1. Abruf von Winddaten

1.0 Python Package importieren

In [8]:

```
import atlite
import geopandas as gpd
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
import cartopy.crs as ccrs
from shapely.geometry import Polygon, LineString, Point
from scipy.stats import weibull_min, rayleigh
```

1.1 Beschreibung der spezifischen Daten

In [9]:

```
island = {"Batanes","Bohol","Catanduanes","Marinduque","Tawi-Tawi"} # Insel von der Philipine
years = {"1980","1990","2000","2010","2020"} # Jahre der Winddaten
hub_height = {12,24,28.5,29,30} # Nabenhöhe
```

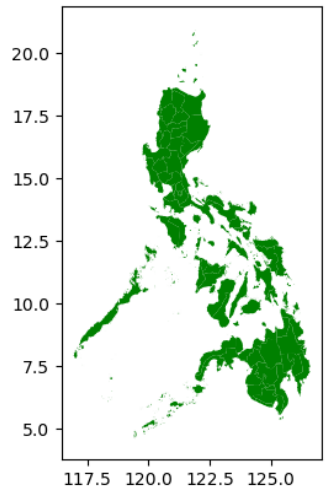
1.2 Cutout von Philipine offen

In [13]:

```
regions = gpd.read_file("gadm_410-levels-ADM_1-PHL.gpkg")
fig, ax = plt.subplots()
regions.plot(ax=ax,color='green')
```

Out[13]:

```
<AxesSubplot: >
```



1.3 Atlite aus verschiedenen Jahren herunterladen

- **CDS API Schlüssel erforderlich** https://cds.climate.copernicus.eu/api-how-to

In [ ]:

```
def download_wind_data(years):
    for year in years:
        minx, miny, maxx, maxy = regions.total_bounds
        buffer = 0.25

        cutout = atlite.Cutout(
           path=f"PHL_atlite_{year}.nc",
           module="era5",
           x=slice(minx-buffer, maxx+buffer),
           y=slice(miny-buffer, maxy+buffer),
           time=year,
        )
        print(f"Preparing Philipine Atlite for the year {year}")
        cutout.prepare()
```

In [ ]:

```
download_wind_data(years)
```

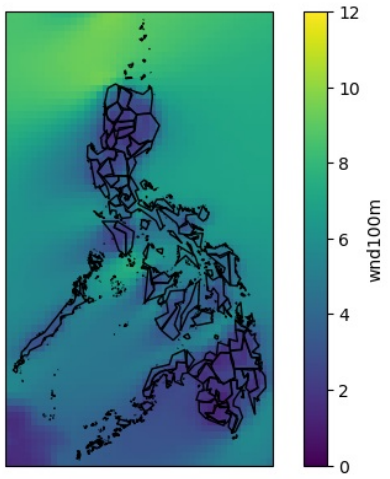
- **das Atlite Ergebnis überprüfen**

In [5]:

```
cutout = atlite.Cutout("PHL_atlite_2020.nc")

ax = plt.axes(projection=ccrs.PlateCarree())

cutout.data.wnd100m.mean(dim='time').plot(ax=ax, vmin=0, vmax=12) # Windgeschwindigkeit in 100 m
regions.simplify(0.1).to_crs(4236).plot(ax=ax, edgecolor='k', color='none')
```

Out[5]:

<GeoAxesSubplot: xlabel='x', ylabel='y'>

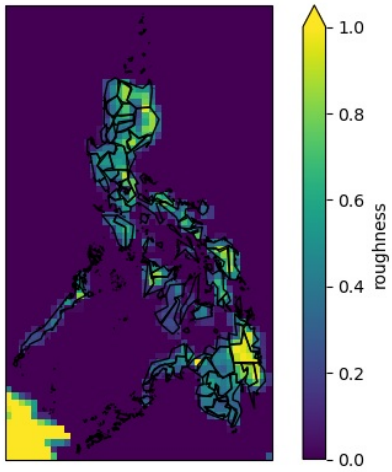


In [6]:

```
cutout = atlite.Cutout("PHL_atlite_2020.nc")

ax = plt.axes(projection=ccrs.PlateCarree())

cutout.data.roughness.mean(dim='time').plot(ax=ax, vmin=0, vmax=1) # Rauhigkeit der Oberfläche
regions.simplify(0.1).to_crs(4236).plot(ax=ax, edgecolor='k', color='none')
```

Out[6]:

<GeoAxesSubplot: xlabel='x', ylabel='y'>



1.4 Zusammenstellung der Windhistogrammen für jede Insel, jedes Jahr und jede Nabenhöhe.

In [10]:

```
def extrapolate_wind_speed(hub_height,year):

    # Gleichung: v = v_ref ln(z/z_0 )/ln(z_ref /z_0 )
    cutout = atlite.Cutout(f"PHL_atlite_{year}.nc")
    wind_100 = cutout.data.wnd100m
    roughness = cutout.data.roughness
    wind_array = wind_100 * np.log(hub_height/roughness)/np.log(100/roughness)

    return wind_array

def region_wind(wind_array,region):
    cell_data=[]
    for x in np.arange(116.75,126.57,0.25):
        x = round(x,2)
        for y in np.arange(4.5,21.25,0.25):
            buffer = Point(x, y).buffer(0.25, cap_style = 3)
            if region.simplify(0.1).overlaps(buffer):
                x_cell = int((x - 116.8)*4)
                y_cell = int((y - 4.5)*4)
                cell_data= cell_data + [[y_cell,x_cell]]

    return sum(wind_array[:,y,x].to_pandas() for y,x in cell_data)/len(cell_data)

def compile_hist(island,hub_height,years):
    for height in hub_height:
        df = pd.DataFrame()
        for year in years:
            wind_array = extrapolate_wind_speed(height,year)
            for i in regions.index:
                if regions.NAME_1[i] in island:
                    print('compiling ' + regions.NAME_1[i]  + 'for year ' + year)
                    wind_series = region_wind(wind_array,regions.geometry[i])
                    n, bins = np.histogram(wind_series, bins=np.arange(0,35,1))
                    df_new = pd.DataFrame(n.reshape(-1, len(n)), index = [regions.NAME_1[i]])
```

```
                    df_new["year"] = year
                    cols = df_new.columns.tolist()
                    cols = cols[-1:] + cols[:-1]
                    df_new = df_new[cols]

                    df = pd.concat([df,df_new])

        df.to_csv(f'wind_histogram/wind_hist_{str(height)}_n.csv')
    return df
```

In [ ]:

```
df_hist = compile_hist(island,hub_height,years)
```

1.5 (Opts) Bestimmung der Weibul- und Rayleigh-Verteilung.

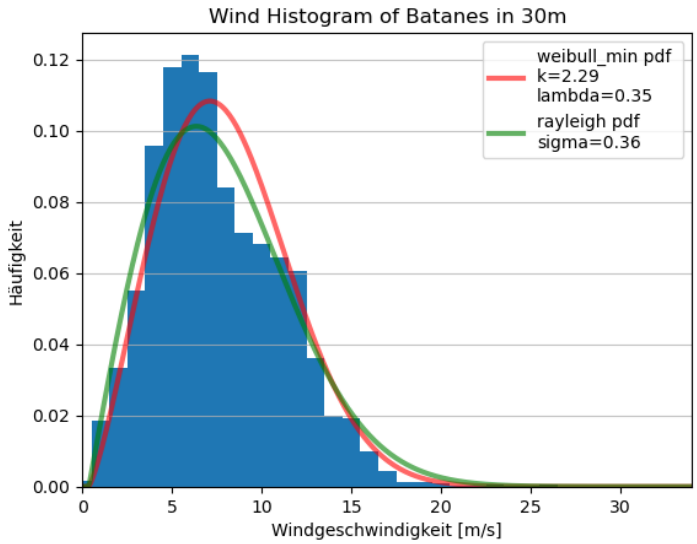
In [11]:

```
def wind_hist(df,name,wind_height):
    n, bins = np.histogram(df, bins=np.arange(0,35,1))
    wind=bins[:-1]#+0.5
    freq=n/8760

    plt.bar(x=wind,height=freq, width=1)
    x = np.arange(0,bins.max()*100.)/10.

    c, loc, scale = weibull_min.fit(df)
    plt.plot(x, weibull_min.pdf(x, c, loc, scale),'r-', lw=3, alpha=0.6,
             label=f'weibull_min pdf \nk={round(c,2)} \nlambda={round(loc,2)}')

    loc, scale = rayleigh.fit(df)
    plt.plot(x, rayleigh.pdf(x, loc, scale),'g-', lw=3, alpha=0.6,
             label=f'rayleigh pdf \nsigma={round(loc,2)}')

    plt.grid(axis='y', alpha=0.75)
    plt.xlabel('Windgeschwindigkeit [m/s]')
    plt.ylabel('Häufigkeit')
    plt.xlim([0,34])
    plt.title(f'Wind Histogram of {name} in {wind_height}m')
    plt.legend()
    #plt.savefig(f'wind_histogram\wind_hist_100_{name}.png')
```

In [14]:

```
year=2000
region=10 # Batanes
wind_height=30 # 30 m

wind_array = extrapolate_wind_speed(wind_height,year)
wind_series = region_wind(wind_array,regions.geometry[region])
wind_hist(wind_series,regions.NAME_1[region],wind_height)
```

```
C:\Users\kunde\anaconda3\envs\esm\lib\site-packages\scipy\stats\_continuous_distns.py:7762: RuntimeWarning: divide by zero encountered in divide
  s3 = (1/xm).sum()
```



2. Abruf von Turbinendaten

2.0 Python Package importieren

In [8]:

```
import pandas as pd
import matplotlib.pyplot as plt

import yaml
from yaml.loader import SafeLoader
from urllib.request import urlretrieve
```

2.1 Beschreibung der spezifischen Turbinendaten

In [9]:

```
turbine_typ = ['WES250','Vestas_V25_200kW','VesV20','En18','JI20kW']
```

```
columns = ['name','manufacturer','HUB_HEIGHT',
           0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,
           20,21,22,23,24,25,26,27,28,29,30,31,32,33,34]
turbine_df = pd.DataFrame(columns=columns,index=turbine_typ)
```

2.2 Zusammenstellung der Turbinendaten

In [10]:

```
for t in turbine_typ:
    with open(f'turbine/{t}.yaml','r') as f:
        data = yaml.load(f, Loader=SafeLoader)
        turbine_df.loc[t,'name']=data['name']
        turbine_df.loc[t,'manufacturer']=data['manufacturer']
        turbine_df.loc[t,'HUB_HEIGHT']=data['HUB_HEIGHT']

        for v in range(len(data['V'])):
            if turbine_df.loc[t,data['V'][v]]<data['POW'][v] or pd.isna(turbine_df.loc[t,data['V'][v]]):
                turbine_df.loc[t,data['V'][v]]=data['POW'][v]

        for v in range(33,-1,-1):
            if pd.isna(turbine_df.loc[t,v]) \
            and pd.isna(turbine_df.loc[t,v+1]) == False:
                turbine_df.loc[t,v]=turbine_df.loc[t,v+1]

turbine_df = turbine_df.fillna(0)
turbine_df.to_csv('turbine.csv')
turbine_df
```

Out[10]:

	name	manufacturer	HUB_HEIGHT	0	1	2	3	4	5	6	...	25	26	27	28	29	30	31	32	33	34
WES250	WES250 250 kW	WES	30.0	0	0	0	0.001	0.0044	0.0149	0.0293	...	0.250	0	0	0	0	0	0	0	0	0
Vestas_V25_200kW	Vestas V25 200 kW	Vestas	29.0	0	0	0	0.000	0.0036	0.0123	0.0244	...	0.200	0	0	0	0	0	0	0	0	0
VesV20	Vestas V20 100 kW	Vestas	24.0	0	0	0	0.000	0.0000	0.0050	0.0130	...	0.105	0	0	0	0	0	0	0	0	0
En18	Enercon E18 80 kW	Enercon	28.5	0	0	0	0.000	0.0037	0.0081	0.0144	...	0.080	0	0	0	0	0	0	0	0	0
JI20kW	Jonica Impianti/ 20 kW	Jonica Impianti	12.0	0	0	0	0.000	0.0000	0.0005	0.0010	...	0.000	0	0	0	0	0	0	0	0	0

5 rows × 38 columns

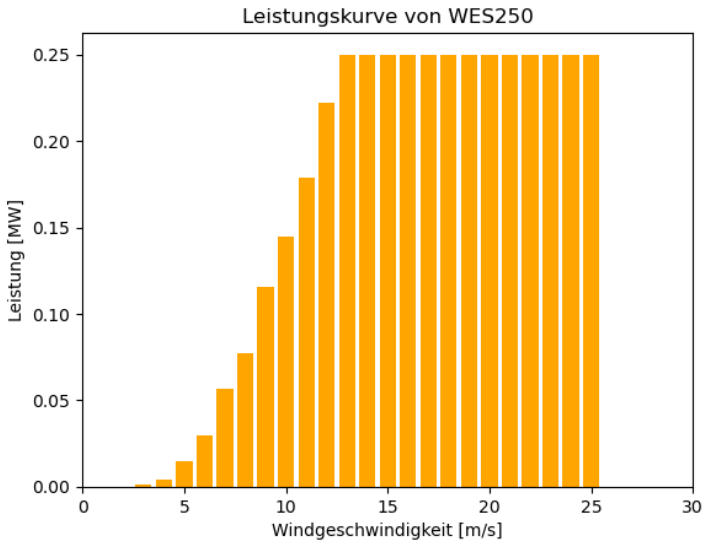
2.3 Leistungkurve erstellen

In [11]:

```
def leistung_hist(index):

    #df_parse = turbine_df.query(f"index == {index}")
    df = pd.DataFrame(columns=['POW'],index=list(range(0,35)))
    for i in range(0,35):
        df.loc[i,'POW']=turbine_df.loc[index,i]

    plt.bar(df.index,df['POW'], color='orange')
    plt.xlabel('Windgeschwindigkeit [m/s]')
    plt.ylabel('Leistung [MW]')
    plt.xlim([0, 30])
    plt.title(f'Leistungskurve von {index}')
    #plt.savefig(f'wind_histogram\leistungskurve_{index}.png')
```

In [12]:

```
leistung_hist('WES250')
```



3. Berechnung des Energieertrags und Flautenanalyse

3.0 Python Package importieren

In [1]:

```
import pandas as pd
import matplotlib.pyplot as plt
```

```
import yaml
from yaml.loader import SafeLoader
from urllib.request import urlretrieve
```

3.1 Beschreibung der Tabellen für Energieerträge und Flautenanalyse

In [2]:

```
turbine_df = pd.read_csv('turbine.csv').rename(columns={'Unnamed: 0':'turbine'}).set_index('turbine')
turbine_typ = ['WES250','Vestas_V25_200kW','VesV20','En18','JI20kW']
island = ["Batanes","Bohol","Catanduanes","Marinduque","Tawi-Tawi"]
years = ["1980","1990","2000","2010","2020"]
```

3.2 Zusammenstellung des Energieertrags

In [3]:

```
power_df = pd.DataFrame(columns=island,index=pd.MultiIndex.from_product([years, turbine_typ]))

for (y,t) in power_df.index:
    turbine = turbine_df.loc[t]
    for r in power_df.columns:
        hub_height = round(float(turbine['HUB_HEIGHT']))
        while True:
            try:
                wind_df = pd.read_csv(f"wind_histogram/wind_hist_{hub_height}_n.csv").rename(columns={'Unnamed: 0':'region'}).set_index(['region'
,'year'])
            except FileNotFoundError:
                hub_height = turbine['HUB_HEIGHT']
                continue
            break
        wind = wind_df.loc[r,int(y)]
        power_df.loc[(y,t),r] = sum(turbine.loc[str(n)]*wind.loc[str(n)] for n in range(len(wind)-1))

power_df.to_csv('results/energieertrag_MWh_a_all_year.csv')
power_df
```

Out[3]:

		Batanes	Bohol	Catanduanes	Marinduque	Tawi-Tawi
1980	**WES250**	747.7724	59.8227	207.1001	108.3761	36.9759
	Vestas_V25_200kW	588.7119	45.8591	161.0502	83.2371	27.5839
	VesV20	304.6	17.811	80.902	39.536	10.214
	En18	281.59341	29.73991	87.68969	49.05332	18.90476
	JI20kW	35.1355	0.76	5.9295	2.2255	0.581
1990	**WES250**	742.5885	73.6565	197.3535	100.3089	54.1442
	Vestas_V25_200kW	585.0483	56.7446	152.8766	77.2994	40.8358
	VesV20	303.62	22.04	75.203	35.074	16.196
	En18	277.53715	36.05762	83.82789	44.85693	27.28937
	JI20kW	35.0615	1.214	5.8305	2.2575	0.9265
2000	**WES250**	748.3731	51.2078	205.4023	129.6568	42.8899
	Vestas_V25_200kW	588.9248	38.7176	159.3941	99.9715	31.7847
	VesV20	302.81	15.28	79.382	48.682	13.19
	En18	280.33491	24.5768	85.89398	56.04645	20.7348
	JI20kW	35.0915	0.7635	6.194	3.194	0.8295
2010	**WES250**	670.1601	37.2752	127.38	81.3699	28.6337
	Vestas_V25_200kW	527.3856	28.0587	97.9068	62.3352	20.8472
	VesV20	271.686	8.784	46.688	29.37	7.415
	En18	253.72972	19.52482	57.05883	36.82748	14.60094
	JI20kW	30.606	0.3295	3.0985	1.623	0.4175
2020	**WES250**	776.3222	44.3448	184.1952	125.8933	45.5401
	Vestas_V25_200kW	612.5076	33.5536	143.1263	96.8204	34.1574
	VesV20	315.604	11.667	70.776	47.307	13.572
	En18	287.99408	22.59203	77.63655	53.58156	22.83324
	JI20kW	36.746	0.4795	5.6175	3.2685	0.804

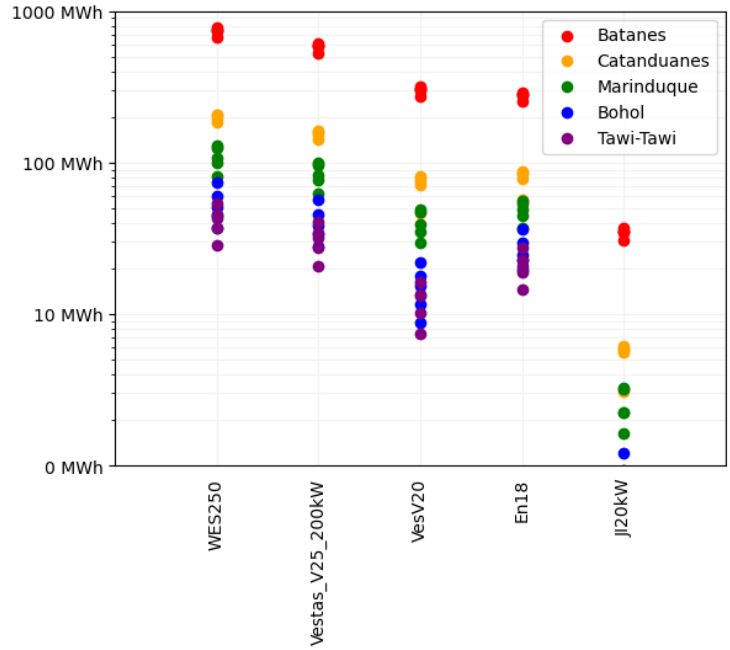
3.3 Energieertrags plotten

In [7]:

```
power_df = pd.read_csv("results/energieertrag_MWh_a_all_year.csv").rename(columns={'Unnamed: 0':'year','Unnamed: 1':'turbine'})

power_df["plot"] = 0
for i in power_df.index:
    if power_df.loc[i,"turbine"] == "WES250":
        power_df.loc[i,"plot"] = 1
    if power_df.loc[i,"turbine"] == "Vestas_V25_200kW":
        power_df.loc[i,"plot"] = 2
    if power_df.loc[i,"turbine"] == "VesV20":
        power_df.loc[i,"plot"] = 3
    if power_df.loc[i,"turbine"] == "En18":
        power_df.loc[i,"plot"] = 4
    if power_df.loc[i,"turbine"] == "JI20kW":
        power_df.loc[i,"plot"] = 5

# The target ist to create an array where the color is based on the region while the x axis is based on turbine
fig, ax = plt.subplots()

plt.scatter(power_df["plot"], power_df['Batanes'], c='red', label='Batanes')
```

```
plt.scatter(power_df["plot"], power_df['Catanduanes'], c='orange', label='Catanduanes')
plt.scatter(power_df["plot"], power_df['Marinduque'], c='green', label='Marinduque')
plt.scatter(power_df["plot"], power_df['Bohol'], c='blue', label='Bohol')
plt.scatter(power_df["plot"], power_df['Tawi-Tawi'], c='purple', label='Tawi-Tawi')

plt.yscale('log')
ax.set(xticklabels=['','WES250','Vestas_V25_200kW','VesV20','En18','JI20kW',''])
ax.set(yticklabels=['','0 MWh','10 MWh','100 MWh','1000 MWh'])

plt.xticks(rotation=90)
ax.tick_params(bottom=False)
plt.ylim([1, 1000])
plt.xlim([0, 6])

plt.grid(axis='x',color='0.95', which='major')
plt.grid(axis='y',color='0.95', which='both')
ax.set_axisbelow(True)

plt.legend()
plt.savefig('leistung.png')
```

```
C:\Users\kunde\AppData\Local\Temp\ipykernel_21876\2741165710.py:26: UserWarning: FixedFormatter should only be used together with FixedLocator
  ax.set(xticklabels=['','WES250','Vestas_V25_200kW','VesV20','En18','JI20kW',''])
C:\Users\kunde\AppData\Local\Temp\ipykernel_21876\2741165710.py:27: UserWarning: FixedFormatter should only be used together with FixedLocator
  ax.set(yticklabels=['','0 MWh','10 MWh','100 MWh','1000 MWh'])
```



3.4 Zusammenstellung der Flautenanalyse

In [4]:

```
nopower_df = pd.DataFrame(columns=island,index=pd.MultiIndex.from_product([years, turbine_typ]))

for (y,t) in nopower_df.index:
    turbine = turbine_df.loc[t]
    neg_turbine = turbine.copy(deep=True)

    for i in neg_turbine.index:
        if neg_turbine.loc[i] == 0:
            neg_turbine.loc[i] = 1
        elif isinstance(neg_turbine.loc[i], float):
            neg_turbine.loc[i] = 0

    for r in nopower_df.columns:
        hub_height = round(float(turbine['HUB_HEIGHT']))
        while True:
            try:
                wind_df = pd.read_csv(f"wind_histogram/wind_hist_{hub_height}_n.csv").rename(columns={'Unnamed: 0':'region'}).set_index(['region'
,'year'])
            except FileNotFoundError:
                hub_height = turbine['HUB_HEIGHT']
                continue
            break
        wind = wind_df.loc[r,int(y)]
        nopower_df.loc[(y,t),r] = sum(neg_turbine.loc[str(n)]*wind.loc[str(n)] for n in range(len(wind)))

nopower_df.to_csv('results/flautenanalyse_h_a.csv')
nopower_df
```

Out[4]:

		Batanes	Bohol	Catanduanes	Marinduque	Tawi-Tawi
1980	WES250	375	3783	2016	3456	3900
	Vestas_V25_200kW	867	5340	3675	4987	6182
	VesV20	1570	6997	5439	6423	7755
	En18	870	5353	3692	4993	6192
	JI20kW	1840	7714	5993	6884	8018
1990	WES250	612	3168	2106	3481	2807
	Vestas_V25_200kW	1274	4537	3613	5146	5314

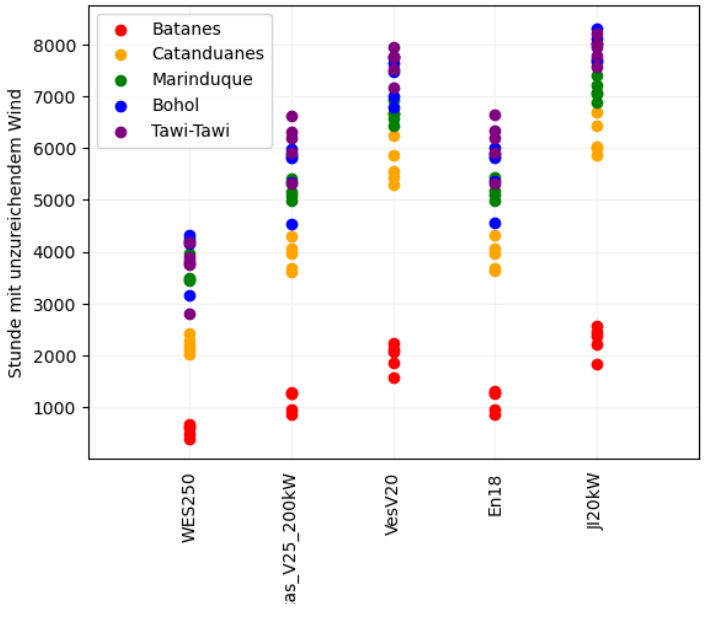
		Batanes	Bohol	Catanduanes	Marinduque	Tawi-Tawi
	VesV20	2076	6792	5303	6659	7164
	En18	1276	4556	3627	5166	5827
	JI20kW	2370	7657	5868	7207	7565
2000	WES250	470	4150	2422	3443	3814
	Vestas_V25_200kW	956	5974	3964	5088	6313
	VesV20	1867	7632	5552	6569	7753
	En18	959	5997	3973	5101	6328
	JI20kW	2223	8124	6036	7037	7958
2010	WES250	666	4310	2294	4238	4181
	Vestas_V25_200kW	1291	5862	4306	5816	6625
	VesV20	2238	7751	6244	6930	7955
	En18	1300	5877	4318	5835	6632
	JI20kW	2576	8311	6698	7401	8201
2020	WES250	591	4213	2185	3977	3741
	Vestas_V25_200kW	1265	5812	4051	5418	5914
	VesV20	2112	7484	5868	6678	7529
	En18	1266	5820	4066	5434	5920
	JI20kW	2460	8022	6421	7069	7777

3.5 Flautenanalyse plotten

In [6]:

```
nopower_df = pd.read_csv("results/flautenanalyse_h_a.csv").rename(columns={'Unnamed: 0':'year','Unnamed: 1':'turbine'})

nopower_df["plot"] = 0
for i in nopower_df.index:
    if nopower_df.loc[i,"turbine"] == "WES250":
        nopower_df.loc[i,"plot"] = 1
    if nopower_df.loc[i,"turbine"] == "Vestas_V25_200kW":
        nopower_df.loc[i,"plot"] = 2
    if nopower_df.loc[i,"turbine"] == "VesV20":
        nopower_df.loc[i,"plot"] = 3
    if nopower_df.loc[i,"turbine"] == "En18":
        nopower_df.loc[i,"plot"] = 4
    if nopower_df.loc[i,"turbine"] == "JI20kW":
        nopower_df.loc[i,"plot"] = 5

# The target ist to create an array where the color is based on the region while the x axis is based on turbine
fig, ax = plt.subplots()#figsize=(7,6)

plt.scatter(nopower_df["plot"], nopower_df['Batanes'], c='red', label='Batanes')
plt.scatter(nopower_df["plot"], nopower_df['Catanduanes'], c='orange', label='Catanduanes')
plt.scatter(nopower_df["plot"], nopower_df['Marinduque'], c='green', label='Marinduque')
plt.scatter(nopower_df["plot"], nopower_df['Bohol'], c='blue', label='Bohol')
plt.scatter(nopower_df["plot"], nopower_df['Tawi-Tawi'], c='purple', label='Tawi-Tawi')

#plt.yscale('log')
ax.set(xticklabels=['','WES250','Vestas_V25_200kW','VesV20','En18','JI20kW',''])
#ax.set(yticklabels=['','0 MWh','10 MWh','100 MWh','1000 MWh'])

plt.xticks(rotation=90)
ax.tick_params(bottom=False)
plt.ylim([1, 8760])
plt.xlim([0, 6])

plt.grid(axis='x',color='0.95', which='major')
plt.grid(axis='y',color='0.95', which='both')
ax.set_axisbelow(True)

plt.legend()
plt.ylabel('Stunde mit unzureichendem Wind')

plt.savefig('flauten.png')
```

```
C:\Users\kunde\AppData\Local\Temp\ipykernel_21876\3429836892.py:26: UserWarning: FixedFormatter should only be used together with FixedLocator
  ax.set(xticklabels=['','WES250','Vestas_V25_200kW','VesV20','En18','JI20kW',''])
```



Vest