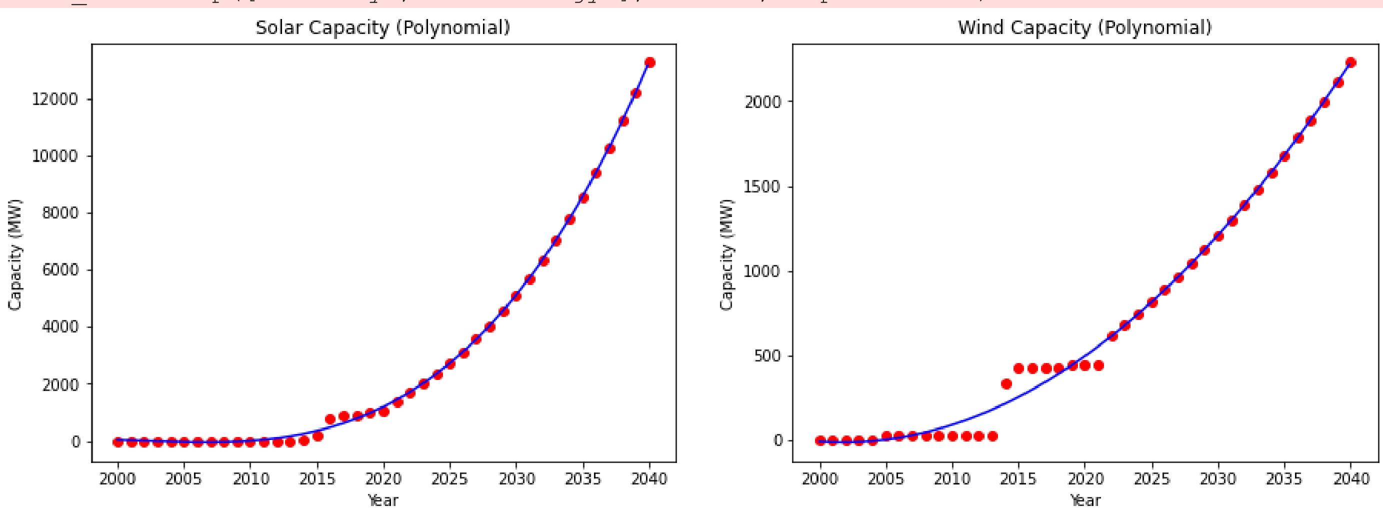
```
#import the libraries
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt

# Read the data into the dataframe for Capacity
```

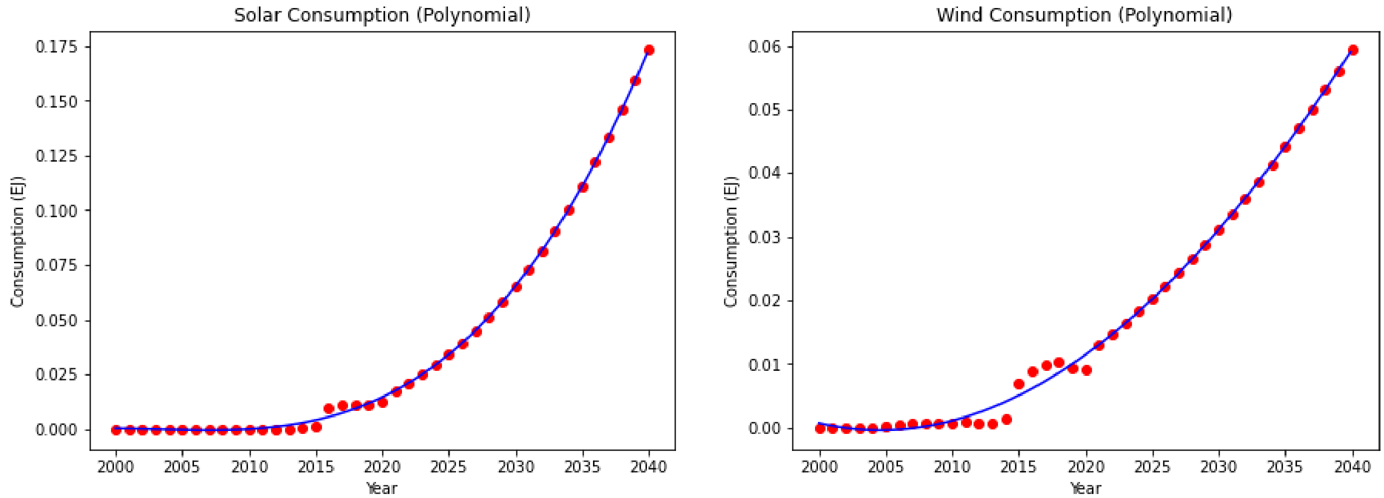
```
df_capacity =  pd.read_csv('Data\InstalledCapacity\RECAP_20220519-053554.csv')
df_capacity = df_capacity.loc[df_capacity['Country'] == 'Philippines']
df_solar = df_capacity.loc[df_capacity['Technology'] == 'Solar']
df_wind = df_capacity.loc[df_capacity['Technology'] == 'Wind']

# Remove Country and Technology columns in place
df_solar.drop(['Country', 'Technology'], axis=1, inplace=True)
df_wind.drop(['Country', 'Technology'], axis=1, inplace=True)


# Take the capacity values
y_solar = df_solar.iloc[0].values
y_solar = y_solar.astype(float)
y_wind = df_wind.iloc[0].values
y_wind = y_wind.astype(float)

# Take the years
X_sw = df_solar.columns.values
X_sw = X_sw.astype(int)
X_sw = X_sw.reshape(-1, 1)

from sklearn.linear_model import LinearRegression
from sklearn.preprocessing import PolynomialFeatures

poly_reg_solar = PolynomialFeatures(degree=4)
poly_reg_wind = PolynomialFeatures(degree=2)
X_poly_solar = poly_reg_solar.fit_transform(X_sw)
X_poly_wind = poly_reg_wind.fit_transform(X_sw)

lin_reg = LinearRegression()
lin_reg.fit(X_poly_solar,y_solar)

lin_reg2 = LinearRegression()
lin_reg2.fit(X_poly_wind,y_wind)

# Making predictions for years 2022 till 2040
years = np.array([[i] for i in range(2022, 2041, 1)])
X_poly_solar = np.concatenate((X_sw,years))
X_poly_wind = np.concatenate((X_sw,years))

y_poly_solar = np.copy(y_solar)
y_poly_wind = np.copy(y_wind)
for i in range(2022, 2041, 1):
   y_poly_solar = np.concatenate((y_poly_solar,lin_reg.predict(poly_reg_solar.fit_transf
   y_poly_wind = np.concatenate((y_poly_wind,lin_reg2.predict(poly_reg_wind.fit_transfor


X_grid_solar = np.arange(min(X_poly_solar),max(X_poly_solar),0.1)
X_grid_solar = X_grid_solar.reshape(len(X_grid_solar),1)
X_grid_wind = np.arange(min(X_poly_wind),max(X_poly_wind),0.1)
X_grid_wind = X_grid_wind.reshape(len(X_grid_wind),1)

plt.subplots(figsize=(15, 5))

plt.subplot(1, 2, 1)
plt.scatter(X_poly_solar,y_poly_solar, color='red')
plt.plot(X_grid_solar, lin_reg.predict(poly_reg_solar.fit_transform(X_grid_solar)),color
plt.title("Solar Capacity (Polynomial)")
plt.xlabel('Year')
plt.ylabel('Capacity (MW)')


plt.subplot(1, 2, 2)
plt.scatter(X_poly_wind,y_poly_wind, color='red')
plt.plot(X_grid_wind, lin_reg2.predict(poly_reg_wind.fit_transform(X_grid_wind)),color='
plt.title("Wind Capacity (Polynomial)")
```

```
plt.xlabel('Year')
plt.ylabel('Capacity (MW)')

plt.show()

# Read the data into the dataframe for Consumption
df_consump_solar = pd.read_excel (r'Data\ConsumptionPercentage\bp-stats-review-2021-all-
df_consump_wind = pd.read_excel (r'Data\ConsumptionPercentage\bp-stats-review-2021-all-d

df1_solar = df_consump_solar.iloc[99]
df1_wind = df_consump_wind.iloc[99]

# Check the consumption values for country Philippines
df1_solar = df_consump_solar.iloc[99,0:57]
df1_wind = df_consump_wind.iloc[99,0:57]

# Take the consumption values from excel sheet into string list
df1_solar_row = df_consump_solar.iloc[99,36:57].to_string(header=False, index=False)
df1_solar_row = df1_solar_row.split('\n')
df1_wind_row = df_consump_wind.iloc[99,36:57].to_string(header=False, index=False)
df1_wind_row = df1_wind_row.split('\n')


# Convert the list into dataframe
df1_solar_row = [float(_.strip()) for _ in df1_solar_row]
y1_solar = pd.DataFrame(df1_solar_row, columns=['Consumption'])
y1_solar = y1_solar.values

df1_wind_row = [float(_.strip()) for _ in df1_wind_row]
y1_wind = pd.DataFrame(df1_wind_row, columns=['Consumption'])
y1_wind = y1_wind.values

# Take the year values from excel sheet into string list
df1_solar_columns = df_consump_solar.iloc[1,36:58].to_string(header=False, index=False)
df1_solar_columns = df1_solar_columns.split('.0\n')
df1_wind_columns = df_consump_wind.iloc[1,36:58].to_string(header=False, index=False)
df1_wind_columns = df1_wind_columns.split('.0\n')

# Convert the list into dataframe
df1_solar_columns = [int(_.strip()) for _ in df1_solar_columns]
X1_solar = pd.DataFrame(df1_solar_columns, columns=['Years'])
X1_solar = X1_solar['Years'].unique()
X1_solar = X1_solar.reshape(-1,1)
df1_wind_columns = [int(_.strip()) for _ in df1_wind_columns]
X1_wind = pd.DataFrame(df1_wind_columns, columns=['Years'])
X1_wind = X1_wind['Years'].unique()
X1_wind = X1_wind.reshape(-1,1)

poly1_reg_solar = PolynomialFeatures(degree=3)
X1_poly_solar = poly1_reg_solar.fit_transform(X1_solar)
lin_reg3 = LinearRegression()
lin_reg3.fit(X1_poly_solar,y1_solar)
poly1_reg_wind = PolynomialFeatures(degree=4)
X1_poly_wind = poly1_reg_wind.fit_transform(X1_wind)
lin_reg4 = LinearRegression()
lin_reg4.fit(X1_poly_wind,y1_wind)

# Making predictions for years 2021 till 2040
years = np.array([[i] for i in range(2021, 2041, 1)])
X1_poly_solar = np.concatenate((X1_solar,years))
y1_poly_solar = np.copy(y1_solar)
X1_poly_wind = np.concatenate((X1_wind,years))
y1_poly_wind = np.copy(y1_wind)

for i in range(2021, 2041, 1):
   y1_poly_solar = np.concatenate((y1_poly_solar,lin_reg3.predict(poly1_reg_solar.fit_tr
```

```
    y1_poly_wind =  np.concatenate((y1_poly_wind,lin_reg4.predict(poly1_reg_wind.fit_tran

X1_grid_solar = np.arange(min(X1_poly_solar),max(X1_poly_solar),0.1)
X1_grid_solar = X1_grid_solar.reshape(len(X1_grid_solar),1)
X1_grid_wind = np.arange(min(X1_poly_wind),max(X1_poly_wind),0.1)
X1_grid_wind = X1_grid_wind.reshape(len(X1_grid_wind),1)

plt.subplots(figsize=(15, 5))

plt.subplot(1, 2, 1)
plt.scatter(X1_poly_solar,y1_poly_solar, color='red')
plt.plot(X1_grid_solar, lin_reg3.predict(poly1_reg_solar.fit_transform(X1_grid_solar)),c
plt.title("Solar Consumption (Polynomial)")
plt.xlabel('Year')
plt.ylabel('Consumption (EJ)')

plt.subplot(1, 2, 2)
plt.scatter(X1_poly_wind,y1_poly_wind, color='red')
plt.plot(X1_grid_wind, lin_reg4.predict(poly1_reg_wind.fit_transform(X1_grid_wind)),colo
plt.title("Wind Consumption (Polynomial)")
plt.xlabel('Year')
plt.ylabel('Consumption (EJ)')

plt.show()
```

```
C:\Users\rayno\AppData\Local\Temp\ipykernel_10100\2810083602.py:13: SettingWithCopyWarni
ng:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_
guide/indexing.html#returning-a-view-versus-a-copy
  df_solar.drop(['Country', 'Technology'], axis=1, inplace=True)
C:\Users\rayno\AppData\Local\Temp\ipykernel_10100\2810083602.py:14: SettingWithCopyWarni
ng:
A value is trying to be set on a copy of a slice from a DataFrame

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_
guide/indexing.html#returning-a-view-versus-a-copy
  df_wind.drop(['Country', 'Technology'], axis=1, inplace=True)
```





In the above graphs, we attempt polynomial regression on solar and wind power generation and extend the model to predict future generation potential. We also project the solar and wind power consumption into the future.

The solar capacity of the Philippines has an upward trend projection similar to its corresponding consumption in the future if the Philippines could increase and maximize the potential of its solar power plants. The wind capacity of the Philippines has abrupt steady changes recorded in the past years similar to its corresponding consumption. If the Philippines manages to increase and maximize the potential of its wind power plants then the upward trend projection in capacity and consumption could be made possible.

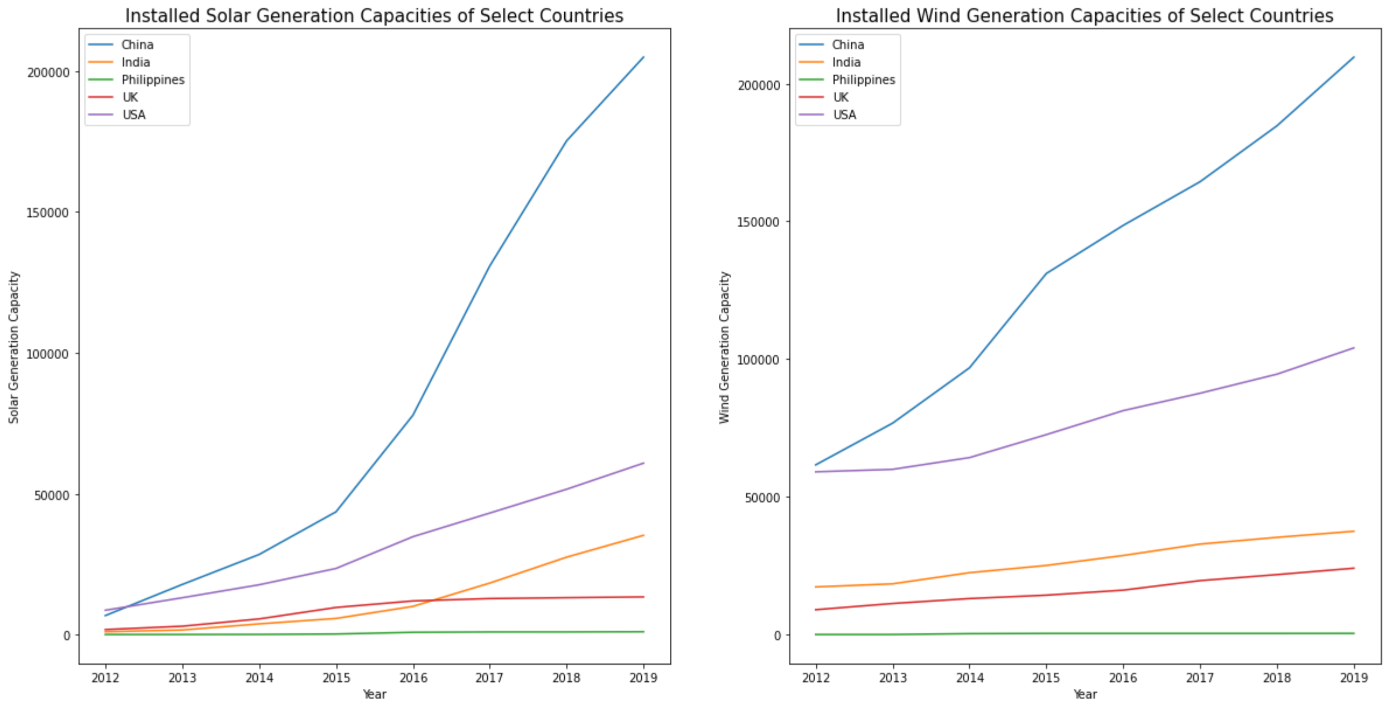
World Solar Power Capacity MW Installed per year

In [7]:

```
years = ["2012","2013","2014","2015","2016","2017","2018","2019"]
years_num = [2012,2013,2014,2015,2016,2017,2018,2019]

fig, (ax1,ax2) = plt.subplots(1,2, figsize=(20,10))

Installed[years] = Installed[years].apply(pd.to_numeric, errors='coerce')
for index,row in Installed.iterrows():
    if row["Country"] in ["Philippines", "China", "USA", "UK", "India"] and row["Technol
        ax1.plot(years, list(row[years]), label = row["Country"])
    elif row["Country"] in ["Philippines", "China", "USA", "UK", "India"] and row["Techn
        ax2.plot(years, list(row[years]), label = row["Country"])

ax1.legend(loc='best')
ax1.set_xlabel("Year")
ax1.set_ylabel("Solar Generation Capacity")
ax2.legend(loc='best')
ax2.set_xlabel("Year")
ax2.set_ylabel("Wind Generation Capacity")

ax1.set_title("Installed Solar Generation Capacities of Select Countries", fontsize=15)
ax2.set_title("Installed Wind Generation Capacities of Select Countries", fontsize=15)
```

Out[7]:

```
Text(0.5, 1.0, 'Installed Wind Generation Capacities of Select Countries')
```



The above graphs show the solar and wind generation potential of the Philippines as opposed to other countries in the world. As we can see, China, India, and the USA greatly increased their solar capacities since between 2012 and 2019. These same countries, including the UK also greatly increased their Wind Generation Capacities during the same time period. The Philippines, in comparison, only increased solar and wind marginally and has had extremely low growth rates in both areas.

KNN

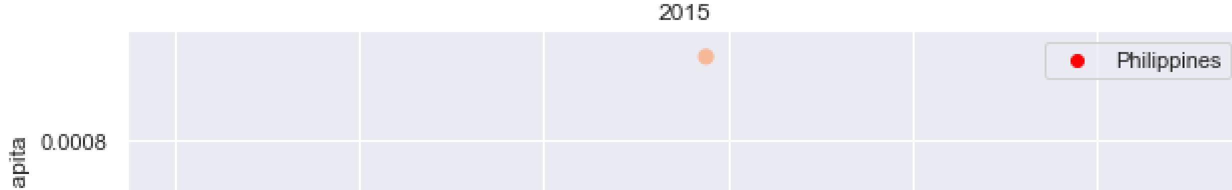
In [8]:

```
# 2D Plots with KNN
sns.set(style = "darkgrid")
fig, ax = plt.subplots(8,1,figsize=(10,50))
for i in range(len(years)):
    X = dfs[5][['GDP']]
    Y = dfs[5][['Installed']]

    parameters = {"n_neighbors": range(1,50)}
    gridsearch = GridSearchCV(KNeighborsRegressor(), parameters)
    gridsearch.fit(X, Y)

    train_preds_grid = gridsearch.predict(X)
    train_mse = mean_squared_error(Y, train_preds_grid)
    train_rmse = sqrt(train_mse)

    #cmap = sns.cubehelix_palette(as_cmap=True)
    points = ax[i].scatter(X, Y, c=train_preds_grid, s=50)#, cmap=cmap)

    #ax[i].scatter(dfs[i].GDP, dfs[i].Installed)
    ax[i].scatter(dfs[i][dfs[i]["Country"] == "Philippines"].GDP, dfs[i][dfs[i]["Country
    ax[i].set_title(years[i])
    ax[i].set_xlabel("GDP Per Capita")
    ax[i].set_ylabel("Installed Solar Capacity Per Capita")
    ax[i].legend()

#fig.suptitle("World: GDP Per Capita vs Installed Solar Capacity Per Capita over the yea
```

2013

2014

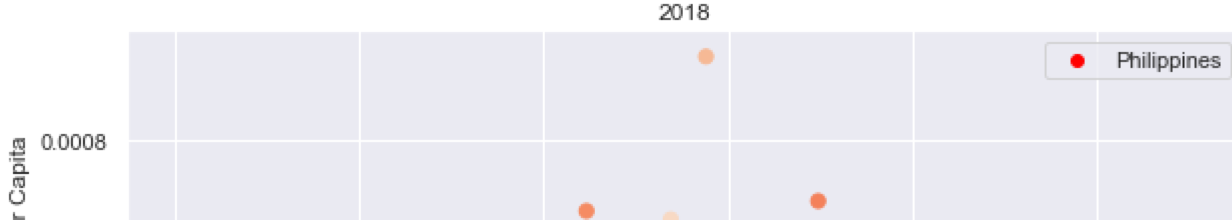
2015

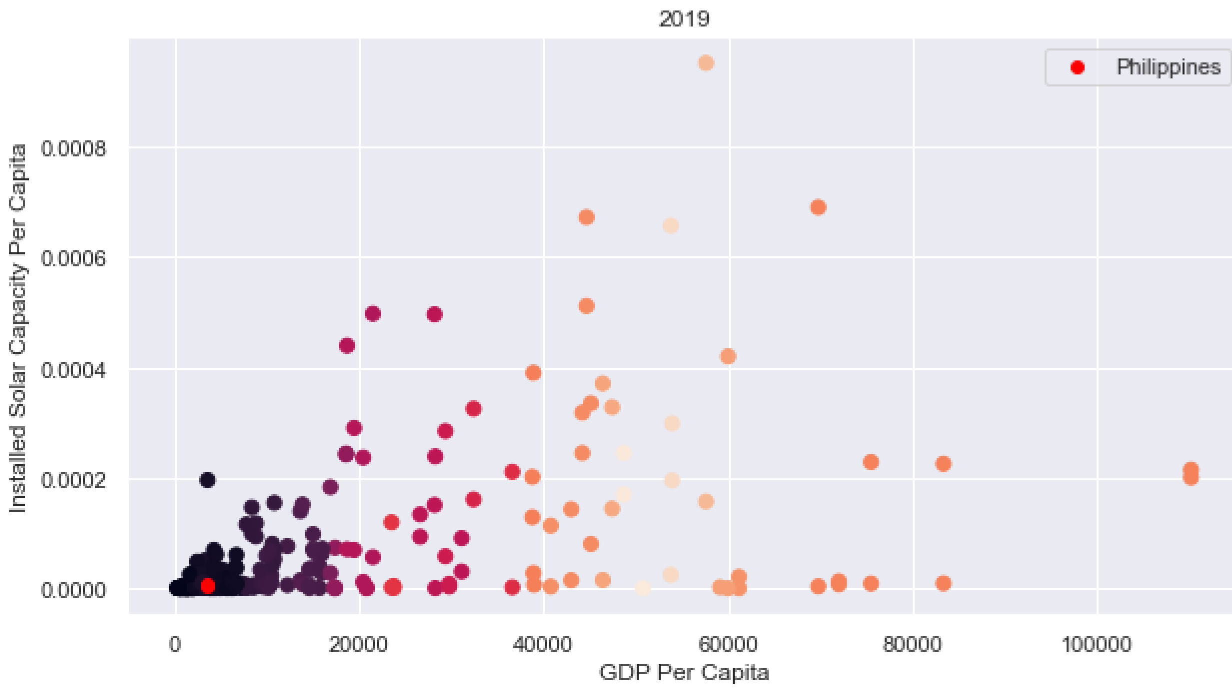


2016

2017

2018





As we can see from the set of graphs above, the Philippines has not moved in Solar Capacity generated per capita (that is, solar generation divided by population). This indicates that a lot more can be done in increasing the velocity in which we construct new solar power plants in the future. We can also see a positive relationship between GDP per capita and solar generation per capita. Virtually no poor country (GDP Per Capita <20000) in fact have a solar generation capacity per capita exceeding o.00004 for all the years represented. It is reasonable to say that if we want to be decrease our reliance on fossil fuels, we must do this in conjunction with the high economic growth needed for the high investment costs of new solar and wind power plants