Renewable energy adoption vs national carbon emissions

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Research question

Research q 1 : How does renewable energy adoption correlate with changes in national carbon emissions?

Research q 2 : If there is a correlation between renewable energy adoption and carbon emissions, what is the time lag between these variables?

Research q 3 : How does GDP affect the correlation between renewable energy adoption and carbon emissions?

Possible data set options for renewables, CO_2, and GDP

CO_2 and renewables from Our World in Data (chosen)

GDP from World Bank (chosen)

CO_2 from EDGAR

World Energy Balances Highlights from IEA

Data methodology of chosen data set

Data methodology for CO2- very important!

Default products of energy consumption from fuels + non-combustion production + gas flaring + industrial processes (cement prod)

Methodology

Renewable energy

The data are based on gross generation and not accounting for cross-border electricity supply. 'Input-equivalent' energy is the amount of fuel that would be required by thermal power stations to generate the reported electricity output. Details on thermal efficiency assumptions are available online.

Renewable power is based on gross generation from renewable sources including wind, geothermal, solar, biomass and waste, and not accounting for cross-border electricity supply.

Biofuels production and consumption

The data includes biogasoline (such as ethanol) and biodiesel. Volumes have been adjusted for energy content.

The biofuels PDF tables are in thousand barrels of oil equivalent per day figures. The data are available in additional units in the Excel workbook.

Electricity

Electricity generation is based on gross output.

Carbon

Carbon emissions from primary energy use are estimated by applying the Default CO_2 Emission Factors for Combustion to the consumption of each energy product type (coal, natural gas and various oil products) from the list of IPCC emission factors. Biofuels are considered as not emitting CO_2, consistent with the practice of the IEA. Second, the revised method takes account of fuel consumption used for non-combustion purposes, such as the use of oil products and natural gas in the petrochemicals industry or of oil to produce bitumen for road construction. Estimates of the share of non-combusted fossil fuels taken from the IEA's energy balances are subtracted from the total consumption of fossil fuels before applying the relevant emission factors.

Carbon emissions from flared natural gas are calculated using data series on volumes of gas flared from two sources: Cedigaz up to 2012, and the Payne Institute for Public Policy, Colorado School of Mines, from 2013 onward. Payne Institute's data include flaring from upstream, downstream oil and gas, while Cedigaz include flaring from upstream only. Volumes of gas flared have been standardised using a Gross Calorific Value (GCV) of 40 MJ/m^3. The IPCC Default CO_2 Emission Factor for Combustion for natural gas (56,100 kg CO_2 per TJ) is used and perfect combustion has been assumed. These emissions represent around 1% of total CO_2 emissions.

Data for methane emissions associated with the production, transportation and distribution of fossil fuels for 1990-2020 are sourced, where available, from IEA (2021, 2022) Greenhouse Gas Emissions from Energy (all rights reserved). For a selected number of fossil fuel-producing countries where methane emission data is not currently available, an estimate of historical methane emissions has been derived using regional average methane intensity of production. For 2021, methane emission estimates are derived for all countries using methane intensity of fossil fuel production in 2020. Total methane emissions at a global and regional level show a discrepancy with IEA data due to non-inclusion of residual emissions i.e. emissions which have not been allocated to named countries. There is a wide range of uncertainty with respect to both current estimates of methane emissions and the global warming potential of methane emissions. To ensure alignment with financial and government reporting standards, the methane to CO_2e factor is a 100-year Global Warming Potential (GWP) of 25, recommended by the IPCC in AR4.

Carbon emissions from industrial processes refer only to non-energy CO_2 emissions from cement production and are sourced for 1990-2021 from Andrew, R. M. (2019) Global CO_2 emissions from cement production, 1928-2018. Earth System Science Data 11, 1675-1710, (updated dataset May 2022).

Minerals

Total proved reserves of minerals are generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known resources under existing economic and geological conditions.

The data series for mineral reserves in this year's review does not necessarily meet the definitions, guidelines and practices used for determining proved reserves at company level nor does it necessarily represent the EI's view of proved reserves by country. Rather the data series has been compiled using a combination of primary official sources and third-party data.

Revisions and corrections

Each year revisions are made to historical data when updated or more reliable data sources become available. Corrections are also made when errors are identified in data. In this Statistical Review corrections have been made to the emissions, biofuels, historic oil prices and oil refinery throughput tables.

Processing of data: initial formats

CO2 data set yearly time series 1990 - 2020

Renewables yearly time series 1965 - 2022

GDP yearly times series depending on country 1971 - 2022

	A	B	C	D
1	Entity	Code	Year	Per capita
2	Africa		1990	0.922554
3	Africa		1991	0.934377
4	Africa		1992	0.927589
5	Africa		1993	0.933574
6	Africa		1994	0.925272
7	Africa		1995	0.951602
8	Africa		1996	0.908937
9	Africa		1997	0.923566
10	Africa		1998	0.962578
11	Africa		1999	0.93127
12	Africa		2000	0.878721
13	Africa		2001	0.873831
14	Africa		2002	0.858644
15	Africa		2003	0.907421
16	Africa		2004	0.942194
17	Africa		2005	0.946151

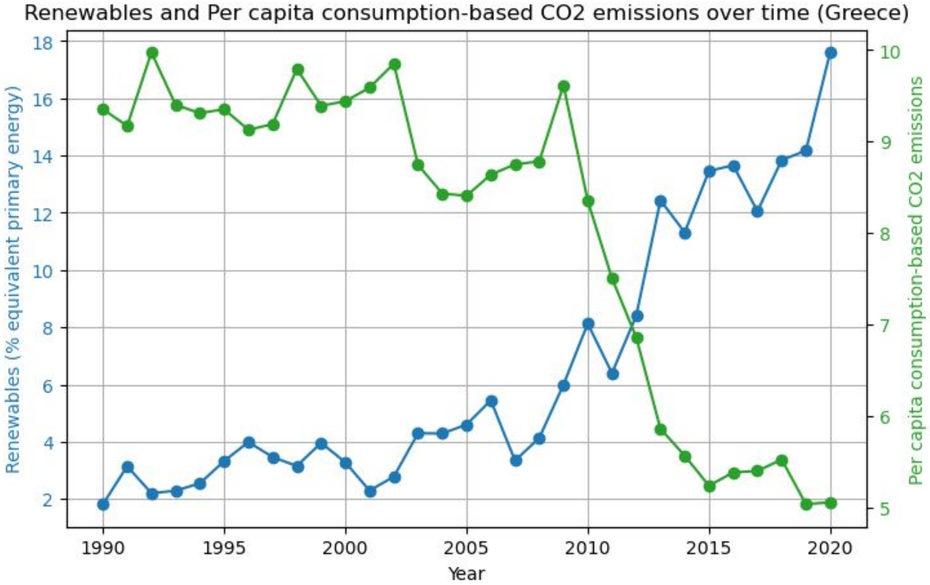
Therefore 1990 - 2020 was chosen with regions that had all the data in CO2 and renewables for the start year and end year

Only leaving 59 national countries in the result

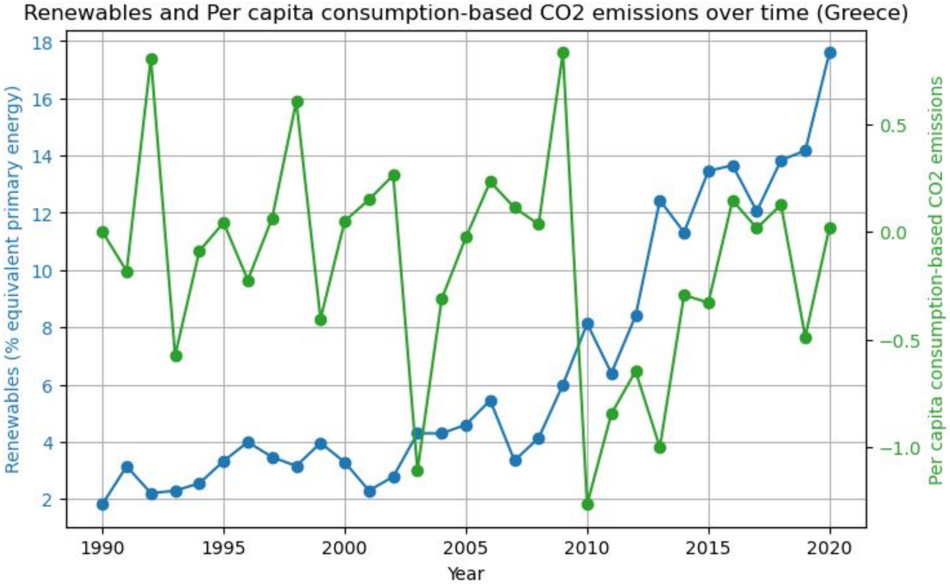
Missing data in the middle interpolated linearly

Processing of data: to detrend or not?

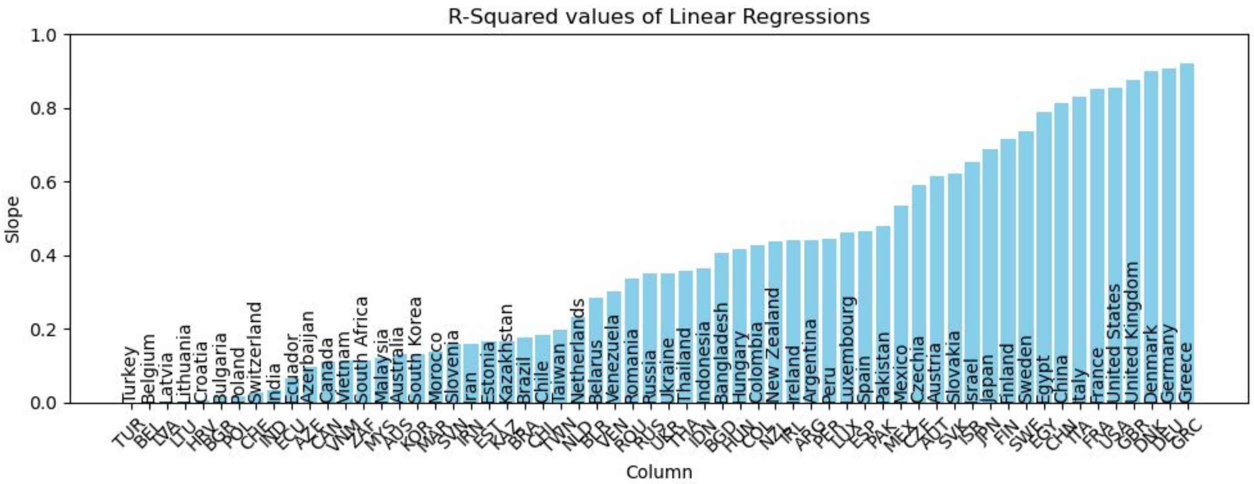
Not detrended



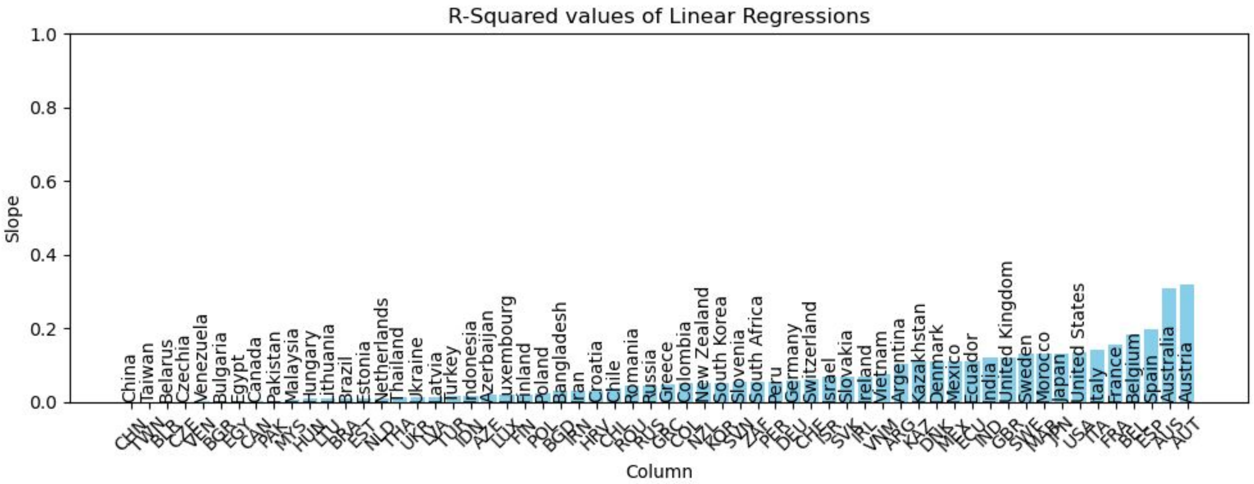
Detrended by differencing



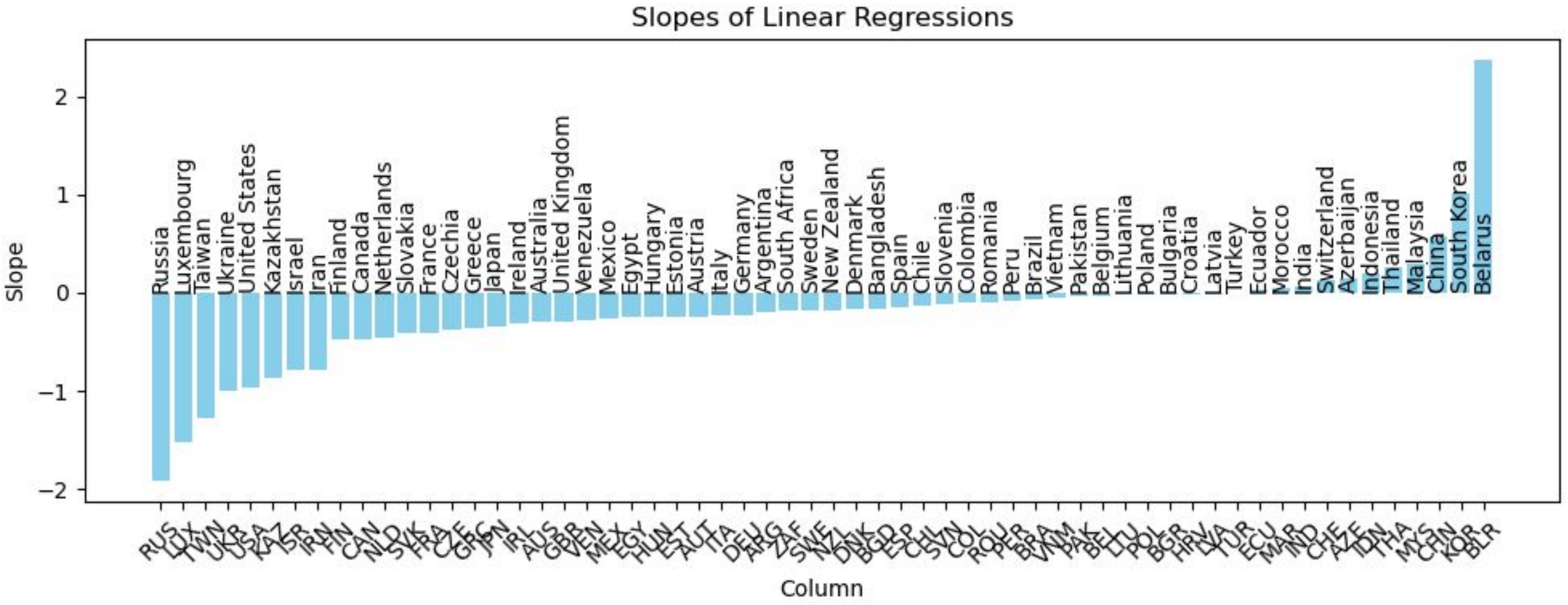
Not detrended

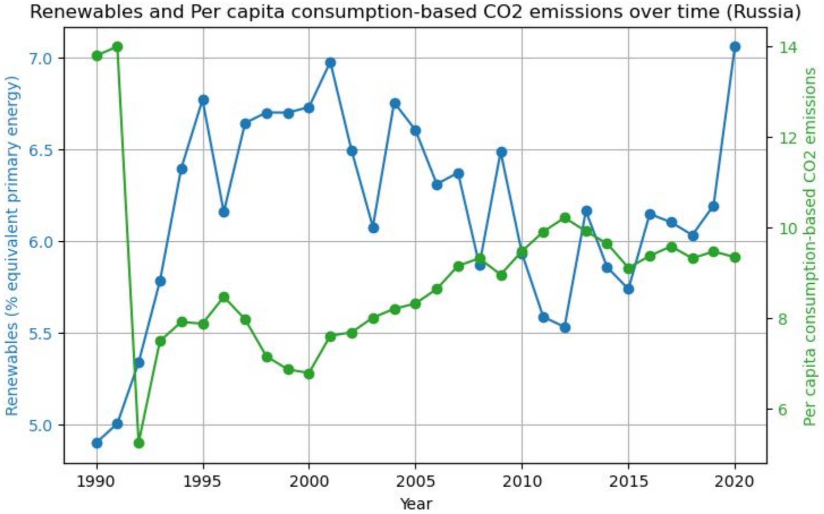


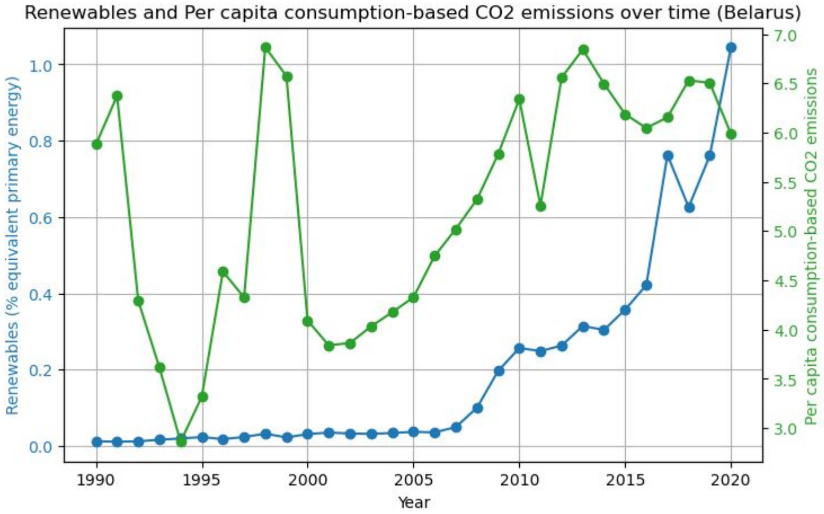
Detrended by differencing

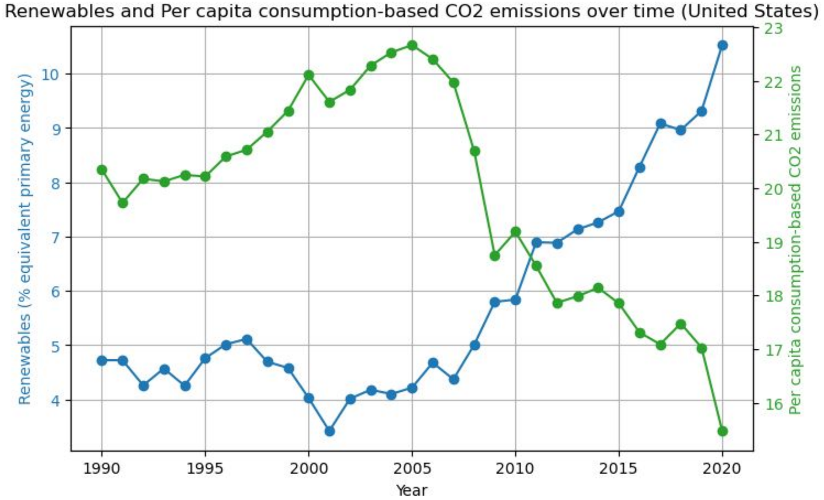


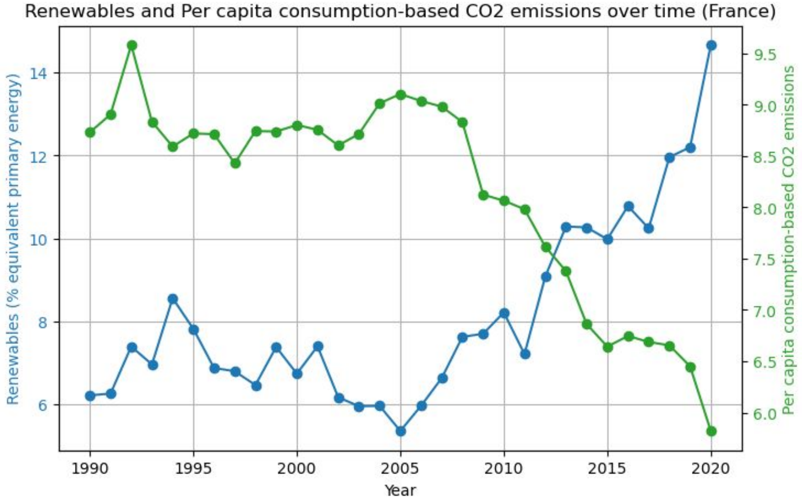
For most countries renewable energy adoption correlates negatively with changes in national carbon emissions

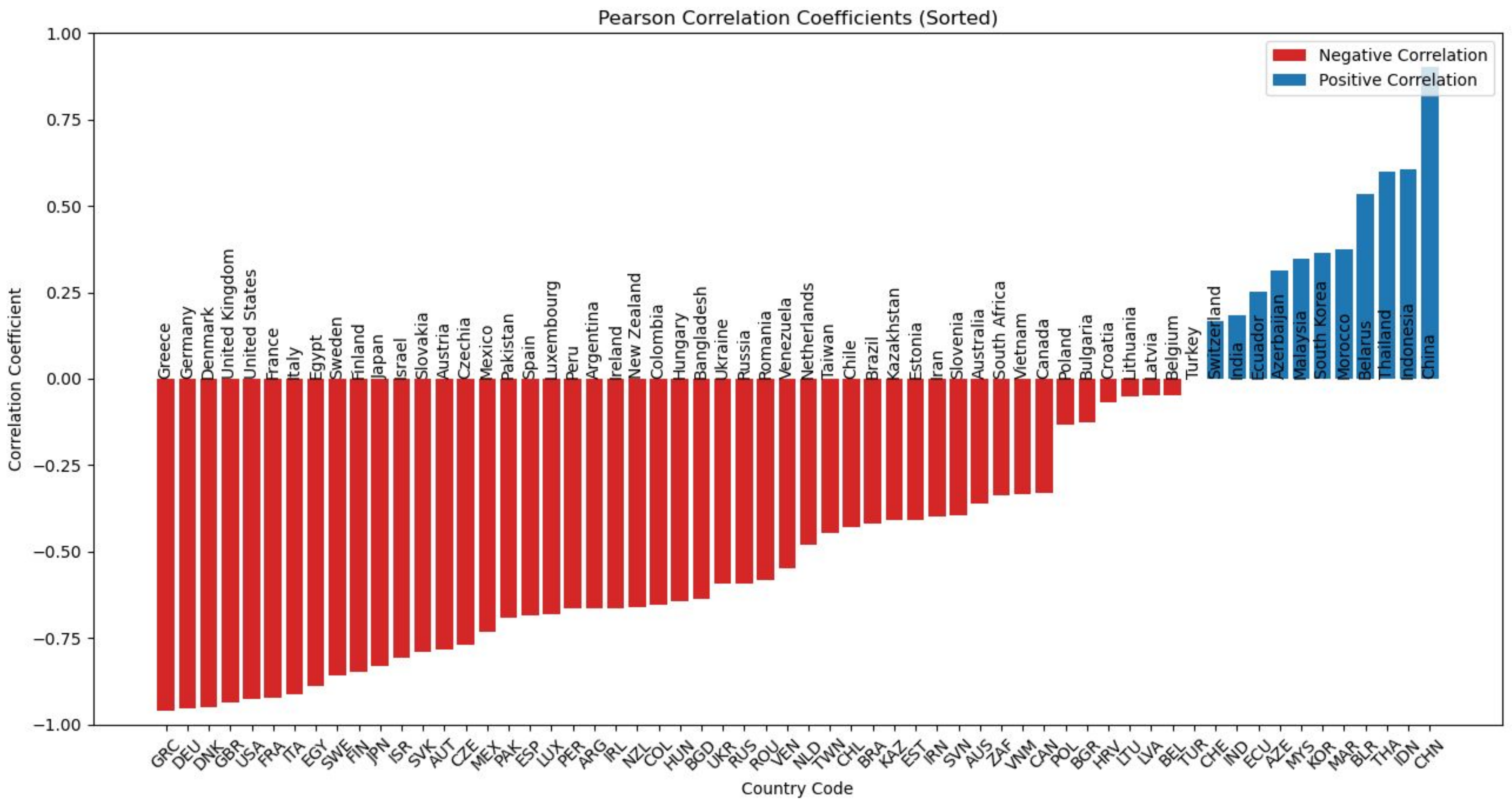



Renewables and Per capita consumption-based CO2 emissions over time (Russia)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
5.0
5.5
6.0
6.5
7.0
6
8
10
12
14
1990
1995
2000
2005
2010
2015
2020

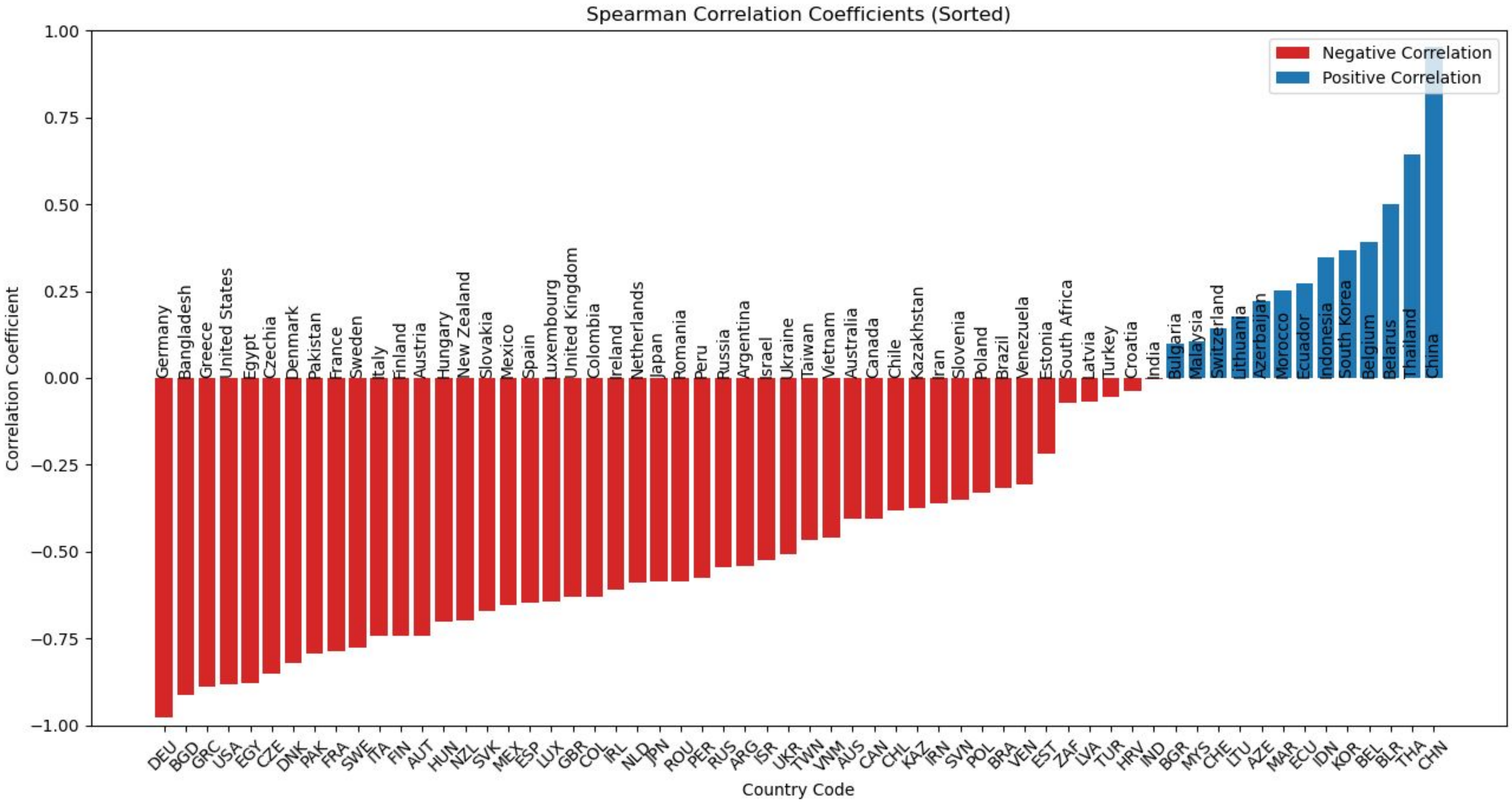

Renewables and Per capita consumption-based CO2 emissions over time (Belarus)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
0.0
0.2
0.4
0.6
0.8
1.0
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
1990
1995
2000
2005
2010
2015
2020


Renewables and Per capita consumption-based CO2 emissions over time (United States)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
4
5
6
7
8
9
10
16
17
18
19
20
21
22
23
1990
1995
2000
2005
2010
2015
2020

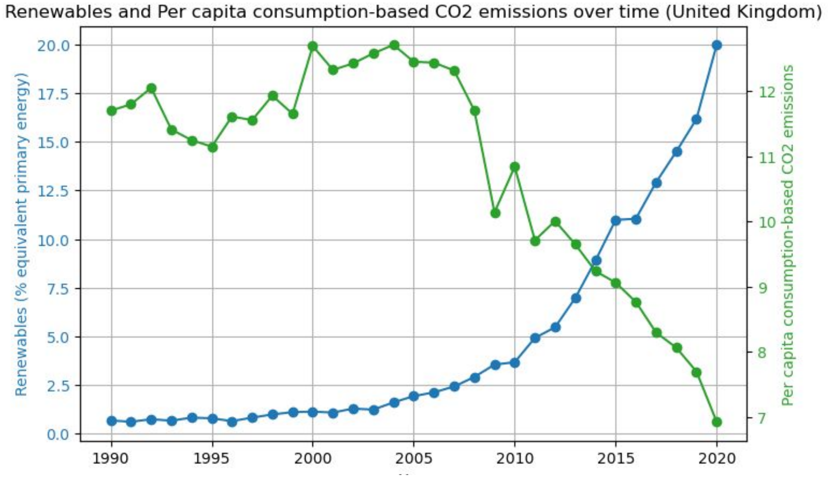

Renewables and Per capita consumption-based CO2 emissions over time (France)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
6
8
10
12
14
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
1990
1995
2000
2005
2010
2015
2020

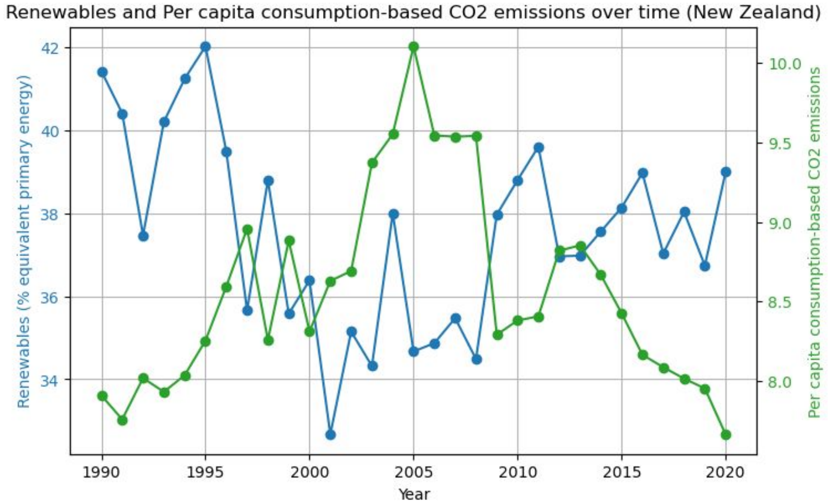


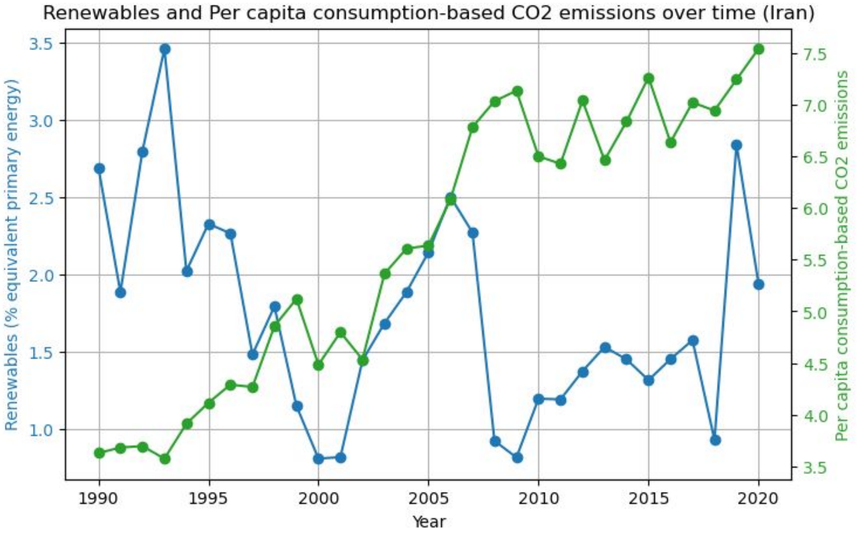
Pearson Correlation Coefficients (Sorted)
Negative Correlation
Positive Correlation
Correlation Coefficient
Country Code
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Greece
Germany
Denmark
United Kingdom
United States
France
Italy
Egypt
Sweden
Finland
Japan
Israel
Slovakia
Austria
Czechia
Mexico
Pakistan
Spain
Luxembourg
Peru
Argentina
Ireland
New Zealand
Colombia
Hungary
Bangladesh
Ukraine
Russia
Romania
Venezuela
Netherlands
Taiwan
Chile
Brazil
Kazakhstan
Estonia
Iran
Slovenia
Australia
South Africa
Vietnam
Canada
Poland
Bulgaria
Croatia
Lithuania
Latvia
Belgium
Turkey
Switzerland
India
Ecuador
Azerbaijan
Malaysia
South Korea
Morocco
Belarus
Thailand
Indonesia
China
GRC
DEU
DNK
GBR
USA
FRA
ITA
EGY
SWE
FIN
JPN
ISR
SVK
AUT
CZE
MEX
PAK
ESP
LUX
PER
ARG
IRL
NZL
COL
HUN
BGD
UKR
RUS
ROU
VEN
NLD
TWN
CHL
BRA
KAZ
EST
IRN
SVN
AUS
ZAF
VNM
CAN
POL
BGR
HRV
LTU
LVA
BEL
TUR
CHE
IND
ECU
AZE
MYS
KOR
MAR
BLR
THA
IDN
CHN

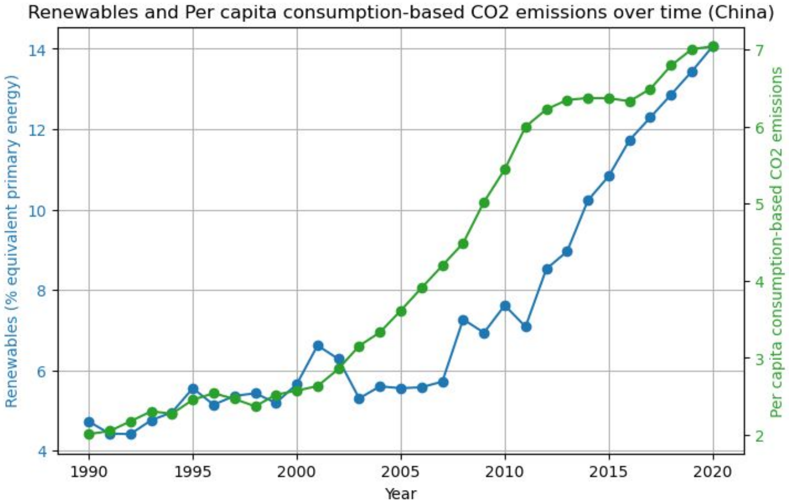


Spearman Correlation Coefficients (Sorted)
Negative Correlation
Positive Correlation
Correlation Coefficient
Country Code
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00
Germany Bangladesh Greece United States Egypt Czechia Denmark Pakistan France Sweden Italy Finland Austria Hungary New Zealand Slovakia Mexico Spain Luxembourg United Kingdom Colombia Ireland Netherlands Japan Romania Peru Russia Argentina Israel Ukraine Taiwan Vietnam Australia Canada Chile Kazakhstan Iran Slovenia Poland Brazil Venezuela Estonia South Africa Latvia Turkey Croatia India Bulgaria Malaysia Switzerland Lithuania Azerbaijan Morocco Ecuador Indonesia South Korea Belgium Belarus Thailand China
DEU BGD GRC USA EGY CZE DNK PAK FRA SWE ITA FIN AUT HUN NZL SVK MEX ESP LUX GBR COL IRL NLD JPN ROU PER RUS ARG ISR UKR TWN VNM AUS CAN CHL KAZ IRN SVN POL BRA VEN EST ZAF LVA TUR HRV IND BGR MYS CHE LTU AZE MAR ECU IDN KOR BEL BLR THA CHN


Renewables and Per capita consumption-based CO2 emissions over time (United Kingdom)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
7
8
9
10
11
12
1990
1995
2000
2005
2010
2015
2020


Renewables and Per capita consumption-based CO2 emissions over time (New Zealand)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
34
36
38
40
42
8.0
8.5
9.0
9.5
10.0
1990
1995
2000
2005
2010
2015
2020


Renewables and Per capita consumption-based CO2 emissions over time (Iran)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
1.0
1.5
2.0
2.5
3.0
3.5
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
1990
1995
2000
2005
2010
2015
2020


Renewables and Per capita consumption-based CO2 emissions over time (China)
Renewables (% equivalent primary energy)
Per capita consumption-based CO2 emissions
Year
4
6
8
10
12
14
2
3
4
5
6
7
1990
1995
2000
2005
2010
2015
2020

Countries with fast economic growth

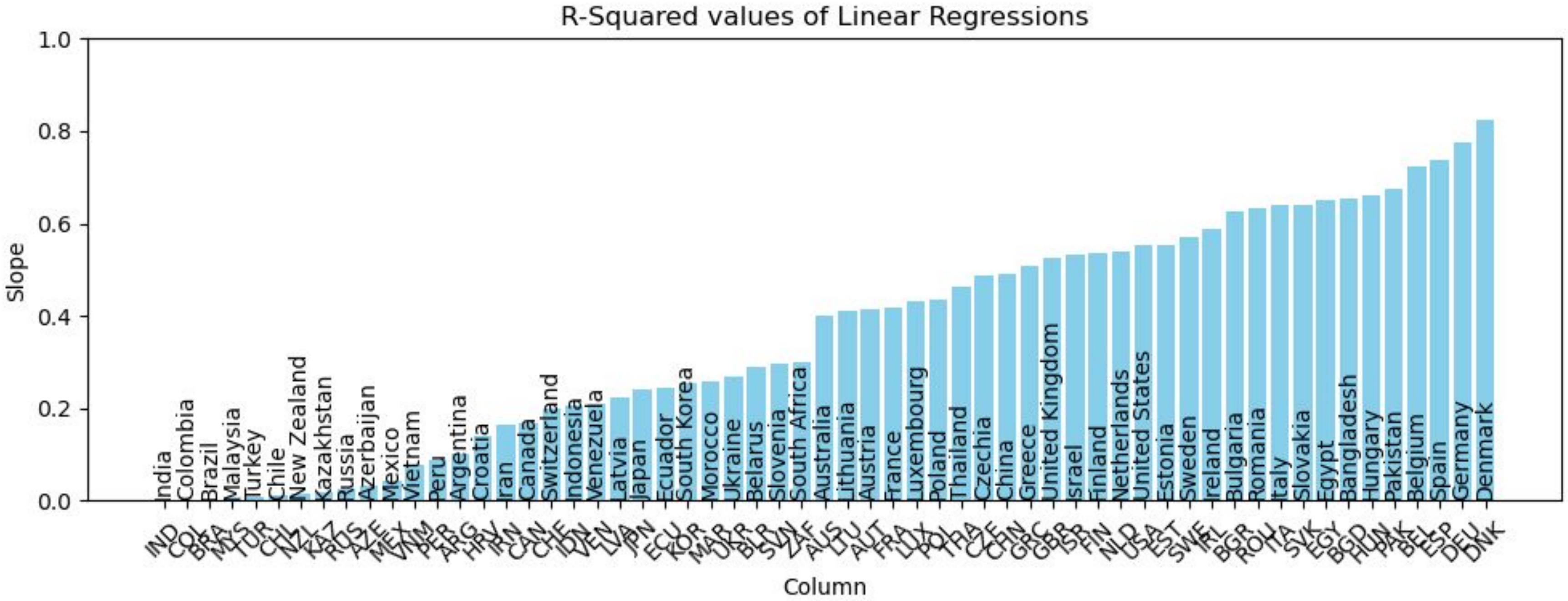
Many asian countries such as China, Indonesia and others with positive correlation

In theory higher GDP leads to higher CO2 output from consumption

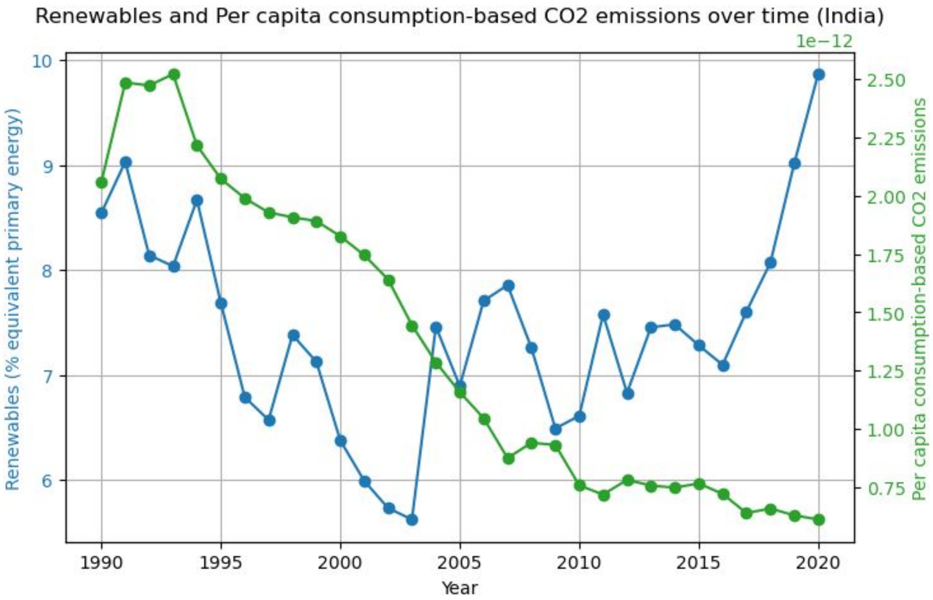
Economic growth —> CO2 output increase even with renewable energy investment

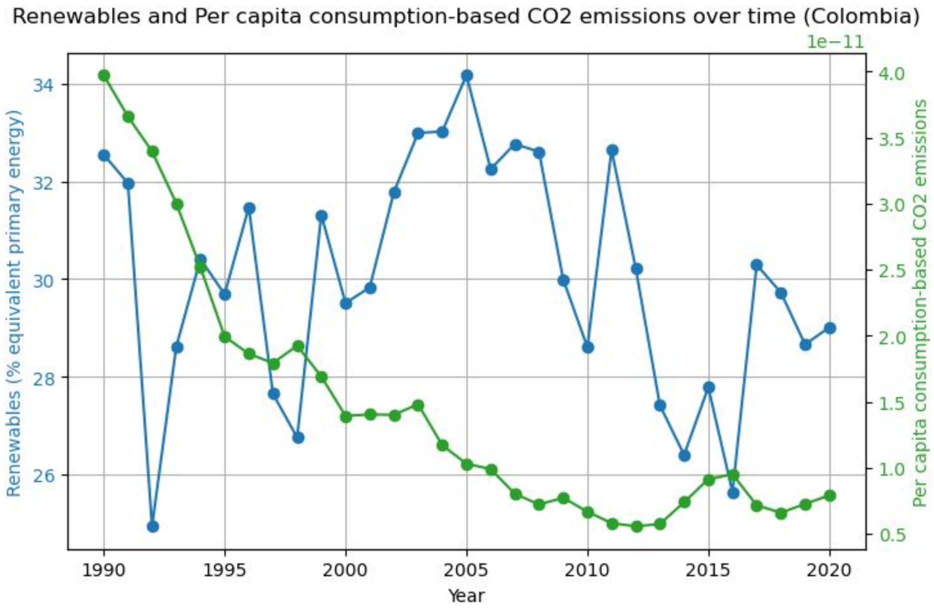
Thus CO2 data is adjusted for GDP (CO2 per capita /GDP) = carbon intensity

With GDP adjustment most R^2 values stay similar

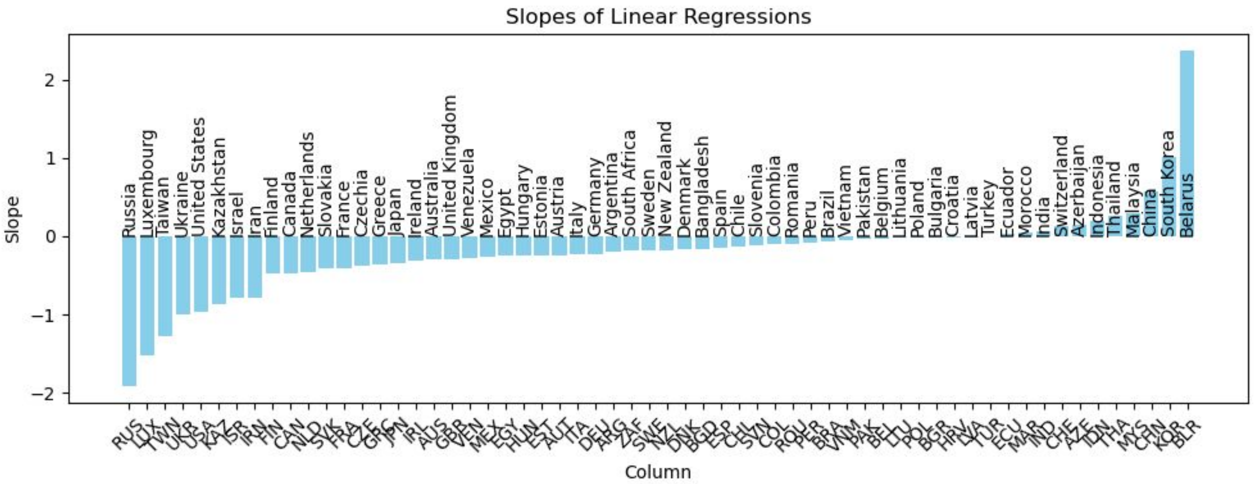


Some countries don’t have a linear correlation due to strange changes in renewables %

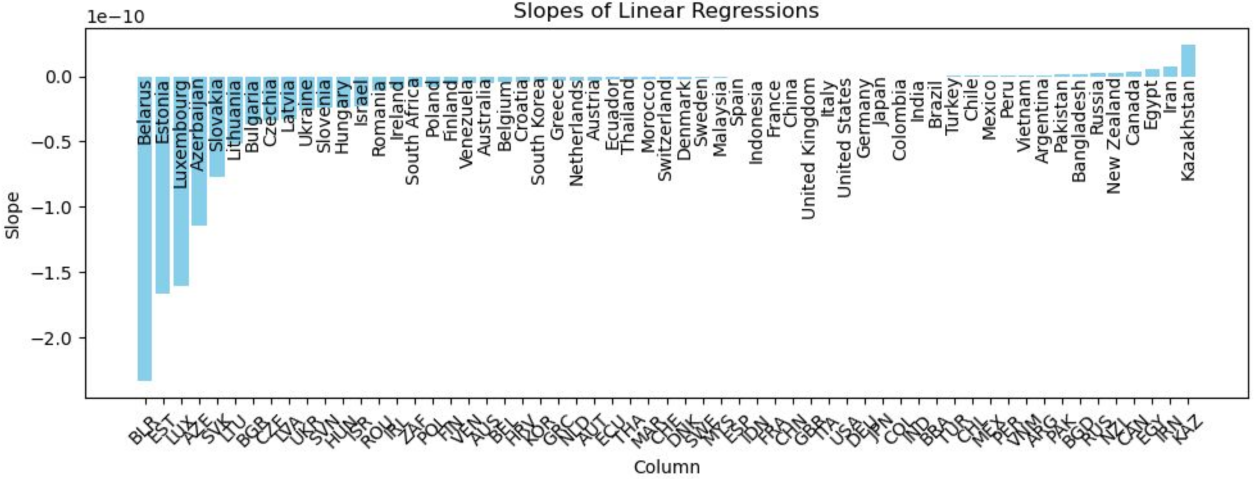




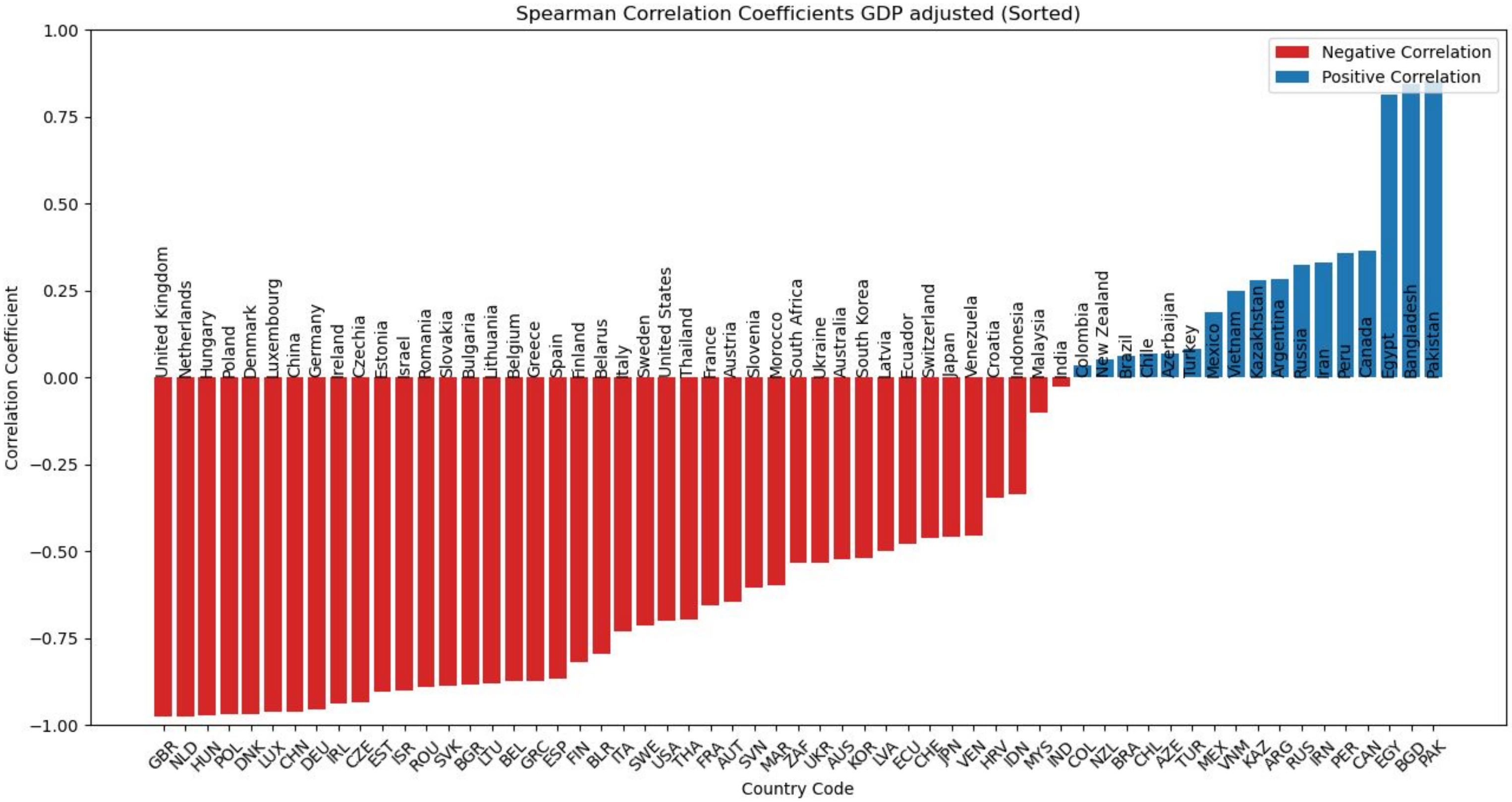
Not adjustment



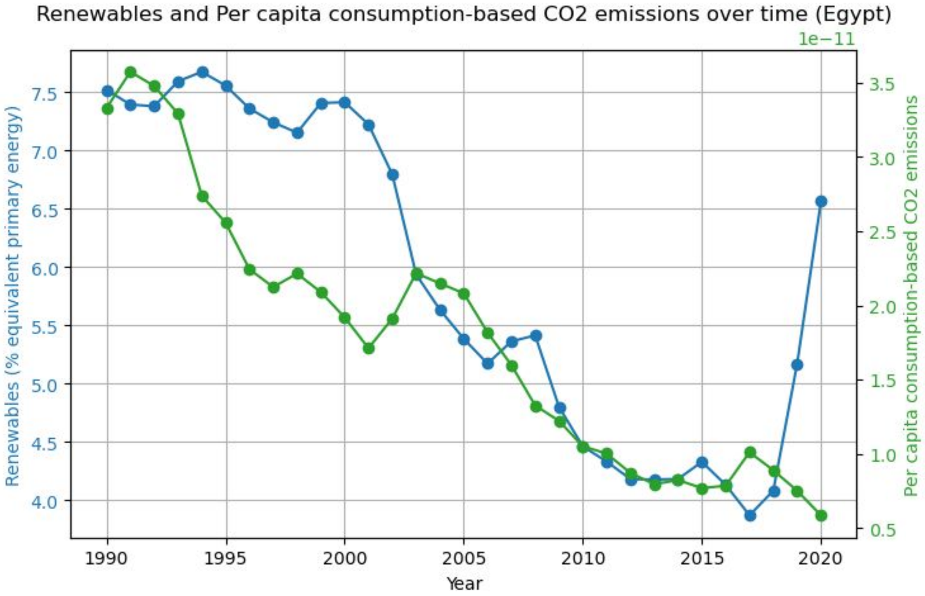
GDP adjustment

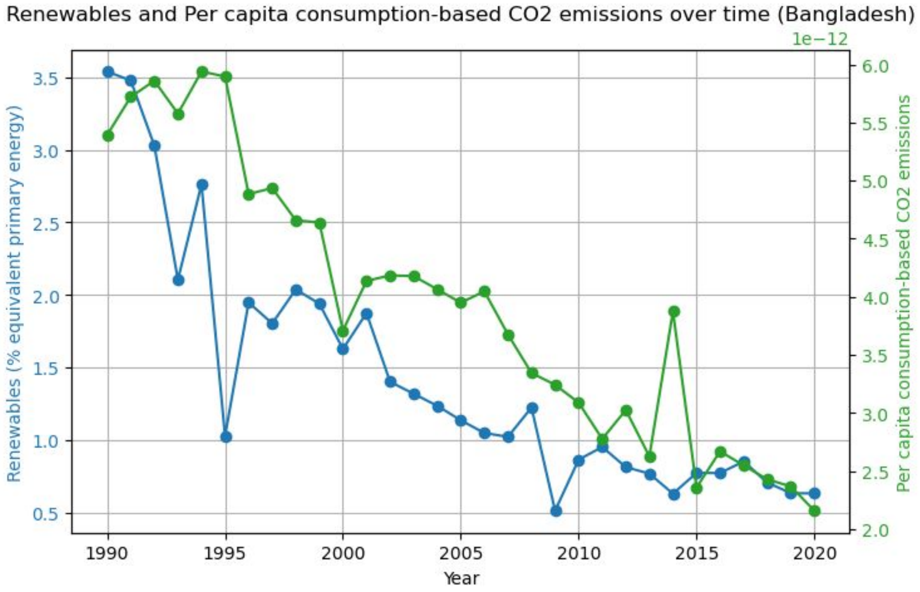


Spearman correlations GDP adjusted

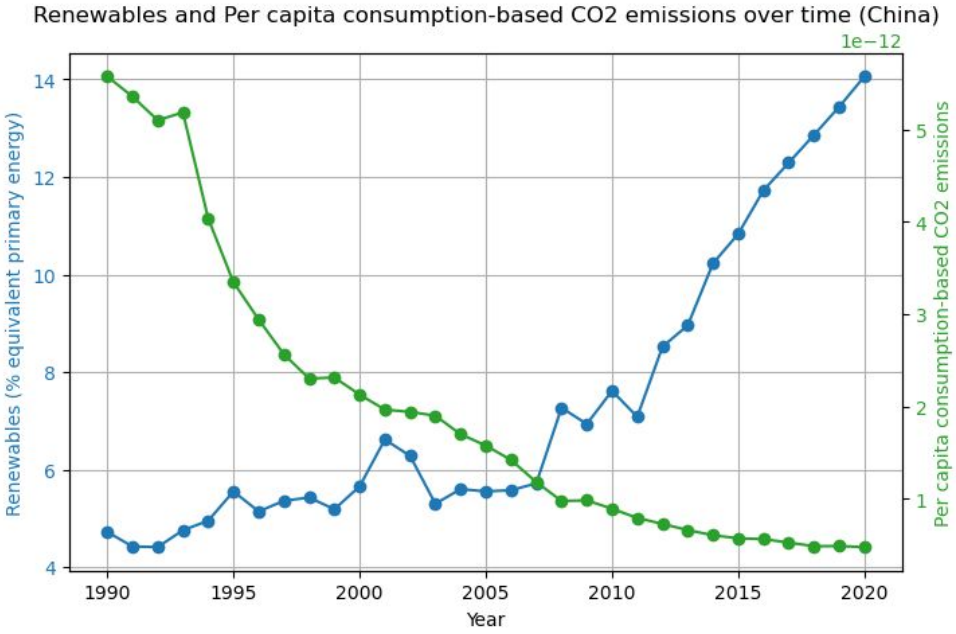


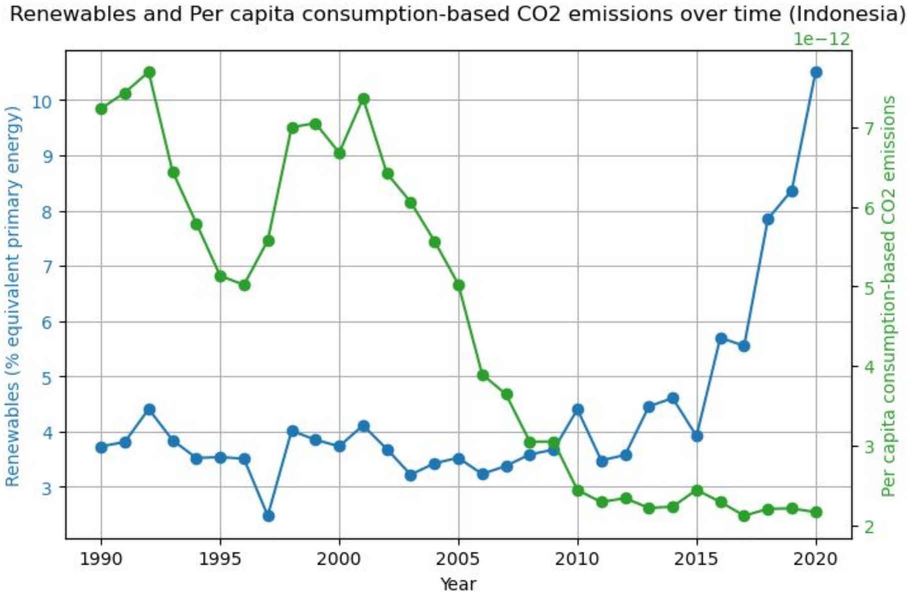
The top 3 positive countries are not a mistake



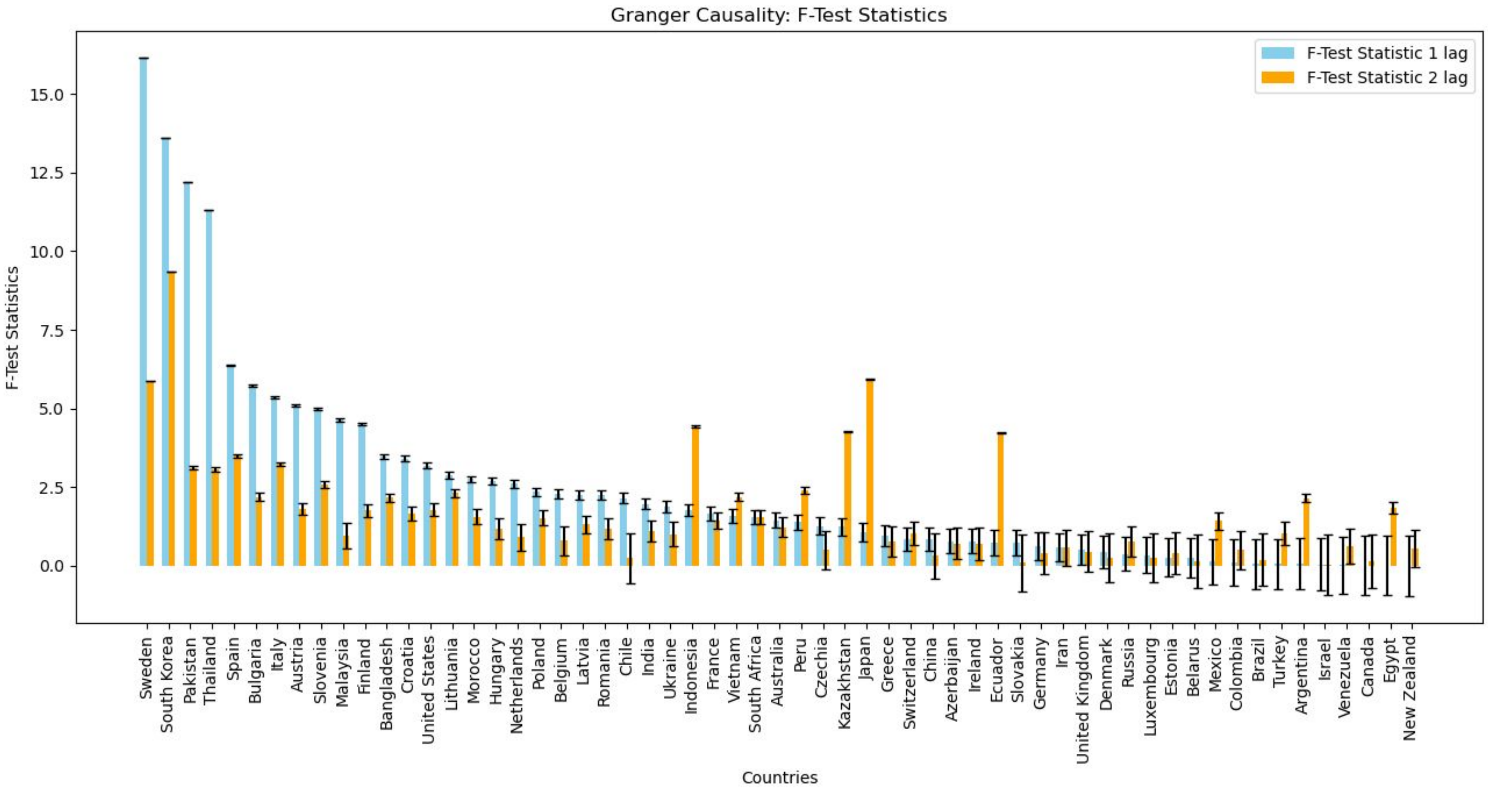


The problem with high growth countries is fixed

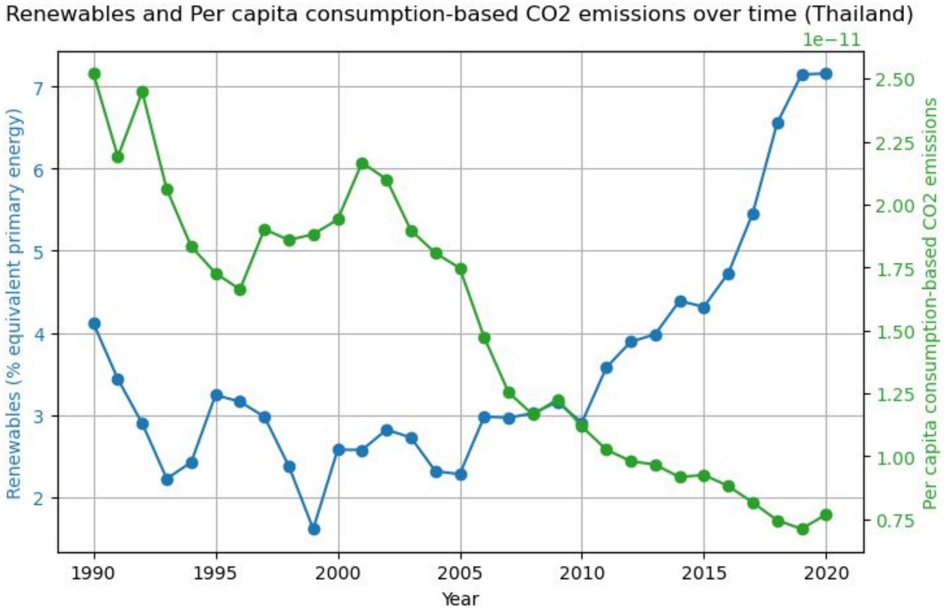


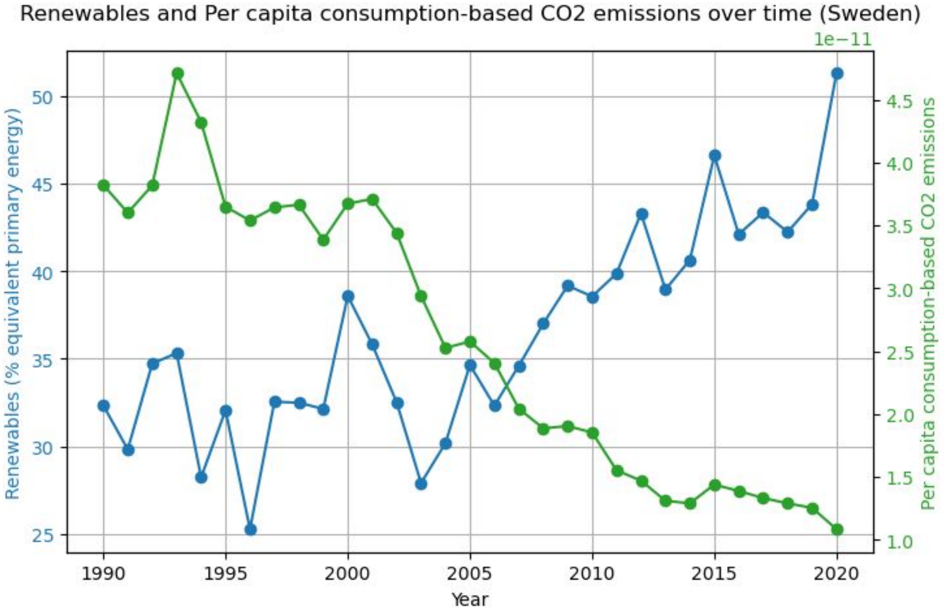


Granger Causality test with GDP adjustment

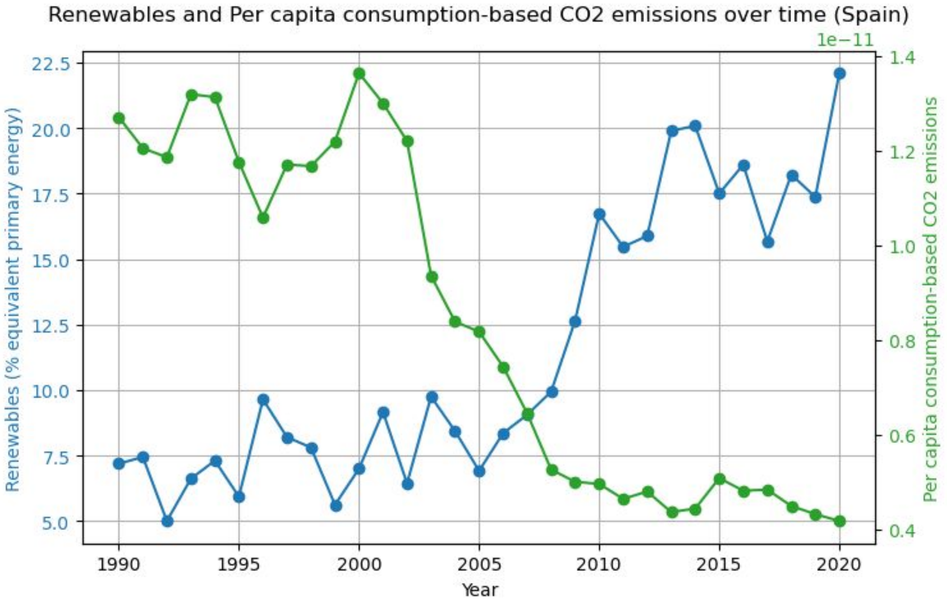


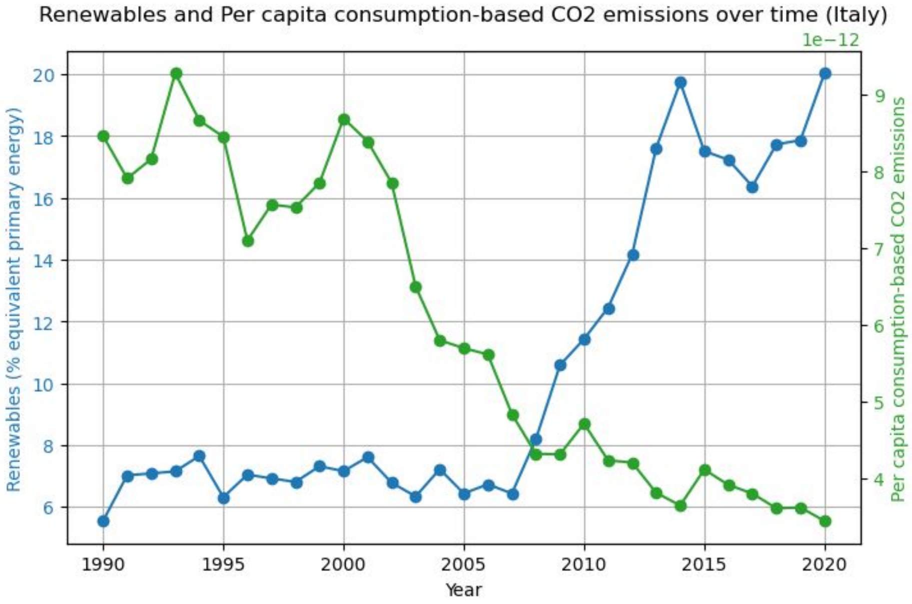
Some of the most predictable countries





Statistically some are predictive, but in reality doubtable





Can we predict future trends in CO2 emissions based on current rates of renewables adoption?

ARIMA was attempted, but it did not produce any impressive results as it produces a simple trend continuation of the increase in renewables and reduction in CO2

National energy policies are make this data unpredictable

The big takeaway

For most countries the renewables % vs GDP adjusted CO_2 the correlation seems to be negative as they go through sustainability changes

Most countries do not have significant causality between renewables % and CO_2

Reported data is reported by national organizations that have their agenda

Countries have different access to renewable energy and different policies on adopting renewables sources

Other things to research

Seeing what other factors could be influencing the CO2 production

End