Münster: Energy and Greenhouse Gas Balance

1990 — 2021

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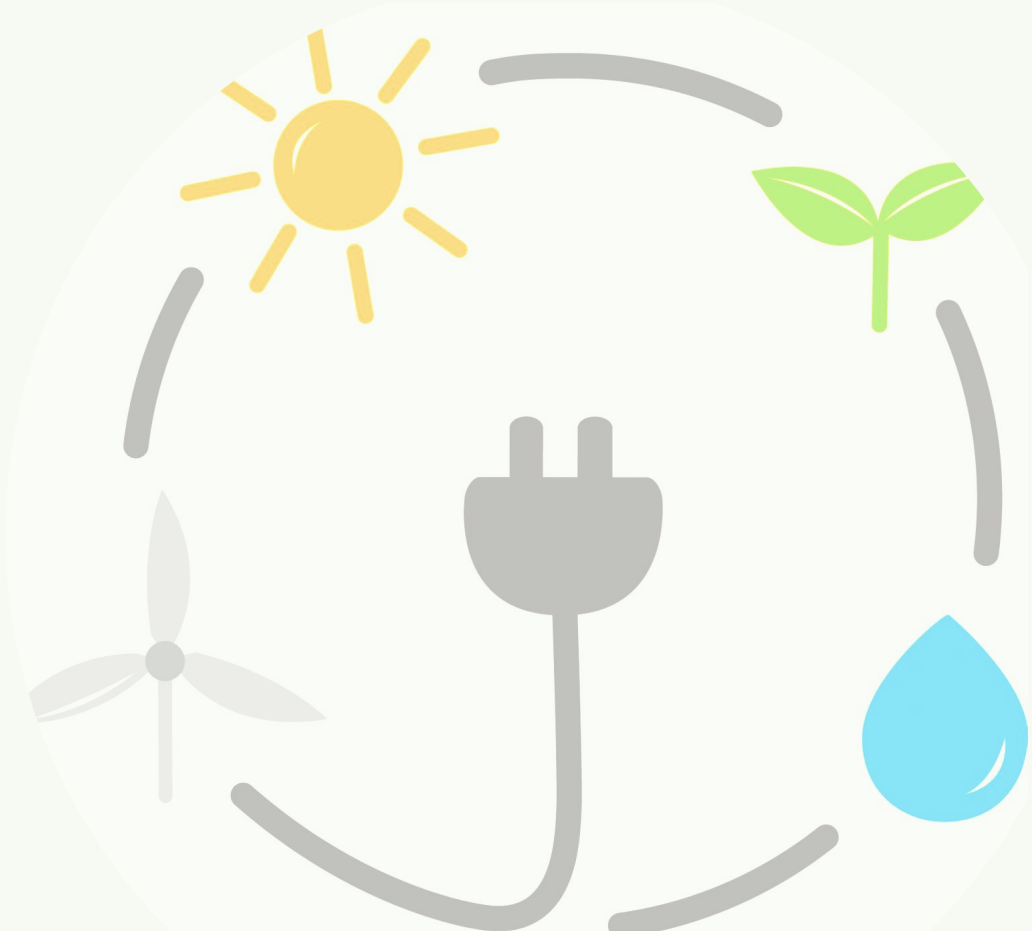
Content:



1. Introduction:

MÜNSTER, GERMANY'S CLIMATE PROTECTION CAPITAL.

CITY'S ENERGY CONSUMPTION AND RELATED GREENHOUSE GAS EMISSIONS.

THE RENEWABLE ENERGY PRODUCTION TRENDS OVER TIME.

USING PUBLICLY AVAILABLE DATASETS AND PYTHON PROGRAMMING LANGUAGE.

Renewable Energy Resources

Wind power that harnesses the power of wind to generate electricity through turbines.

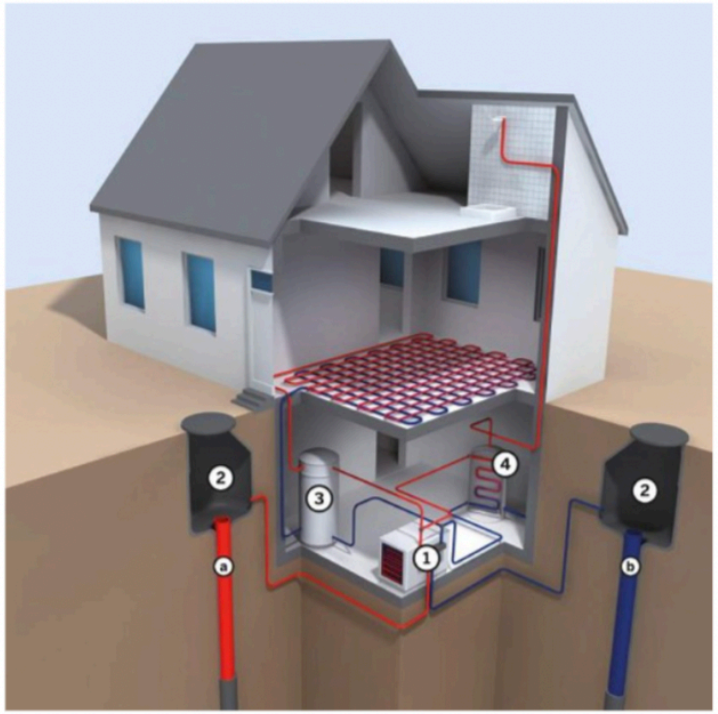
Hydropower utilizes the movement of water to generate electricity.

Hydropower utilizes the movement of water to generate electricity.

Photovoltaik which involves converting sunlight into electricity.

Renewable Energy Resources

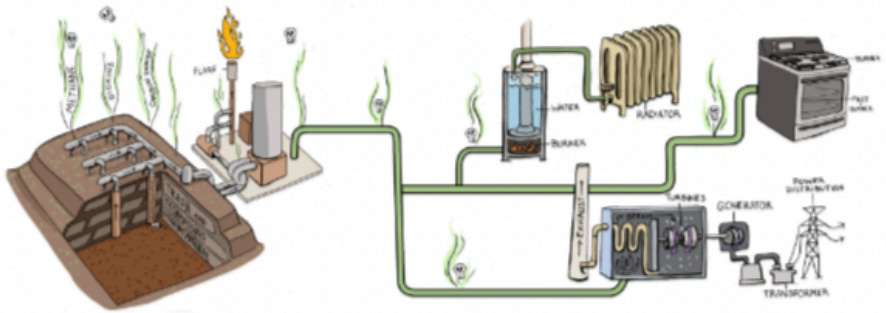
Heat pumps are electrical devices transferring heat between locations.



Pellets are compressed wood chips used as a fuel source.

Firewood refers to firewood that is cut and prepared in log form.

Sewage/landfill gas is the gas byproduct from sewage treatment and landfills.



renewable_energy_electricity and renewable_energy_heat before processing

```
renewable_energy_electricity
```

✓ 0.0s

	year	Photovoltaik	Windkraft	Wasserkraft	Biogasanlagen	Klär- / Deponiegas	Biomethan	Gesamt EE
0	1990	0.00000	63.20	239.8	0.0	0.00	0	303.00000
1	1995	28.01120	63.20	239.8	0.0	0.00	0	331.01120
2	2000	482.53884	63.20	239.8	0.0	11850.00	0	12635.53884
3	2005	2637.63906	21804.00	239.8	0.0	11850.00	0	36531.43906
4	2010	16953.45818	22815.20	436.0	16417.4	11850.00	0	68472.05818
5	2015	36430.82880	34406.08	436.0	44952.2	12290.20	14816	143331.30880
6	2016	37358.18730	34456.64	436.0	44952.2	15708.24	23218	156129.26730
7	2017	39083.18440	55059.84	436.0	44952.2	15414.22	12059	167004.44440
8	2018	42910.06126	60545.60	436.0	44952.2	15617.32	20490	184951.18126
9	2019	47745.49056	60545.60	436.0	44952.2	15617.32	17479	186775.61056
10	2020	53857.60000	60545.60	436.0	44952.2	15617.32	18767	194175.72000

```
renewable_energy_heat
```

✓ 0.0s

	year	Solarthermie	Wärmepumpen	Pellets	Stückholz	Biogasanlagen	Klär- / Deponiegas	Biomethan	Gesamt
0	1990	24.840	42.96875	0.0	0.0	0.000	0.00	0	67.80875
1	1995	349.140	195.31250	0.0	0.0	0.000	0.00	0	544.45250
2	2000	1852.420	347.65625	12.5	0.0	0.000	15000.00	0	17212.57625
3	2005	4110.660	500.00000	487.5	495.0	1237.700	15000.00	0	21830.86000
4	2010	8827.300	8277.50000	2712.5	2370.0	14649.420	15000.00	0	51836.72000
5	2015	10670.060	14890.00000	3812.5	3810.0	37828.736	7570.27	21963	100544.56600
6	2016	10944.818	15617.00000	3950.0	4033.8	37828.736	10762.24	31864	115000.59400
7	2017	11078.678	16492.00000	4075.0	4078.8	37828.736	8370.43	19457	101380.64400
8	2018	11217.598	17531.50000	4212.5	4168.2	37828.736	8043.99	26793	109795.52400
9	2019	11396.998	18731.50000	4275.0	4641.9	37828.736	7740.00	22673	107287.13400
10	2020	11652.298	19969.00000	4437.5	4641.9	37828.736	7740.00	23153	109422.43400

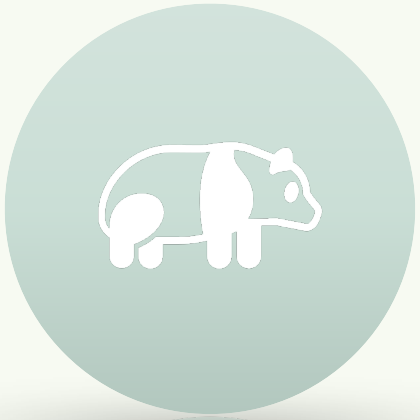
CO2 Emissions dataset:

	year	Private households	Trade and others	Industry	Transport	Heat	Electricity	Total_co2	Total as of 1990
0	1990	817146.280496	846374.365518	293939.743986	660748.806226	1.120973e+06	836487.800000	4.575670e+06	0.000000
1	1995	774039.745963	801725.975522	278433.678515	649866.500561	1.055941e+06	798258.216000	4.358265e+06	-0.047513
2	2000	773328.016727	800988.788810	278177.658859	638984.194897	1.058948e+06	793546.832000	4.343973e+06	-0.050637
3	2005	806450.639618	835296.157763	290092.361925	628101.889233	9.614061e+05	970433.036634	4.491780e+06	-0.018334
4	2010	684161.375550	735889.940880	185496.828653	622684.731430	7.880783e+05	817469.875512	3.833781e+06	-0.162138
5	2015	636894.098977	629441.403926	217637.183252	596134.946082	7.446007e+05	739371.946216	3.564080e+06	-0.221080
6	2016	607277.947909	632025.211201	214250.898995	598972.703684	7.553259e+05	698228.112507	3.506081e+06	-0.233756
7	2017	578793.984793	623804.379543	215604.505102	593667.548910	7.686083e+05	649594.561599	3.430073e+06	-0.250367
8	2018	588419.949975	592654.296510	232468.641927	588925.588842	7.778818e+05	635661.057120	3.416011e+06	-0.253440
9	2019	533848.636234	549176.926239	225833.358416	582527.299609	7.073147e+05	601544.172097	3.200245e+06	-0.300595
10	2020	521173.267714	512646.285622	204680.188045	571041.010283	7.183262e+05	520173.520334	3.048040e+06	-0.333859
11	2021	510254.304258	549104.268798	191003.122482	565862.335120	7.136122e+05	536749.473380	3.066586e+06	-0.329806

The Question:

"How can Münster enhance its sustainable urban development strategies, focusing on reducing CO2 emissions and reinforcing renewable energy production?"

2. Methods:



2.1. LOADING THE DATASETS INTO PANDAS DATAFRAME.

2.2. PROCESSING

2.3. INTEGRATION

2.1. Loading the datasets into Pandas dataframe.

```
#!/usr/bin/env python3.11
# -*- coding: utf-8 -*-
import pandas as pd
from sqlalchemy import create_engine
import matplotlib.pyplot as plt
import numpy as np
import seaborn as sns
import os
```

✓ 3.9s

```
# Adjust display options for NumPy and pandas

pd.set_option('display.max_columns', None)
np.set_printoptions(threshold=np.inf)
```

✓ 0.0s

```
#print("Loadin Renewable Energy of the city of Münster in the years 1990-2020 data....")
#download data from here:https://opendata.stadt-muenster.de/sites/default/files/Muenster-Erneuerbare-Energien_2020.xls
renewable_energy_url = "https://opendata.stadt-muenster.de/sites/default/files/Muenster-Erneuerbare-Energien_2020.xls" #
renewable_energy = pd.read_excel(renewable_energy_url, sheet_name=None)


#print("Loadin CO2 emissions of the city of Münster in the years 1990-2021 data....")
        #download data from here: https://opendata.stadt-muenster.de/sites/default/files/Muenster-CO2-Emissionen_2021.xls
co2_emissions_url = "https://opendata.stadt-muenster.de/sites/default/files/Muenster-CO2-Emissionen_2021.xls" #
co2_emissions = pd.read_excel(co2_emissions_url, sheet_name=None) # to add all the three  sheets  into CO2emissions,  beca
```

2.2. Processing

```
#### The first dataset renewable_energy

renewable_energy_electricity = pd.read_excel(renewable_energy_url, sheet_name=0) # the first sheet contains the data that describes the production of *electricity* through renewable energy.
renewable_energy_electricity= renewable_energy_electricity.rename(columns={'Erneuerbare Stromproduktion nach Technologie in (MWh)': 'year'} ) #rename for later merging

renewable_energy_heat = pd.read_excel(renewable_energy_url, sheet_name=1) #the second sheet contains the data that describes the production of *heat* through renewable energy.
renewable_energy_heat= renewable_energy_heat.rename(columns={'Erneuerbare Wärmeproduktion nach Technologie in (MWh)': 'year'} ) #rename for later merging

# merge the data of the renewable_energy_electricity and renewable_energy_heat
renewable_energy = pd.merge(renewable_energy_electricity, renewable_energy_heat,  on='year' ) #merge the two exel sheets into one datafram.

#rename and translate columns
renewable_energy.rename(columns={
    'year': 'year',
    'Photovoltaik': 'Photovoltaic',
    'Windkraft': 'Wind power',
    'Wasserkraft': 'Hydropower',
    'Biogasanlagen_x': 'Biogas plants in electricity',
    'Klär- / Deponiegas_x': 'Sewage / landfill gas in electricity',
    'Biomethan_x': 'Biomethane in electricity',
    'Gesamt EE': 'Total RE in electricity',
    'Solarthermie': 'Solar thermal',
    'Wärmepumpen': 'Heat pumps',
    'Pellets': 'Pellets',
    'Stückholz': 'Firewood',
    'Biogasanlagen_y': 'Biogas plants in heat',
    'Klär- / Deponiegas_y': 'Sewage / landfill gas in heat',
    'Biomethan_y': 'Biomethane in heat',
    'Gesamt': 'Total RE in heat',
}, inplace=True)

#Cleaning data and replacing missing values
renewable_energy.fillna(0, inplace=True)
renewable_energy['Total RE production'] = renewable_energy[['Total RE in electricity','Total RE in heat']].sum(axis=1)

########################################
```

2.2. Processing

```
#### The second dataset co2 emissions


#store each sheet in a data frame >>>  then creat a new CO2emissions data frame from these data frames (merge them!):
co2_emissions_sectors  = pd.read_excel(co2_emissions_url, sheet_name=0) # the first sheet (at 0) define CO2emissions by sectors
co2_emissions_sectors =co2_emissions_sectors.rename(columns={'CO2-Emissionen nach Sektoren in (t)': 'year'} ) #rename the CO2-Emissionen nach Sektoren column into >>> year. Thi


co2_emissions_applications = pd.read_excel(co2_emissions_url, sheet_name=1)# the second sheet (at 1) define CO2emissions by application
co2_emissions_applications =co2_emissions_applications.rename(columns={'CO2-Emissionen nach Anwendungen in (kt)': 'year'} ) #rename the CO2-Emissionen nach Anwendungen column i

# merge the data of the CO2emissions_sectors and CO2emissions_applications
co2_emissions = pd.merge(co2_emissions_sectors, co2_emissions_applications,  on='year' ) #merge the two exel sheets into one datafram. cO2_emissions_applications.index.name = '


### process the merged dataFrame CO2emissions
co2_emissions.rename(columns={
    'year': 'year',
    'Private Haushalte': 'Private households',
    'Gewerbe + Sonstiges': 'Trade and others',
    'Industrie': 'Industry',
    'Verkehr_x':'Transport',
    'Wärme': 'Heat', # Kt >> convert to t!!
    'Strom': 'Electricity', # Kt!!
    'Gesamt_y': 'Total_co2', # Kt and update to the new values!!
    'Gesamt in % zu 1990': 'Total as of 1990'  # update to the new values!!
    }    ,inplace=True)


 # Drop the unnesseciry columns   columns
co2_emissions = co2_emissions.drop(columns=[col for col in ['Verkehr in %', 'Gesamt_x', 'Wärme in %', 'Strom in %', 'Verkehr_y'] if col in co2_emissions.columns], axis=1)

co2_emissions['Heat']= co2_emissions['Heat']*1000
co2_emissions['Electricity'] = co2_emissions['Electricity']*1000
co2_emissions['Total_co2'] = co2_emissions.iloc[:, 1:-2].sum(axis=1)
co2_emissions['Total as of 1990'] = ((co2_emissions['Total_co2'] - co2_emissions['Total_co2'].iloc[0]) / co2_emissions['Total_co2'].iloc[0])


#Cleaning data and replacing missing values
co2_emissions.fillna(0, inplace=True)
#########################################################
```

2.2. Processing

```
#### THe third dataset co2 emissions by energy source

co2_by_energy_source = pd.read_excel(co2_emissions_url, sheet_name=2)# the third sheet (at 2) define CO2emissions by energy source

#rename and translate the columns
column_mapping = {
    'CO2 Emissionen nach Energieträgern und Sektoren in 2021 in (t)':"CO2 Emissions by Energy Source and Sector (2021)",
    'Erdgas': 'Natural Gas',
    'Fernwärme': 'District Heating',
    'Heizöl': 'Heating Oil',
    'EE Wärme': 'Renewable Heat',
    'Kraftstoffmix Verkehr': 'Fuel Mix Traffic',
    'Strom': 'Electricity',
    'Summe': 'Total',
    'Anteil': 'Share'
}
# Rename columns
co2_by_energy_source.rename(columns=column_mapping, inplace=True)
co2_by_energy_source.set_index('CO2 Emissions by Energy Source and Sector (2021)', inplace=True)

# rename and translate the rows
index_mapping = {
    'Private Haushalte': 'Private households',
    'Gewerbe+Sonstiges': 'Trade+Other',
    'Industrie': 'Industry',
    'Verkehr': 'Traffic',
    'Summe': 'Total',
    'Anteil': 'Share'
}

# Rename index (rows)
co2_by_energy_source.rename(index=index_mapping, inplace=True)


#Cleaning data and replacing missing values
co2_by_energy_source.fillna(0, inplace=True)
```

2.3 Integration into SQL:

```
#Creating SQLite files
print("Creating CO2 Emissions Energy and Renewable Energy SQLite files: ")
sqlite_path = '../data/co2_emissions_renewable_energy.sqlite'
engine = create_engine(f'sqlite:///{sqlite_path}')

print("creating CO2 Emissions data table ...")
co2_emissions.to_sql("co2_emissions_table", engine, if_exists='replace', index=False)


print("creating Renewable Energy data table...")
renewable_energy.to_sql("renewable_energy_table", engine ,if_exists='replace', index=False)

print("creating CO2 Emissions by Energy Source data table...")
co2_by_energy_source.to_sql("co2_emissions_energy_source_table", engine ,if_exists='replace', index=True)# index=True



print("SQLite files created successfully!!!")
```

2.3 Integration into SQL:

Tables (3)
co2_emissions_table
renewable_energy_table
co2_emissions_energy_source_table

	year	Private house...	Trade and oth...	Industry	Transport	Heat	Electricity	Total_co2	Total as of 1990
1	1990	817146.28049578...	846374.36551813...	293939.74398608...	660748.80622557...	1120972.59	836487.8	4575669.5862255...	0
2	1995	774039.74596263...	801725.97552234...	278433.678515023	649866.50056141...	1055941.1840000...	798258.21599999...	4358265.30056142	-0.047513108533...
3	2000	773328.01672684...	800988.78880958...	278177.65885936...	638984.19489726...	1058947.6323957...	793546.83199999...	4343973.1236888...	-0.050636624470...
4	2005	806450.63961849...	835296.15776341...	290092.36192454...	628101.88923310...	961406.12267234...	970433.03663411...	4491780.2078460...	-0.018333792857...
5	2010	684161.37554975...	735889.94088020...	185496.82865309...	622684.73143002...	788078.26957102...	817469.87551203...	3833781.0215961...	-0.162137704799...
6	2015	636894.09897666...	629441.403926151	217637.18325246...	596134.94608171...	744600.73993956...	739371.94621571...	3564080.3183922...	-0.221080051513...
7	2016	607277.94790935...	632025.21120086...	214250.89899473...	598972.70368360...	755325.94559757...	698228.11250738...	3506080.8198935...	-0.233755682349...
8	2017	578793.98479325...	623804.37954298...	215604.50510163...	593667.54891031...	768608.30783904...	649594.56159883...	3430073.2877860...	-0.250366919387...
9	2018	588419.94997515...	592654.296510337	232468.64192687...	588925.58884212...	777881.83129194...	635661.05712042...	3416011.3656668...	-0.253440113781...
10	2019	533848.63623419...	549176.92623865...	225833.35841584...	582527.29960925...	707314.74879157...	601544.17209711...	3200245.1413866...	-0.300595228505...
11	2020	521173.26771446...	512646.28562178...	204680.18804485...	571041.01028308...	718326.22104706...	520173.520334033	3048040.4930452...	-0.333859135672...
12	2021	510254.30425752...	549104.26879818...	191003.12248186...	565862.33512017...	713612.22215789...	536749.47337967...	3066585.7261953...	-0.329806125987...

Tables (3)
co2_emissions_table
renewable_energy_table
co2_emissions_energy_source_table

	year	Photovoltaic	Wind power	Hydropower	Biogas plants ...	Sewage / land...	Biomethane i...	Total RE in ele...	Solar thermal	Heat pumps	Pellets	Firewood	Biogas plants ...	Sewage / land...	Biomethane i...	Total RE in heat	Total RE prod...
1	1990	0	63.2	239.8	0	0	0	303	24.84	42.96875	0	0	0	0	0	67.80875	370.80875000000...
2	1995	28.0112	63.2	239.8	0	0	0	331.01120000000...	349.14	195.3125	0	0	0	0	0	544.4525	875.4637
3	2000	482.53883999999...	63.2	239.8	0	11850	0	12635.53884	1852.42	347.65625	12.5	0	0	15000	0	17212.57625	29848.11509
4	2005	2637.63906	21884	239.8	0	11850	0	36531.439060000...	4110.66	500	487.5	495	1237.7	15000	0	21830.86	58362.299060000...
5	2010	16953.45818	22815.2	436	16417.4	11850	0	68472.058179999...	8027.3	8277.5	2712.5	2370	14649.42	15000	0	51836.72	120308.77818
6	2015	36430.8288	34406.88	436	44952.2	12290.2	14816	143331.3088	10670.86	14890	3812.5	3810	37828.736	7570.27	21963	100544.566	243875.8748
7	2016	37358.187300000...	34456.64	436	44952.2	15708.24	23218	156129.2673	10944.818	15617	3950	4033.8	37828.736	10762.24	31864	115000.594	271129.8613
8	2017	39083.184400000...	55059.84	436	44952.2	15414.22	12059	167004.4444	11078.678	16492	4075	4078.8	37828.736	8370.43	19457	101380.644	268385.0884
9	2018	42910.061259999...	60545.6	436	44952.2	15617.32	20490	184951.18125999...	11217.598	17531.5	4212.5	4168.2	37828.736	8043.99	26793	109795.52399999...	294746.70525999...
10	2019	47745.490560000...	60545.6	436	44952.2	15617.32	17479	186775.61056	11396.998	18731.5	4275	4641.9	37828.736	7740	22673	107287.13399999...	294062.74456
11	2020	53857.6	60545.6	436	44952.2	15617.32	18767	194175.72	11652.298	19969	4437.5	4641.9	37828.736	7740	23153	109422.43400000...	303598.154

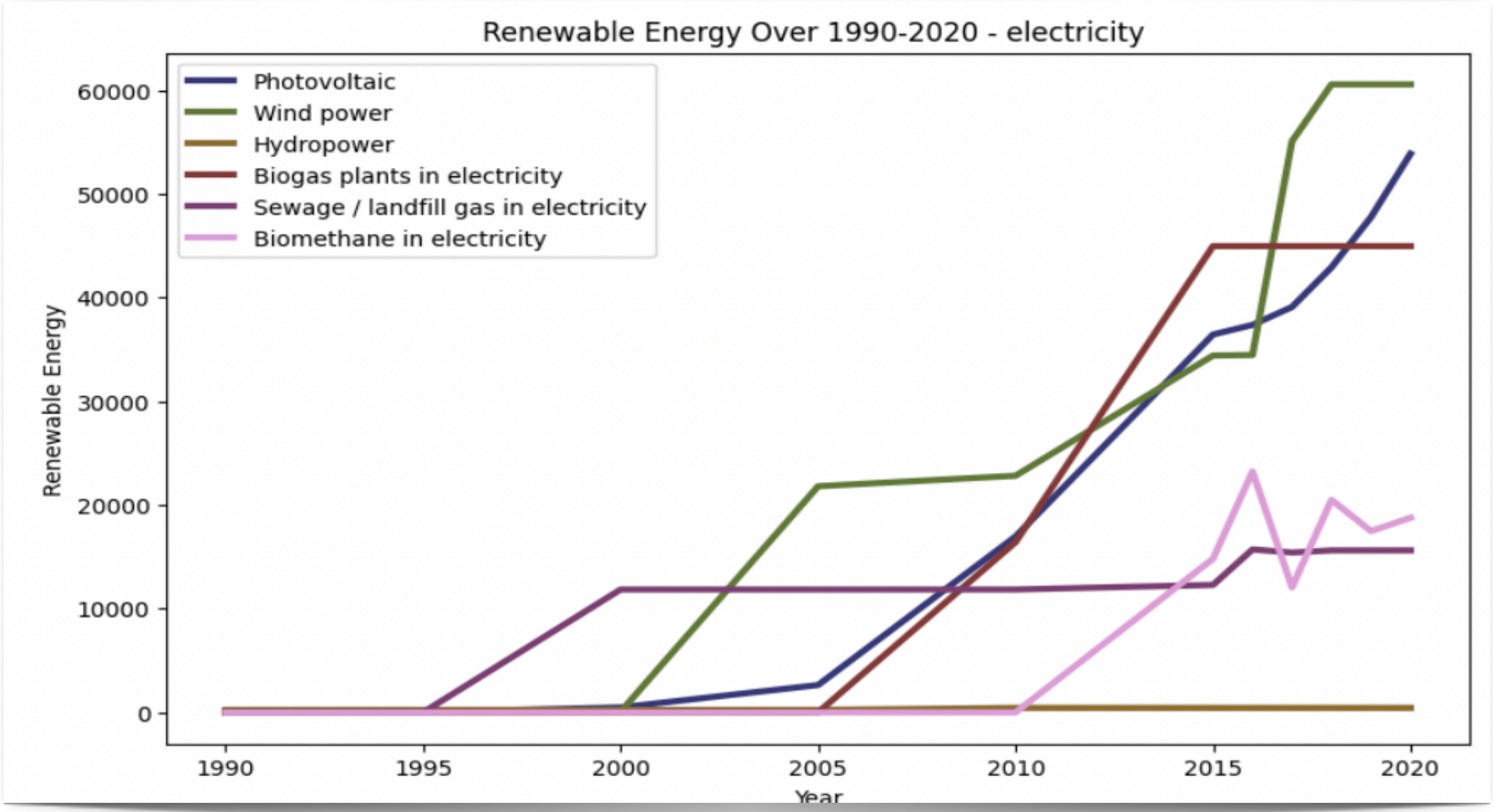
Tables (3)
co2_emissions_table
renewable_energy_table
co2_emissions_energy_source_table

	CO2 Emission...	Natural Gas	District Heating	Heating Oil	Renewable H...	Fuel Mix Traffic	Electricity	Total	Share
1	Private households	238981.29622636...	11415.403693938...	98807.497200000...	1052.1870990381...	0	159997.92003818...	510254.30425752...	0.280945942100332
2	Trade+Other	120189.23487588...	85194.8032814226	36684.48	348.86081013613...	0	306686.89063074...	549104.26879818...	0.302336726651034
3	Industry	107276.17718935...	0	1630.8277646429...	0	0	82073.433625839...	190980.43857983...	0.105153800353769
4	Traffic	0	0	0	0	549788	16082	565862	0.311563530894865
5	Total	466446.787491605	96610.206975360...	137122.80496464...	1401.0479091743...	549788	564840.24429477...	1816201.0116355...	1
6	Share	0.2568254860025...	0.0531935652256...	0.0754997954995...	0.0007714167651...	0.3027087841476...	0.3110009523594...	1	-

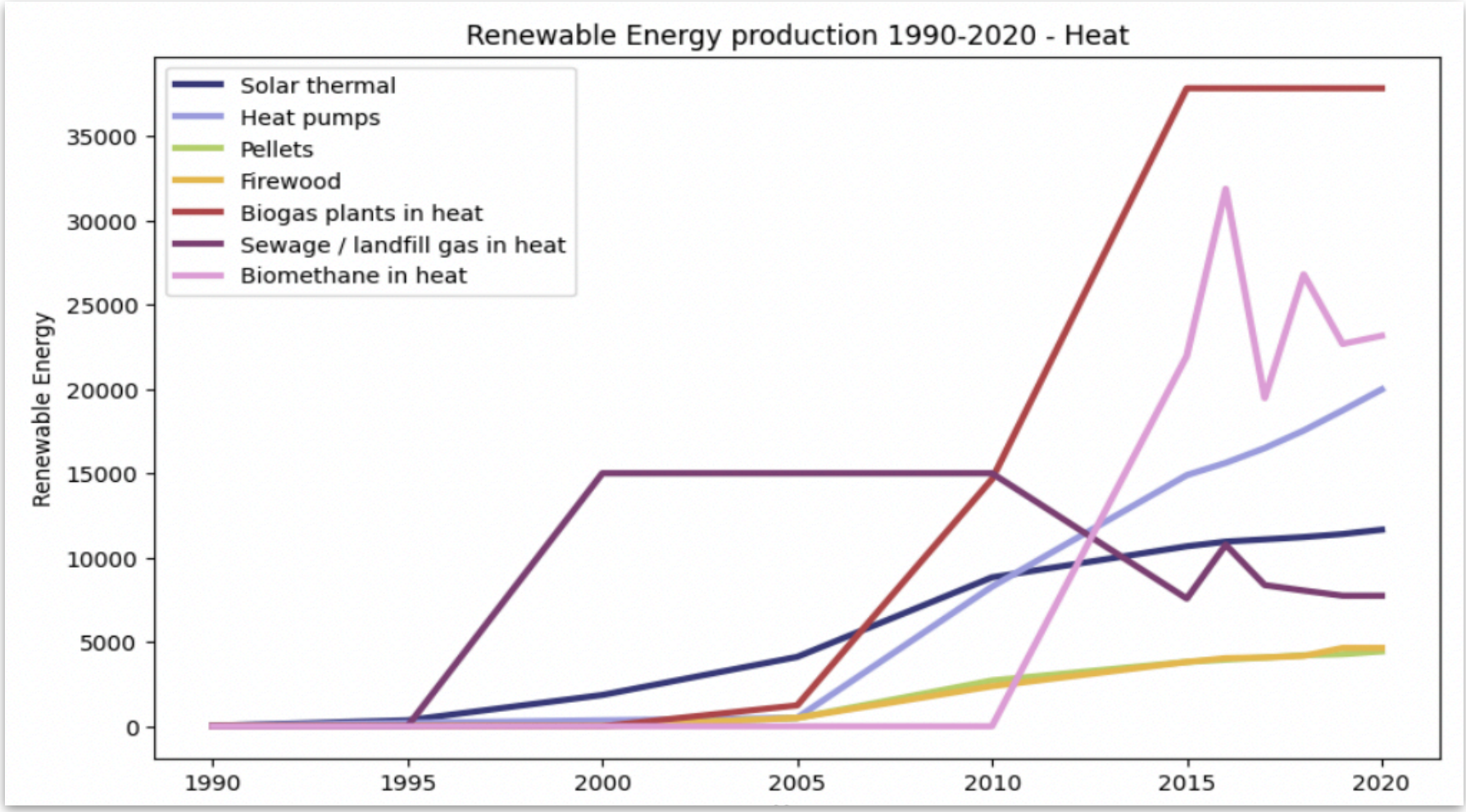
2.3 Pickle the files:

- Object Serialisation.
- Data Persistence.
- Interprocess Communication.
- Model Persistence in Machine Learning.

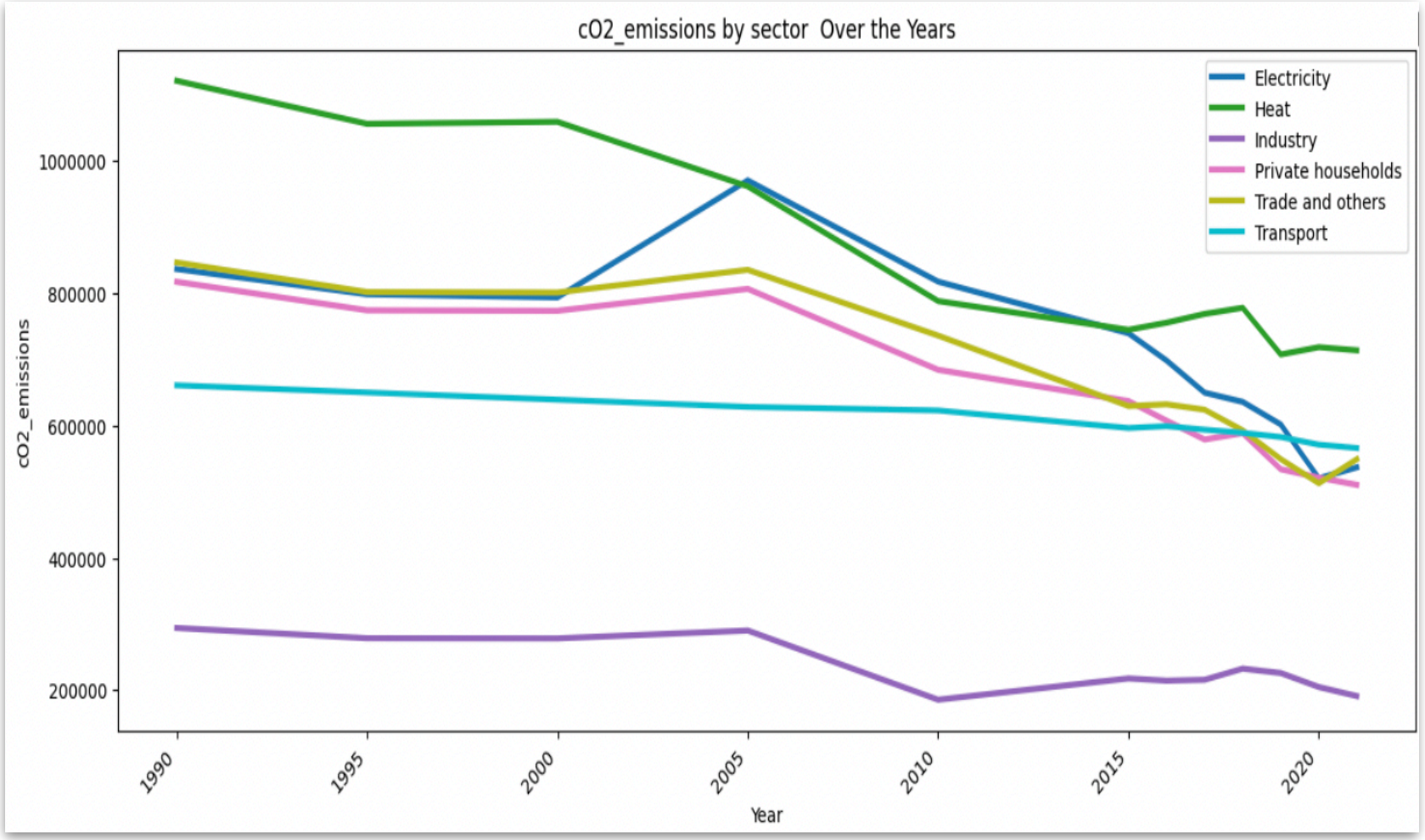
```
# df.to_pickle

out = '../project'

df_list = [renewable_energy, co2_emissions, co2_by_energy_source]
for i, df in enumerate(df_list, 1):
    df.to_pickle(os.path.join(out, f'df{i}.pkl'))
```



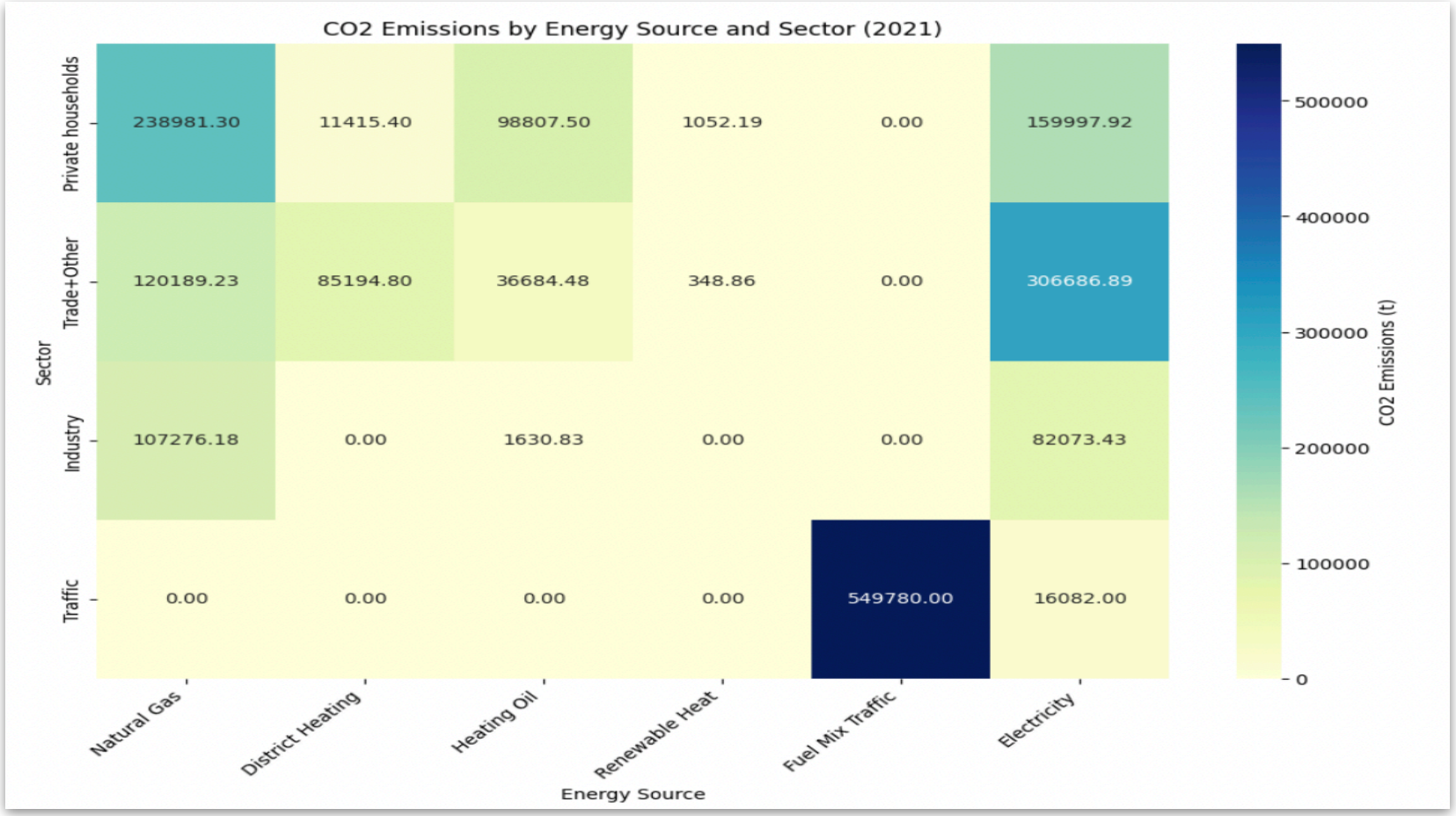
3. Results- Renewable Electricity



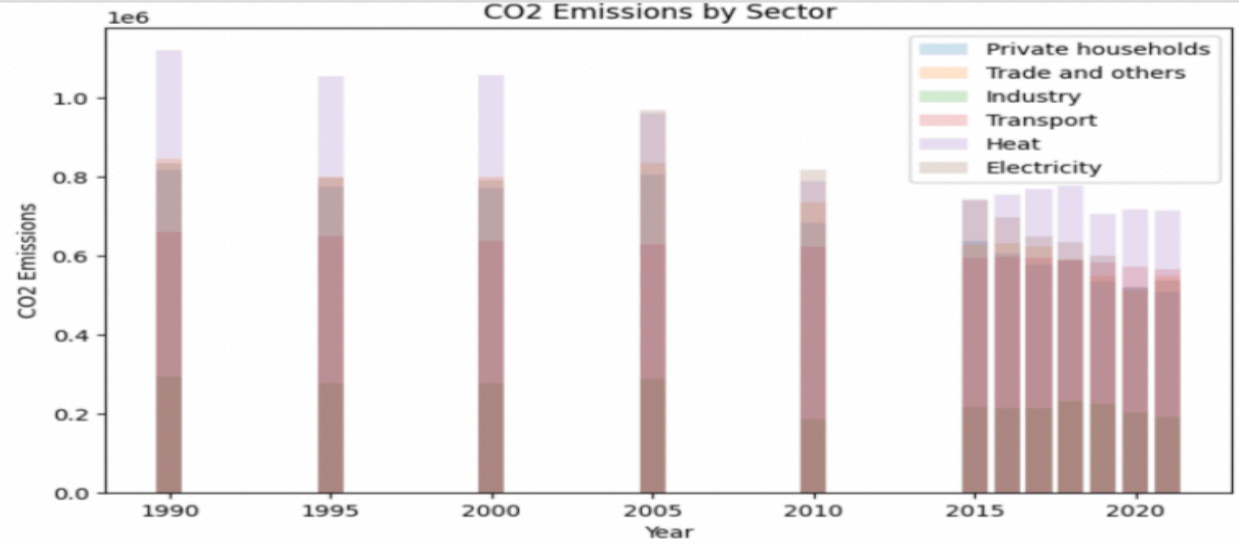
3. Results- Renewable Heat

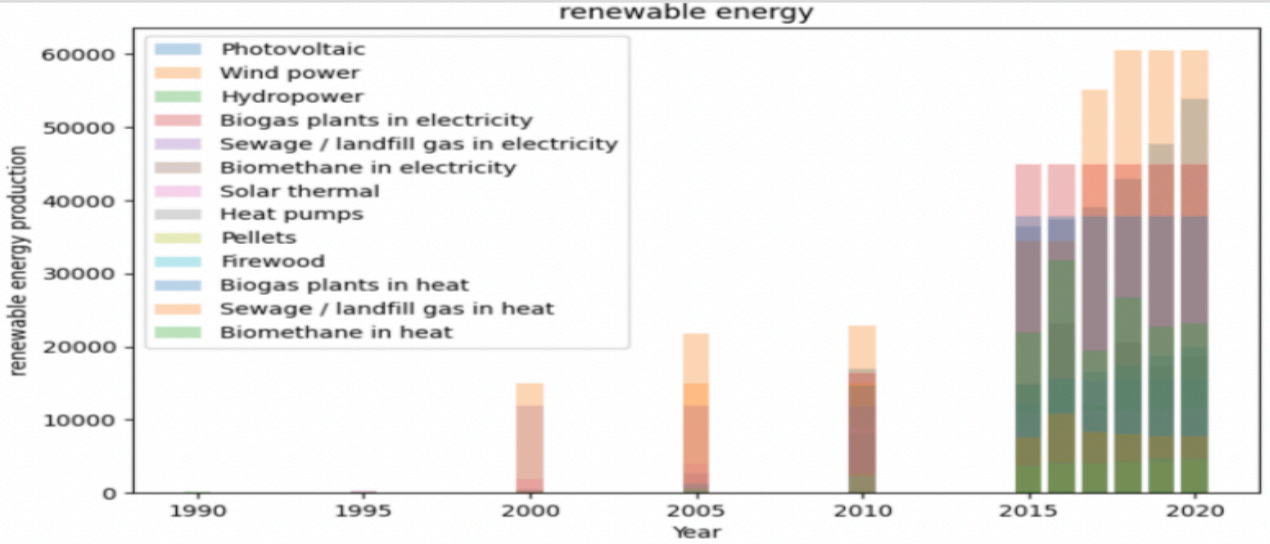


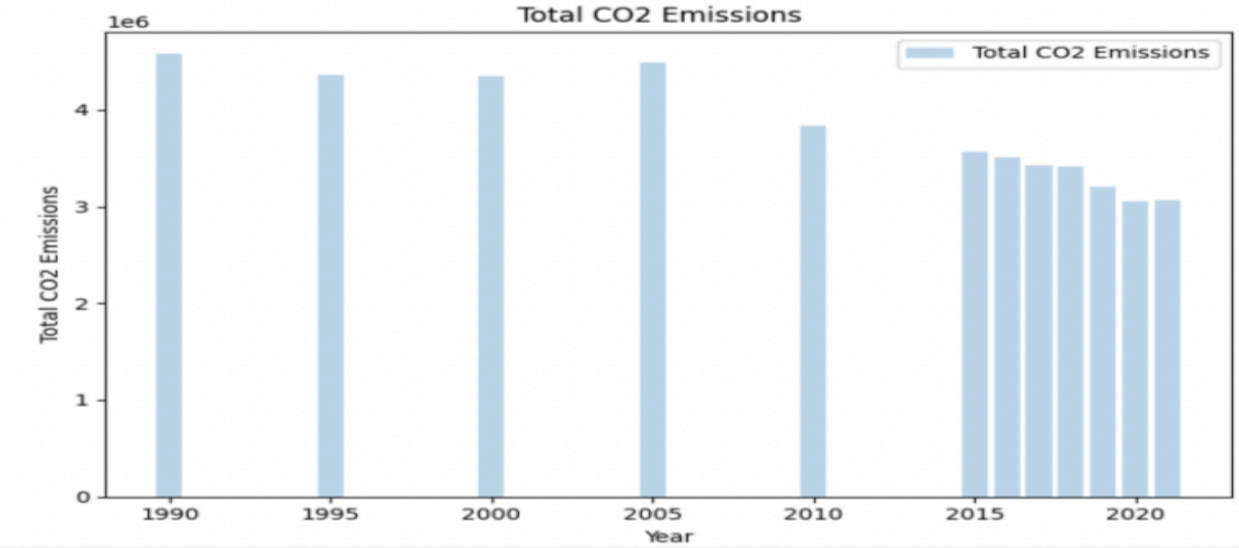
3. Results- Co2 Emissions

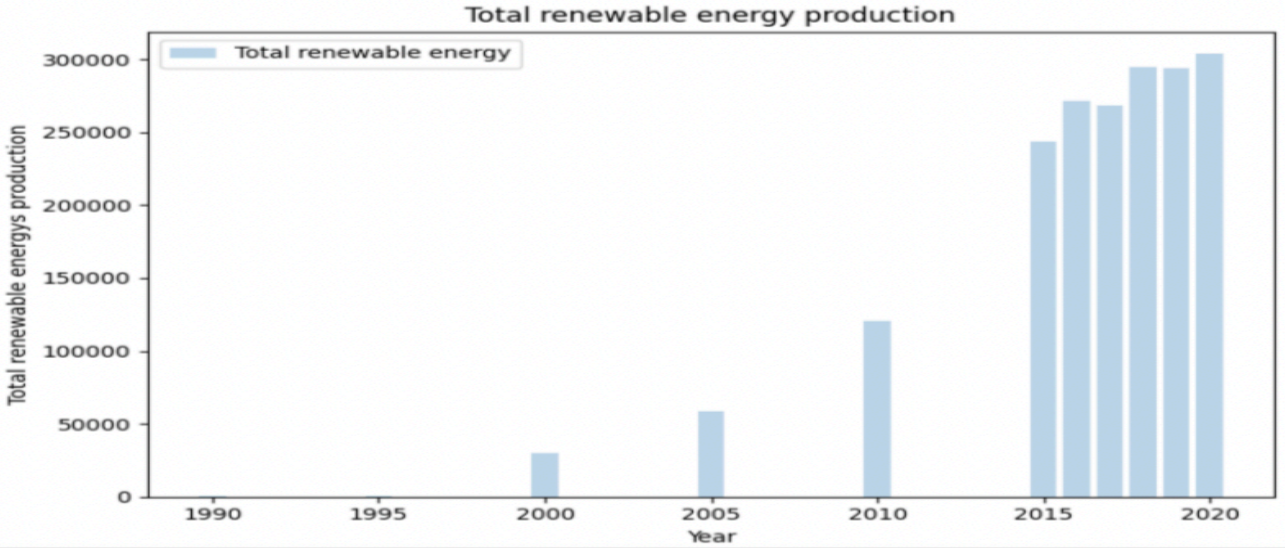


3. Results- Co2 2021 (the third dataset)


CO2 Emissions by Sector
1e6
CO2 Emissions
Year
Private households
Trade and others
Industry
Transport
Heat
Electricity


renewable energy
renewable energy production
Year
Photovoltaic
Wind power
Hydropower
Biogas plants in electricity
Sewage / landfill gas in electricity
Biomethane in electricity
Solar thermal
Heat pumps
Pellets
Firewood
Biogas plants in heat
Sewage / landfill gas in heat
Biomethane in heat


Total CO2 Emissions
1e6
Total CO2 Emissions
Year
Total CO2 Emissions


Total renewable energy production
Total renewable energys production
Year
Total renewable energy

3. Results

4. Conclusion:

- **The correlation between renewable energy** growth and **CO2 emission reduction.**
- **Continued monitoring and implementation of policies**
- **Improve in sectors showing slower declines.**
- **Combining data-driven** insights with **proactive policy measures and collaborative efforts.**
- **In future work, time series analysis.**

Question?

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