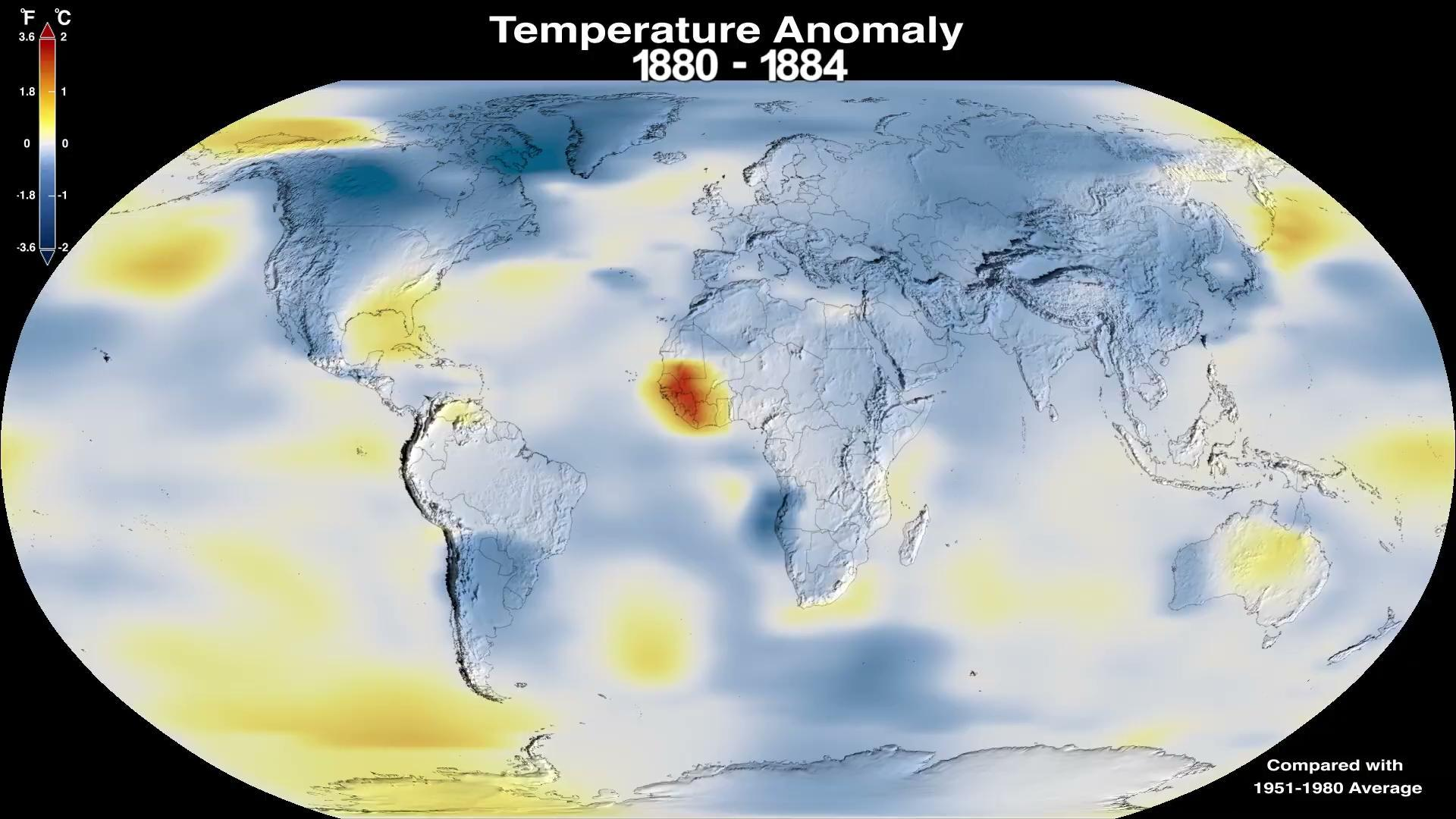
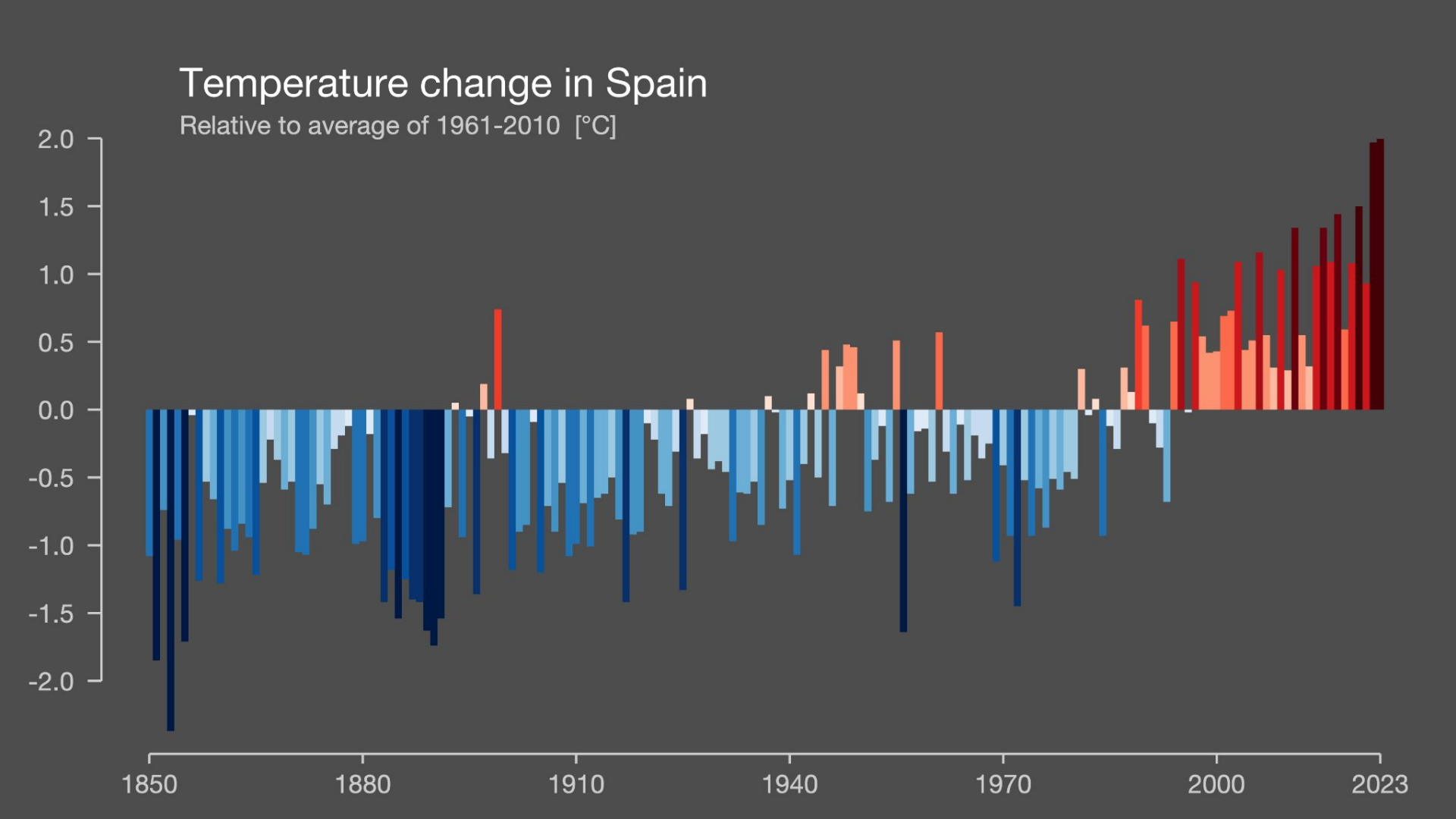
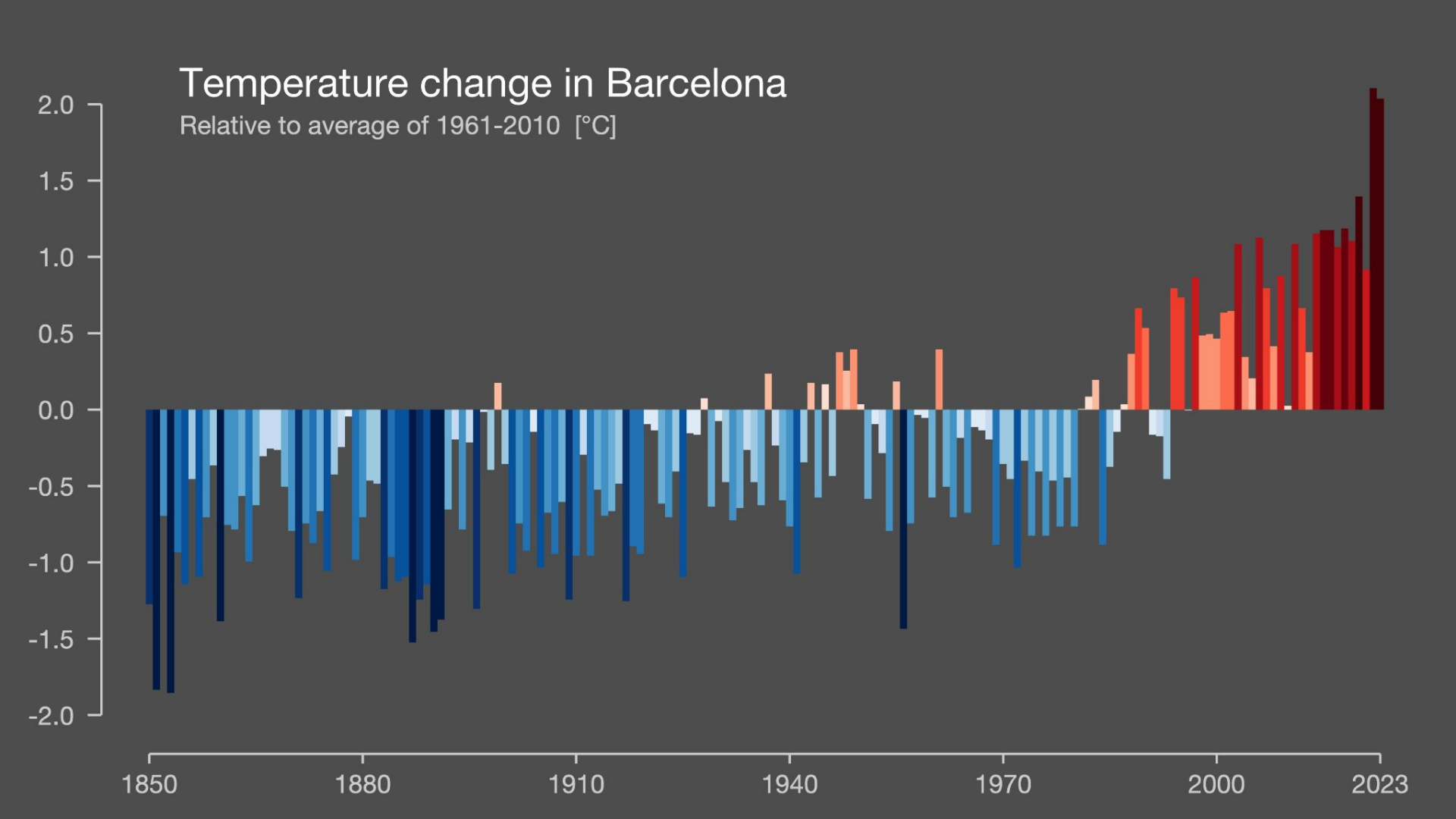
Greenhouse Gases Emissions Reductions through the Development of Renewable Energy Production in Catalonia

Made by Olga Kalugina


Temperature Anomaly
1880 - 1884
°F
°C
3.6
2
1.8
1
0
0
-1.8
-1
-3.6
-2
Compared with
1951-1980 Average


Temperature change in Spain
Relative to average of 1961-2010 [°C]
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1850
1880
1910
1940
1970
2000
2023


Temperature change in Barcelona
Relative to average of 1961-2010 [°C]
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
1850
1880
1910
1940
1970
2000
2023

What are climate change consequences for Spain?

- Risks to marine ecosystems

Specimen of orange gorgonian (Leptogorgia sarmentosa) in the waters of Barcelona / Susi Navarro

What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems

Parques Naturales de Cataluña – Delta del Ebro / Dreamstime.com

What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems
- Inland flooding

Guadiamar River, as it passes through Gerena (Sevilla) and on its way to Doñana Park, November 4, 2024 / Fermín Cabanillas

What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems
- Inland flooding
- Coastal sea-level rise

The damage on the promenade of Fenals beach in Lloret de Mar, spring 2024 / Lloret de Mar City Council

What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems
- Inland flooding
- Coastal sea-level rise
- Risks to human health

DANA, Valencia / Clarin.com

What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems
- Inland flooding
- Coastal sea-level rise
- Risks to human health
- Water scarcity and drought

Effects of drought on the Sau reservoir (Barcelona) / David Ramírez

What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems
- Inland flooding
- Coastal sea-level rise
- Risks to human health
- Water scarcity and drought
- Wildfires

Forest fire in Catalonia, 2020 / Conversesacatalunya.cat

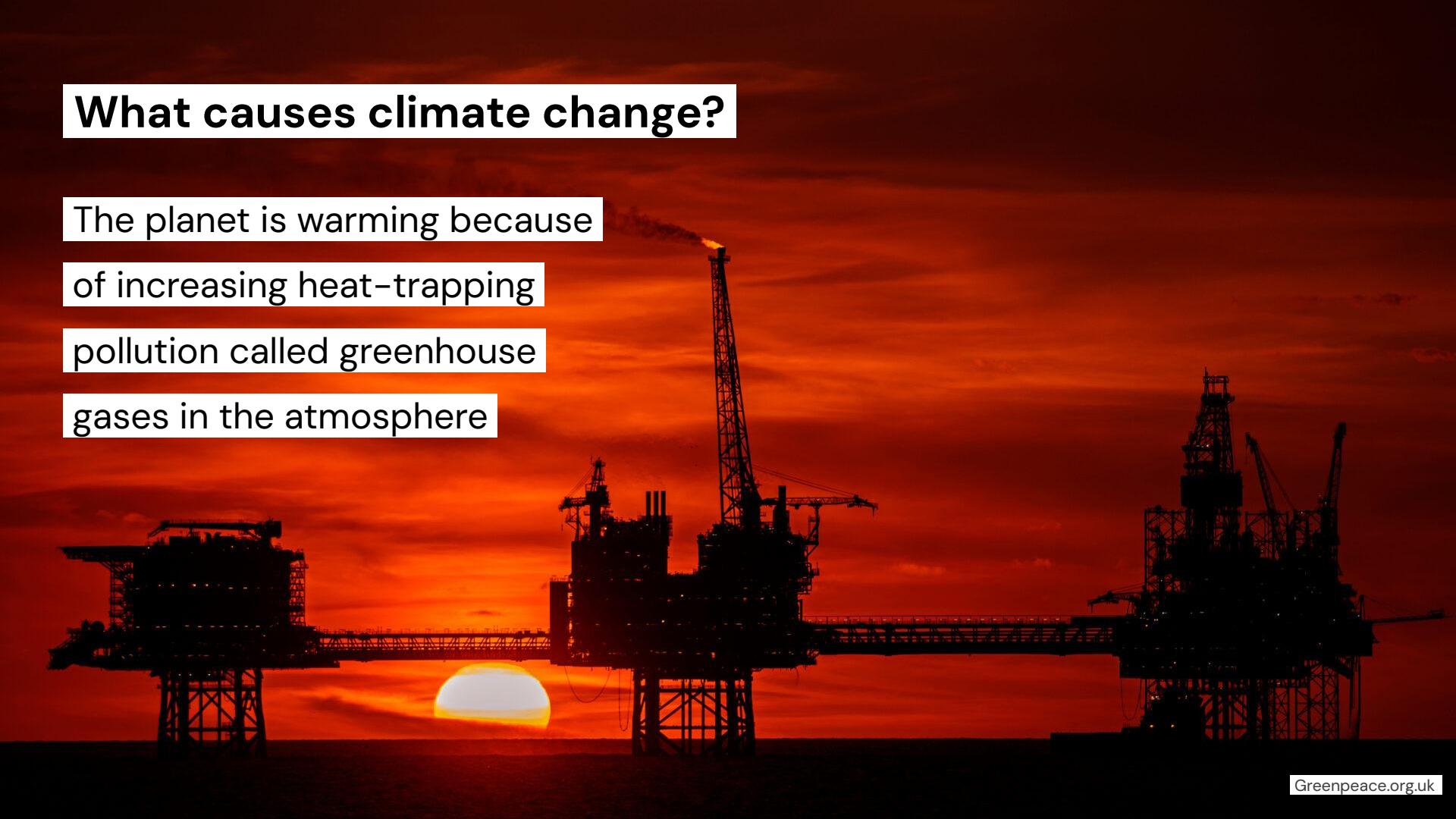
What are climate change consequences for Spain?

- Risks to marine ecosystems
- Risks to terrestrial ecosystems
- Inland flooding
- Coastal sea-level rise
- Risks to human health
- Water scarcity and drought
- Wildfires
- Decreased crop yield

Catalunya / Jarc.cat

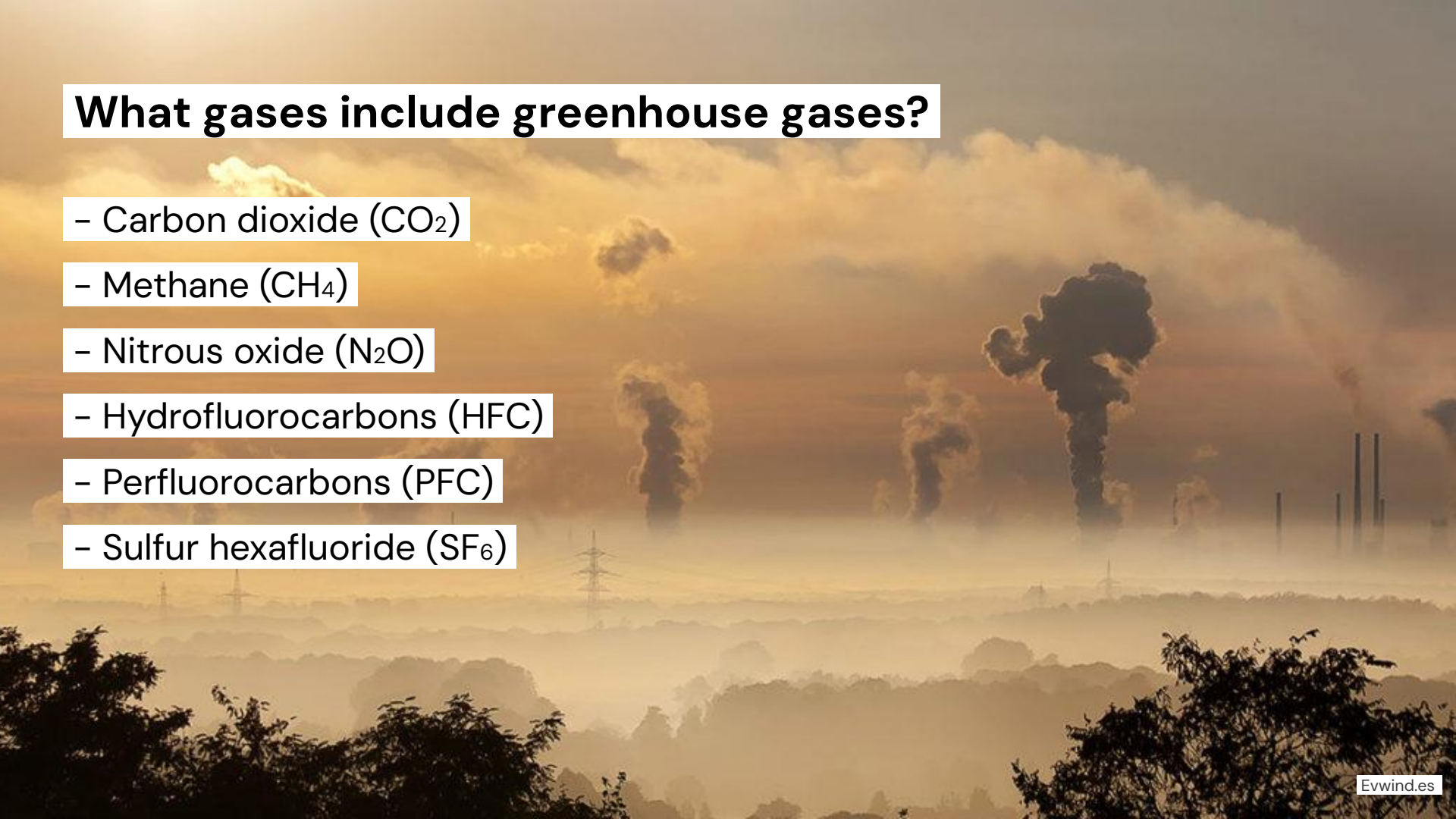
What causes climate change?

The planet is warming because of increasing heat-trapping pollution called greenhouse gases in the atmosphere

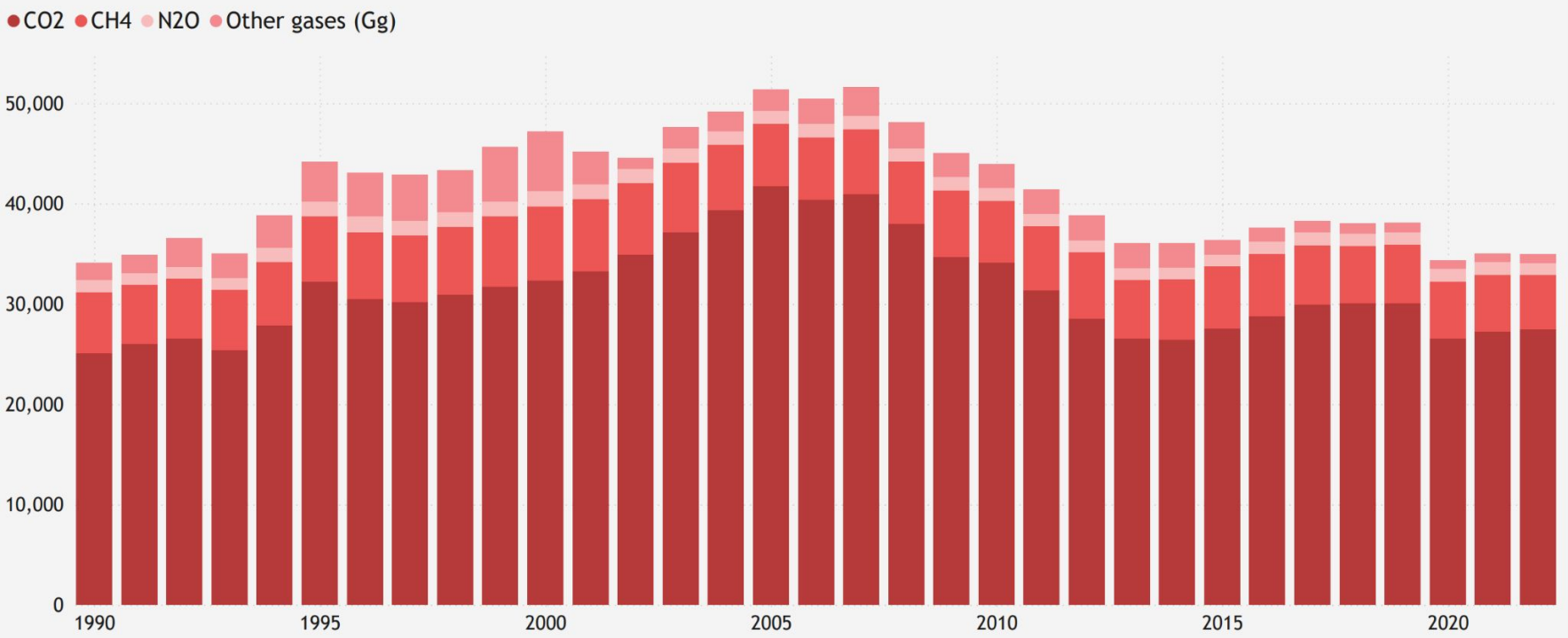


What gases include greenhouse gases?

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFC)
- Perfluorocarbons (PFC)
- Sulfur hexafluoride (SF_6)

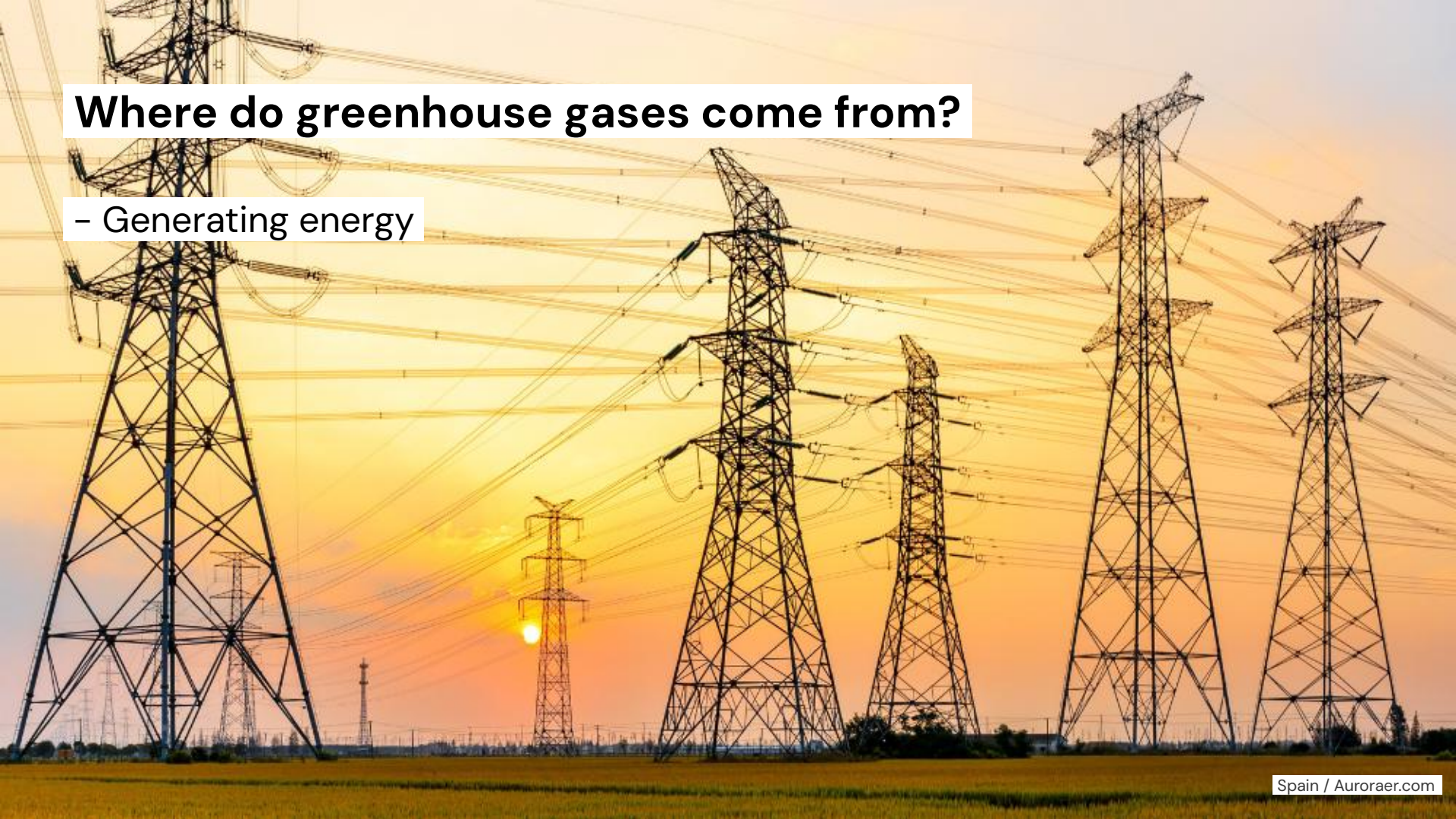


What are greenhouse gases emissions in Catalonia?



Where do greenhouse gases come from?

- Generating energy



Spain / Auroraer.com

Where do greenhouse gases come from?

- Generating energy
- Transport

Where do greenhouse gases come from?

- Generating energy
- Transport
- Animal husbandry

Where do greenhouse gases come from?

- Generating energy
- Transport
- Animal husbandry
- Deforestation

Europarl.europa.eu, Richard Carey

Where do greenhouse gases come from?

- Generating energy
- Transport
- Animal husbandry
- Deforestation
- Powering industry

Oil well, Perm region, Russia / Pstu.ru

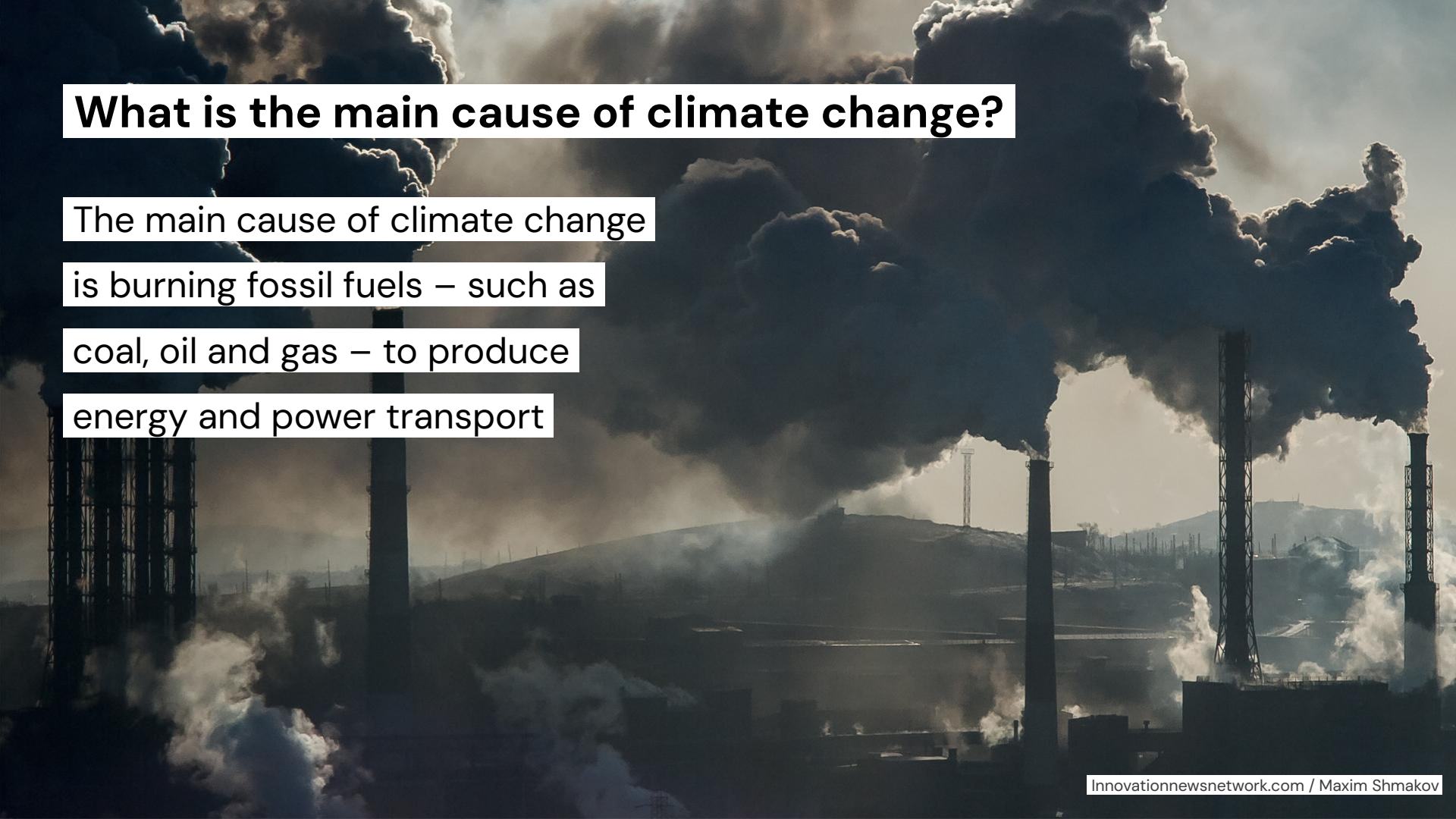
Where do greenhouse gases come from?

- Generating energy
- Transport
- Animal husbandry
- Deforestation
- Powering industry
- Plastics and waste

España / Elperiodico.com

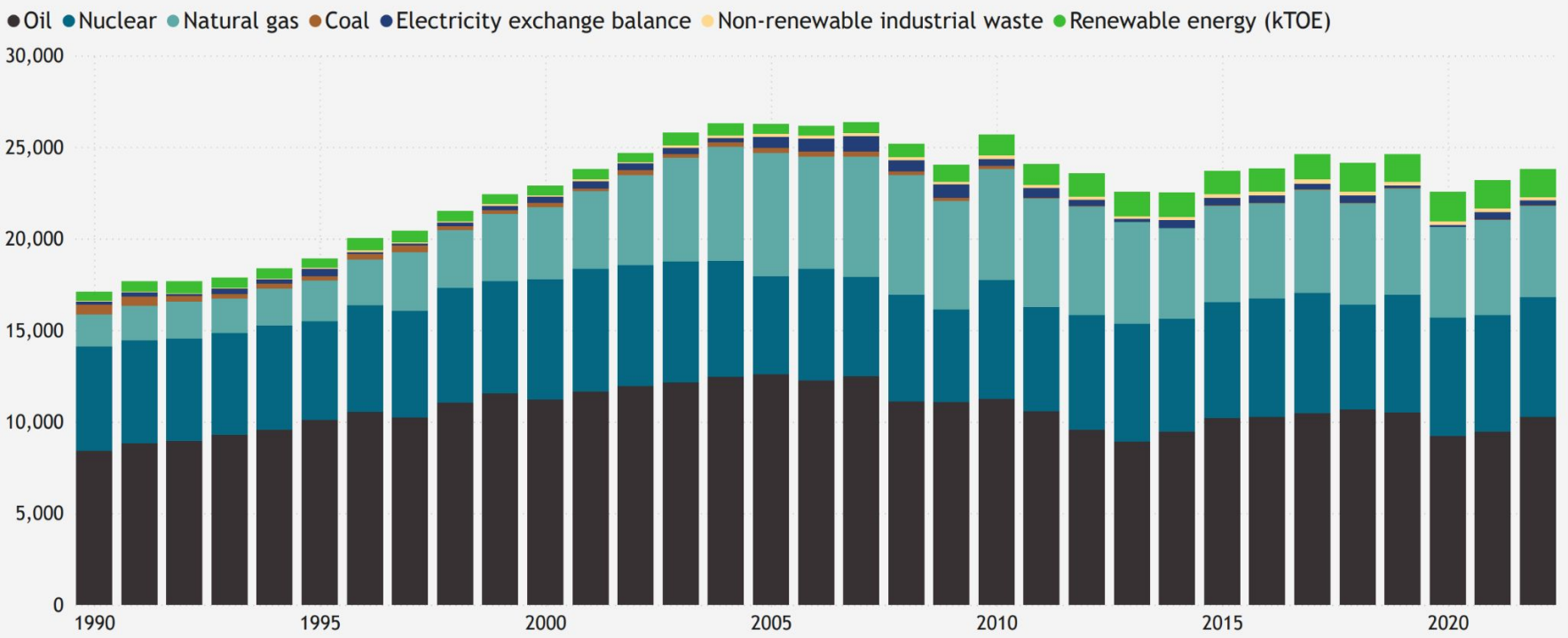
What is the main cause of climate change?

The main cause of climate change is burning fossil fuels – such as coal, oil and gas – to produce energy and power transport



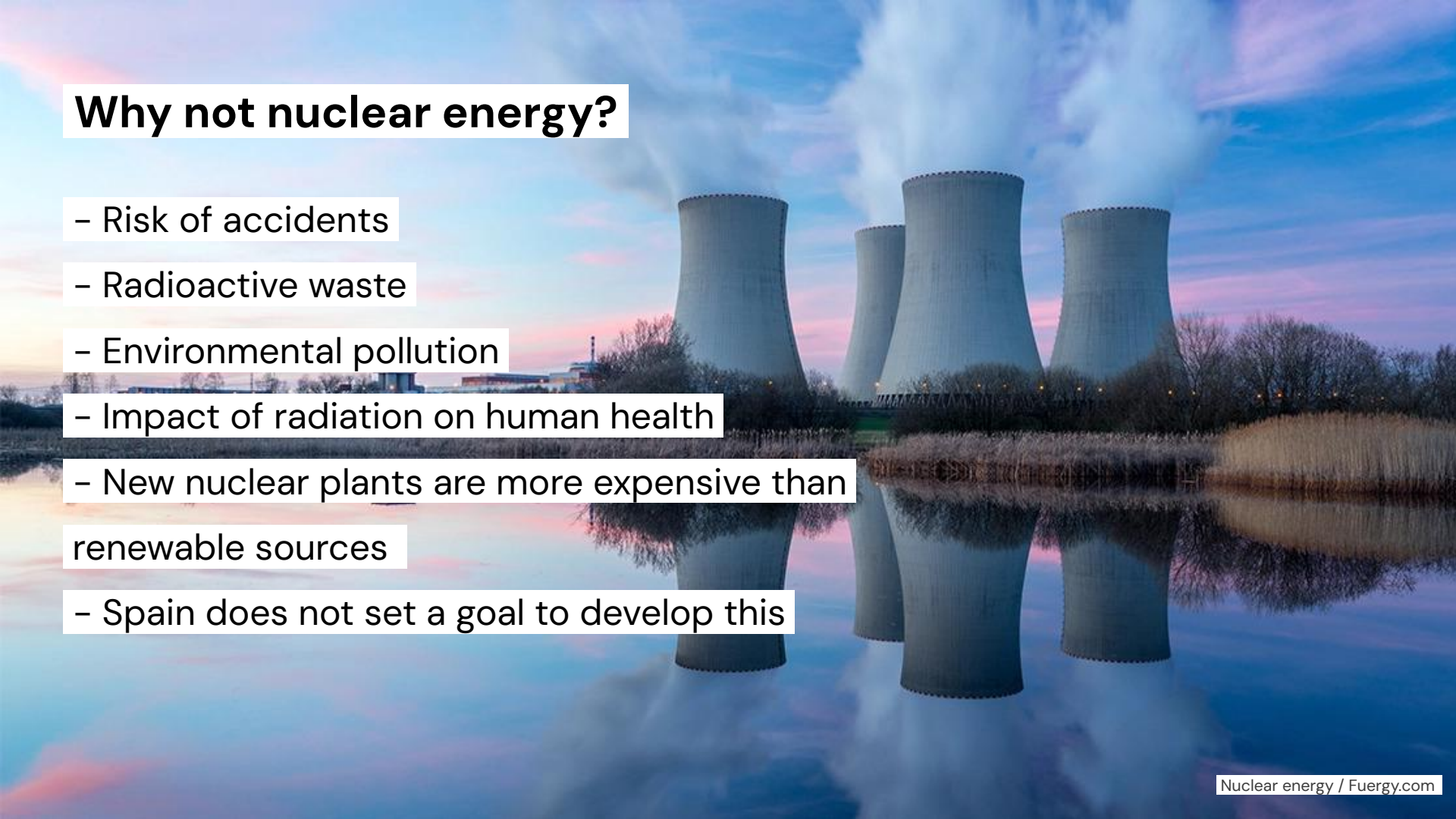
Innovationnewsnetwork.com / Maxim Shmakov

What energy is consumed in Catalonia?



Why not nuclear energy?

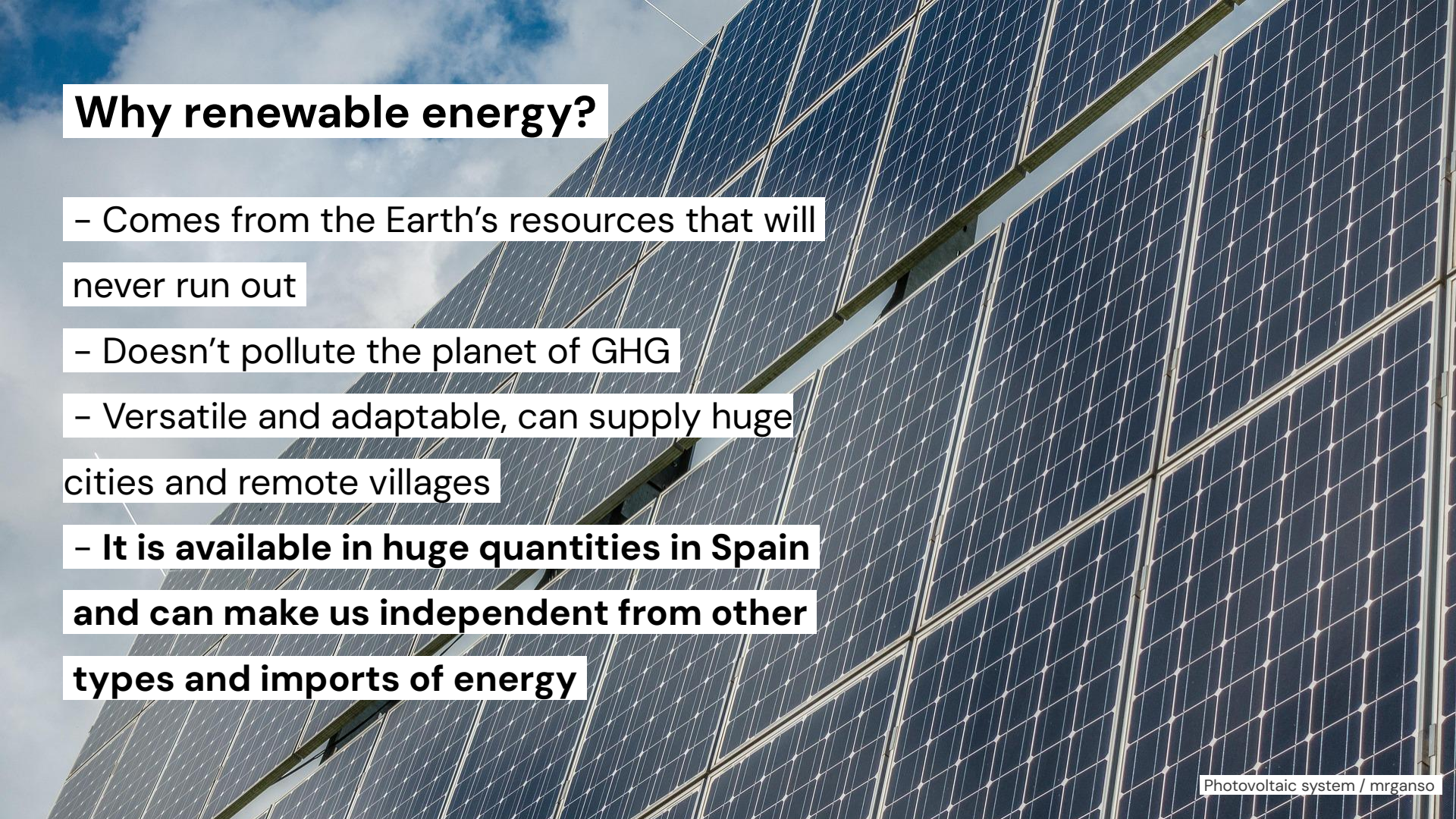
- Risk of accidents
- Radioactive waste
- Environmental pollution
- Impact of radiation on human health
- New nuclear plants are more expensive than renewable sources
- Spain does not set a goal to develop this



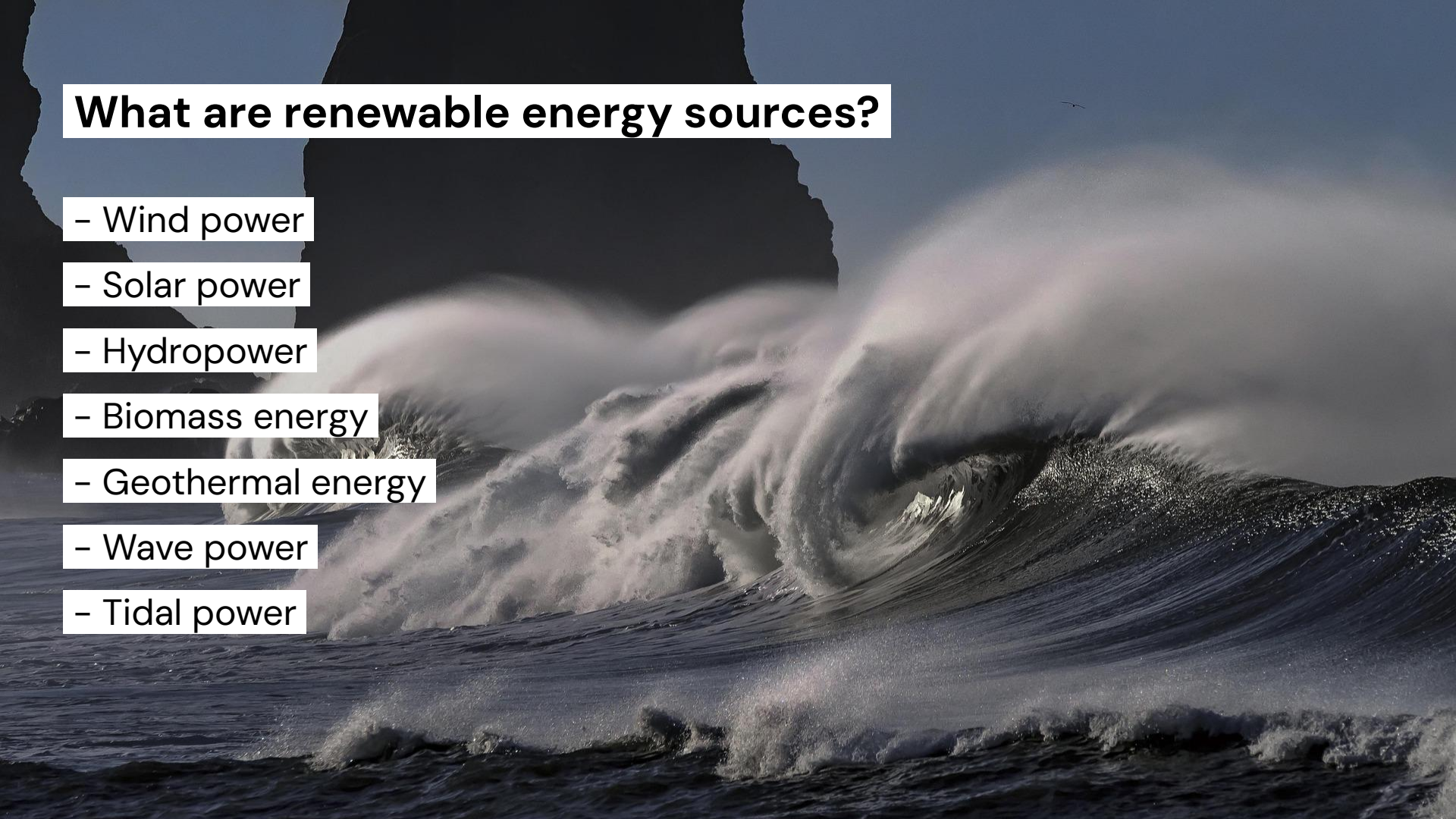
Nuclear energy / Fuergy.com

Why renewable energy?

- Comes from the Earth's resources that will never run out
- Doesn't pollute the planet of GHG
- Versatile and adaptable, can supply huge cities and remote villages
- **It is available in huge quantities in Spain and can make us independent from other types and imports of energy**



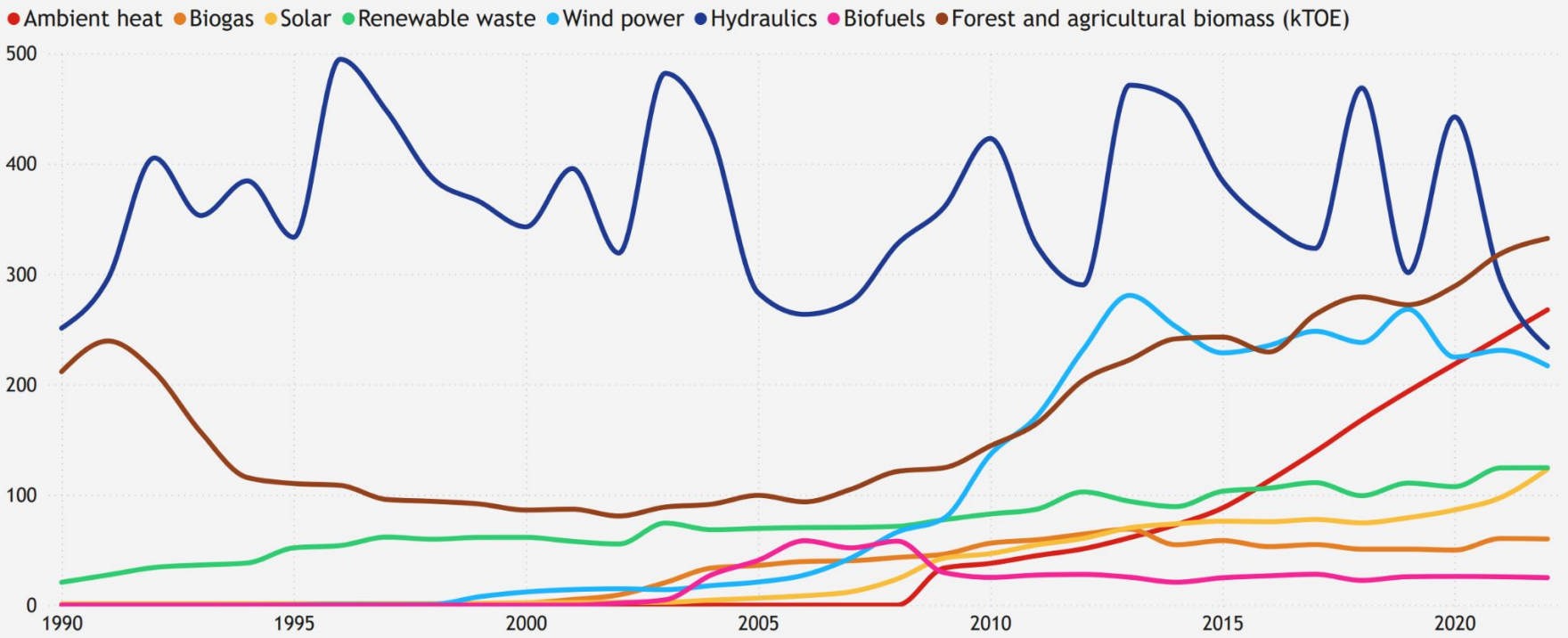
Photovoltaic system / mrganso



What are renewable energy sources?

- Wind power
- Solar power
- Hydropower
- Biomass energy
- Geothermal energy
- Wave power
- Tidal power

What renewable energy do we produce in Catalonia?



What are Spain and Catalonia goals 2050?

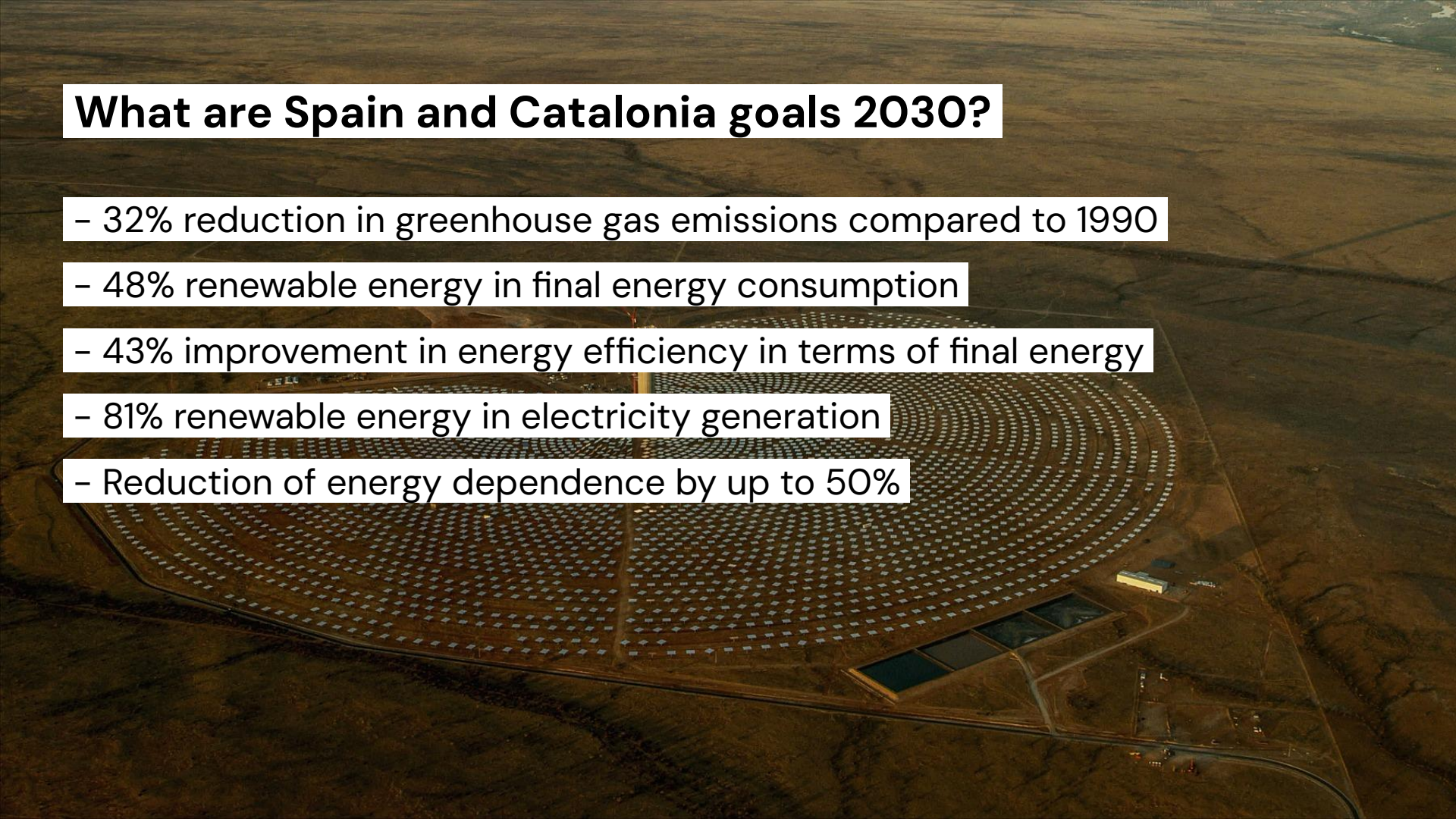
The Goal is 100% renewable energy

to achieve an economic and energy model

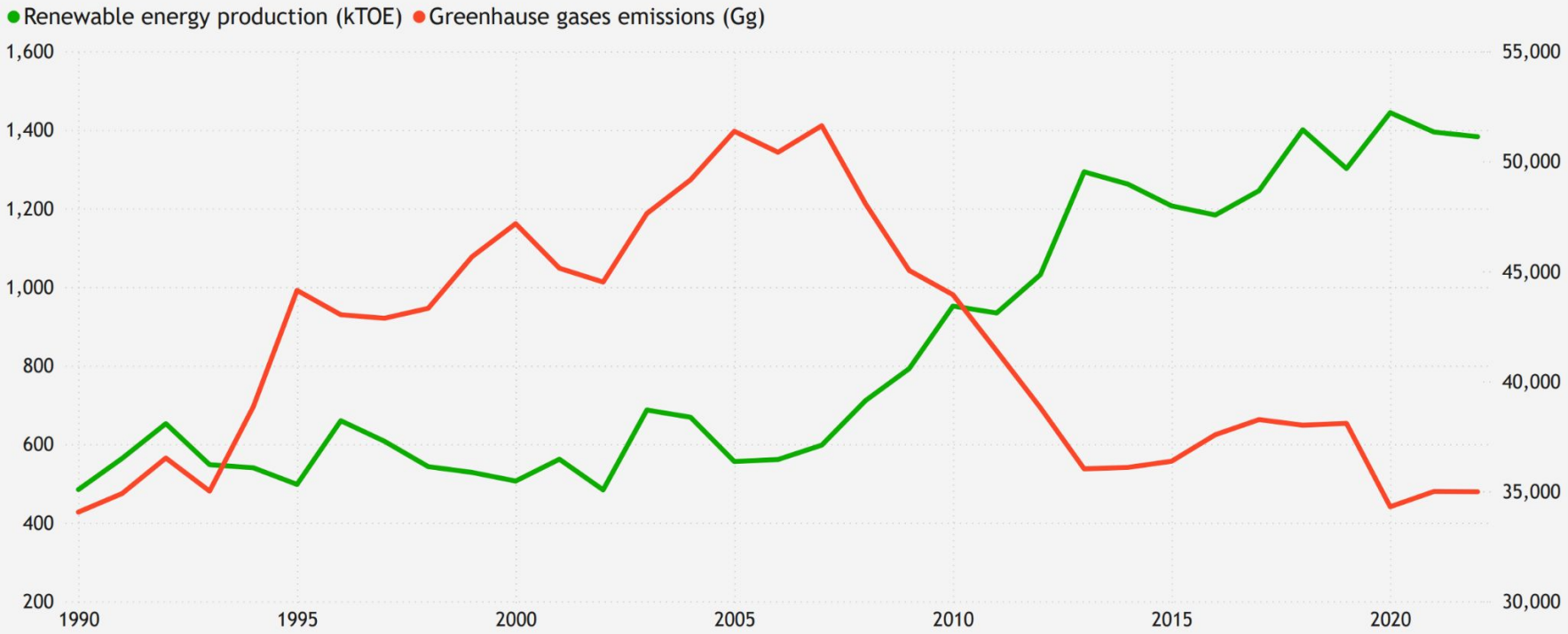
independent of fossil or nuclear fuels by 2050

What are Spain and Catalonia goals 2030?

- 32% reduction in greenhouse gas emissions compared to 1990
- 48% renewable energy in final energy consumption
- 43% improvement in energy efficiency in terms of final energy
- 81% renewable energy in electricity generation
- Reduction of energy dependence by up to 50%



Are renewable energy and emissions related?



Datasets

- GHG emissions in Catalonia from 1990 to 2022

from Department of Climate Action, Food and Rural Agenda

	ANY	PROVINCIA	ACTIVITAT	IPCC_SECTOR	IPCC_DIVISIO	IPCC_CLASSE	IPCC_SUBCLASSE	NOM_SECTOR	NOM_DIVISIO	NOM_CLASSE	NOM_SUBCLASSE	CONTAMINANT	UNITATS	CO2EQ	EMISSIO GAS
7349	1998	GIRONA	2F4a	2	F	4.0	a	Processos Industrials	Usos de productes com a substituts per a les s...	Aerosols	Inhaladors de dosi mesurada	HFC-134a	Gg	2.675513	0.002058
12781	1997	LLEIDA	2G1a	2	G	1.0	a	Processos Industrials	Producció i ús d'altres productes	Equips elèctrics	Etapa de fabricació	SF6	Gg	0.742537	0.000032
10134	2014	GIRONA	3A46	3	A	4.0	6	Agricultura	Fermentació entèrica	Altre bestiar	Conills	CH4	Gg	4.611056	0.164681
15574	2013	LLEIDA	4B11	4	B	1.0	1	Ús del sòl, canvis d'ús del sòl i silvicultura	Terres de cultiu	Terres de cultiu que romanen com a tal	Subclasse auxiliar	N2O	Gg	0.046345	0.000175
10765	2018	GIRONA	1A2g	1	A	2.0	g	Processament de l'energia	Activitats de combustió	Indústries manufactureres i de la construcció	Altres sectors manufacturers i de la construcció	N2O	Gg	1.166572	0.004402
7771	2000	GIRONA	4B11	4	B	1.0	1	Ús del sòl, canvis d'ús del sòl i silvicultura	Terres de cultiu	Terres de cultiu que romanen com a tal	Subclasse auxiliar	CO2	Gg	-5.135241	-5.135241

Datasets

- Energy balance of Catalonia from 1990 to 2022

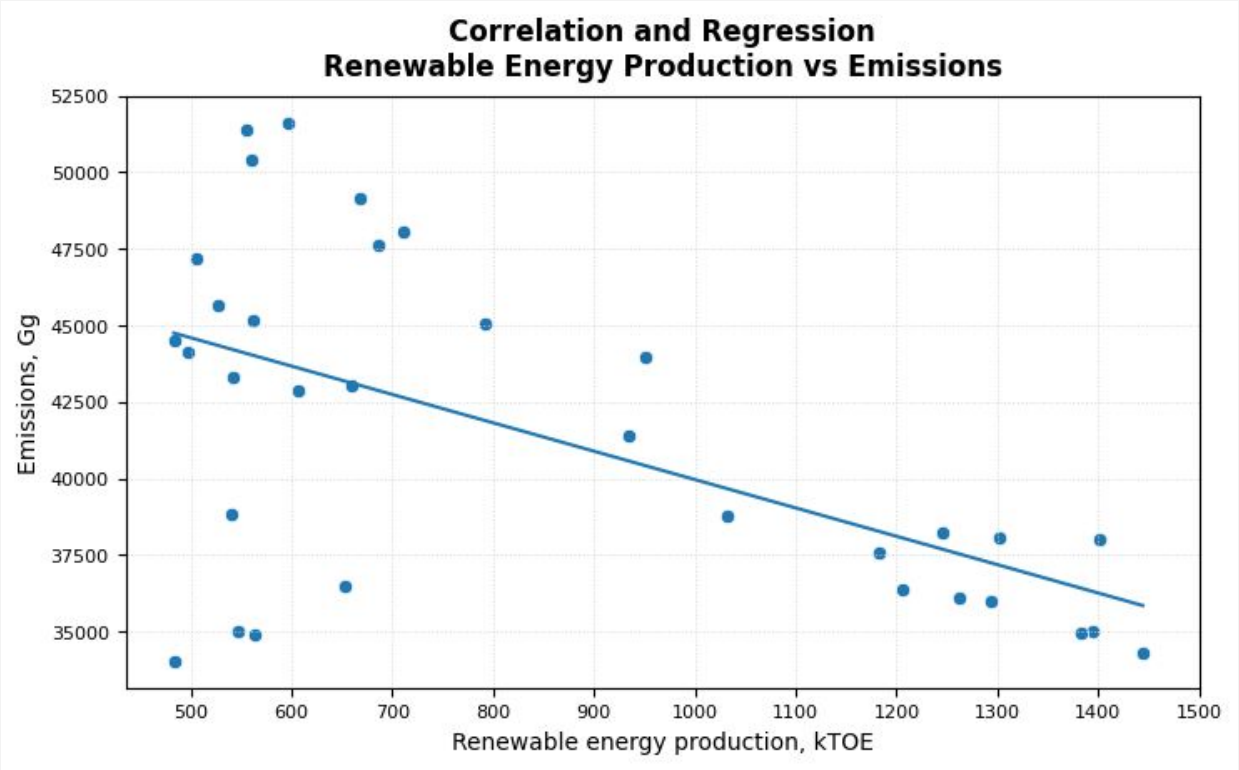
from Catalan Energy Institute

	Unnamed: 0	Unnamed: 1	1990	1991	1992	1993	1994	1995	1996	1997	...	2016	2017	2018	2019	2020	2021	2022
0	Carbó	NaN	170.400000	198.600000	142.800000	147.000000	159.000000	135.300000	137.800000	142.400000	...	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
1	Petroli	NaN	686.800000	980.900000	1012.100000	848.900000	802.300000	647.900000	503.300000	371.500000	...	136.114963	121.624783	87.900978	35.782185	25.855087	4.838212	0.000000
2	Gas natural	NaN	2.300000	2.300000	2.200000	2.300000	2.100000	2.100000	1.800000	1.700000	...	1.406425	2.200025	1.473368	0.667456	0.516586	0.130817	0.000000
3	Nuclear	NaN	5674.896900	5642.749530	5602.039272	5540.879403	5712.643503	5406.786216	5806.025910	5837.554710	...	6438.113236	6580.831378	5716.463005	6407.385337	6485.198560	6360.907818	6523.836994
4	Residus industrials no renovables	NaN	32.650000	39.971622	45.948462	47.485972	50.491684	65.567164	70.231202	79.793316	...	209.702990	210.775850	176.009430	201.854500	192.566837	215.715359	200.359445
5	Energies renovables	NaN	484.277026	563.743324	652.274498	547.739964	539.805751	497.465693	659.620063	607.274901	...	1183.342564	1245.229041	1400.509734	1301.669451	1443.911561	1394.594593	1382.670164
6	NaN	Solar	1.200000	1.300000	1.300000	1.300000	1.300000	1.300000	1.400000	1.406517	...	75.543758	77.595226	74.520571	79.207881	86.230451	97.606074	123.177894
7	NaN	Eòlica	0.003870	0.061892	0.062522	0.080549	0.119699	0.343761	0.708830	0.603061	...	235.247253	248.153255	237.999387	268.191814	224.765895	230.903751	216.817770
8	NaN	Hidràulica	250.923156	295.781432	405.232748	353.072837	384.424080	333.378003	494.661808	447.910058	...	345.248079	323.273772	468.672347	301.357923	442.422617	294.068063	233.503861
9	NaN	Biomassa forestal i agrària	211.500000	239.300000	211.600000	156.700000	115.600000	110.200000	108.500000	95.700000	...	229.351127	263.350326	279.290557	272.146711	288.965213	318.659910	332.296629
10	NaN	Residus renovables	20.650000	27.300000	34.079228	36.320608	38.149015	51.878714	53.944949	61.626982	...	105.955027	110.976063	99.162936	110.585539	107.356830	124.356133	124.503403
11	NaN	Biogàs	0.000000	0.000000	0.000000	0.265969	0.212957	0.365216	0.404476	0.028283	...	53.008387	54.842111	50.703501	50.709522	49.836076	60.356100	59.936101
12	NaN	Biocarburants	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	...	26.511941	27.953498	22.394129	25.731678	25.978736	25.671446	24.844001
13	NaN	Calor ambient	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	...	112.476992	139.084790	167.766306	193.738384	218.355743	242.973116	267.590504
14	TOTAL	NaN	7051.323926	7428.264476	7457.362232	7134.305339	7266.340938	6755.119072	7178.777175	7040.222927	...	7968.680178	8160.661077	7382.356514	7947.358929	8148.048630	7976.186799	8106.866603

Methods


```
import numpy as np
import pandas as pd

import seaborn as sns
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D

import scipy.stats as stats
from scipy.stats import linregress
from sklearn.linear_model import LinearRegression

import statsmodels.api as sm
from statsmodels.stats.outliers_influence import variance_inflation_factor
```

Hypothesis 1: Does increasing renewable energy production contribute to reducing GHG emissions?




```
from scipy.stats import linregress
```

```
x = df_concated['Renewable energy production']
y = df_concated['Total emissions']
```

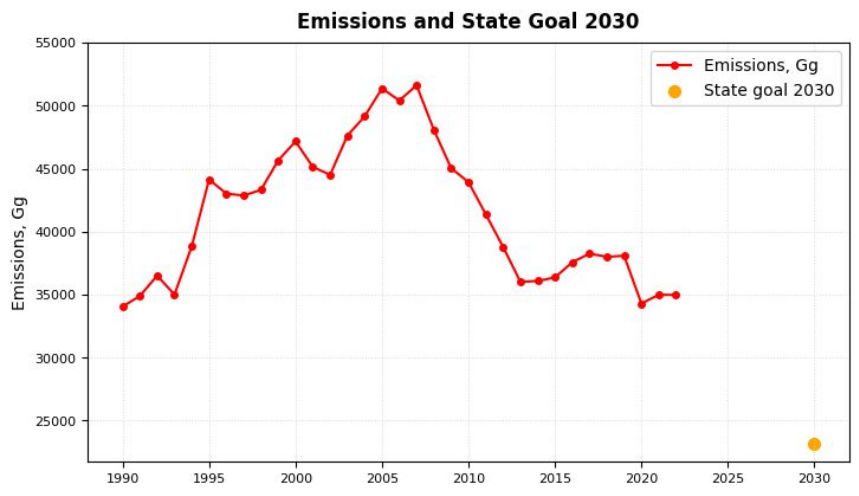
```
equation: y = -9.26x + 49225.32

slope: -9.26
intercept: 49225.32
standart error: 2.37

correlation: -0.57487
p-value: 0.00047

Yes, the dependence is significant
```

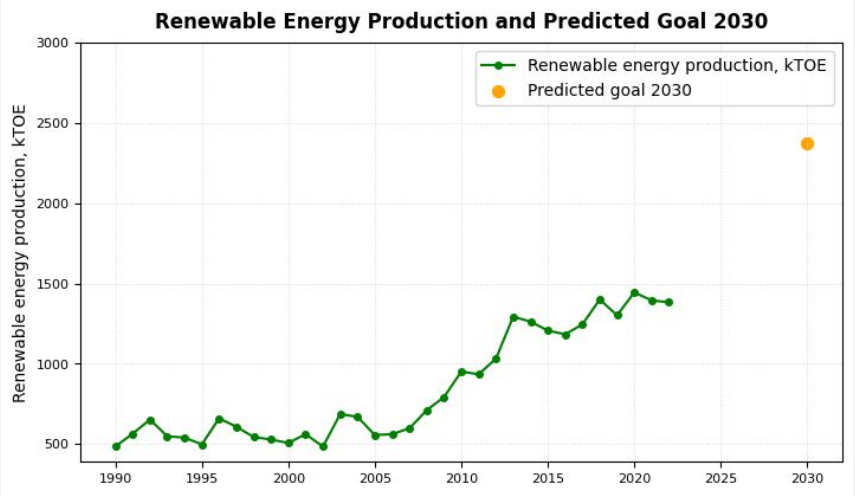
Hypothesis 2: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels?

```
y = -9.26x + 49225.32
```

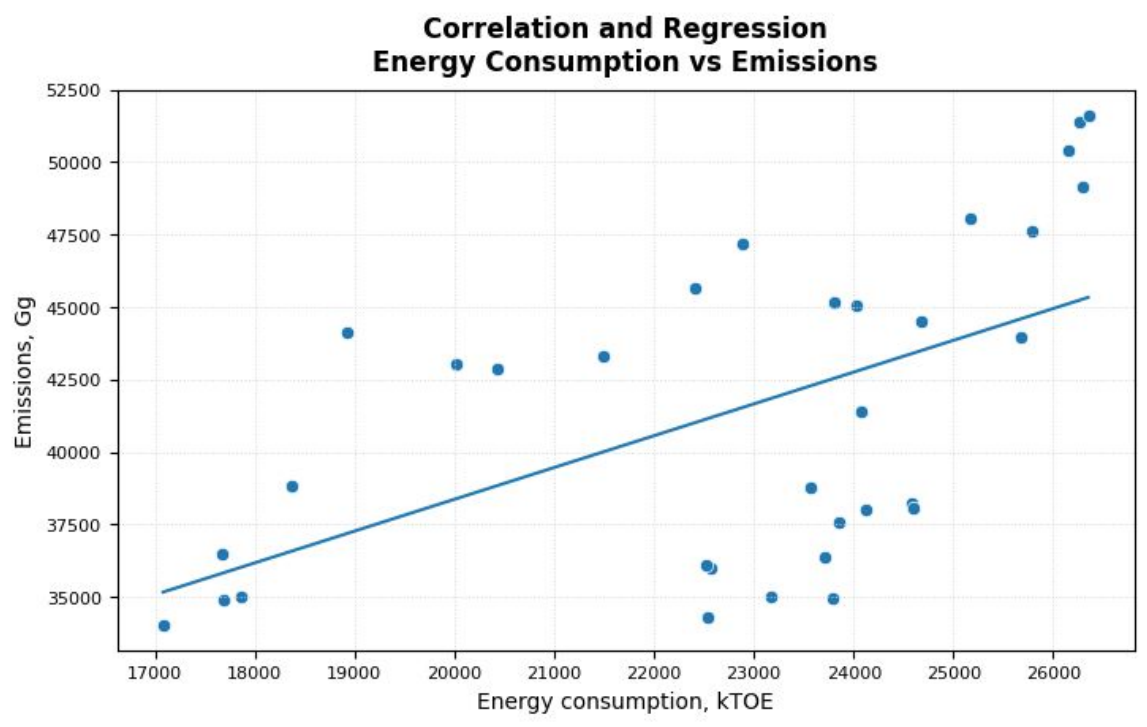
```
based_emissons = df_concated['Total emissions'].iloc[0]
target_emissons = based_emissons * 0.68
```

```
To reduce emissions by 32% compared to 1990 levels,
renewable energy production needs to increase to: 2815.20
```





Hypothesis 3: Is it possible to reduce GHG emissions by 32% compared to 1990 levels solely through consumption reduction without increasing renewable energy production?




```
from scipy.stats import linregress
```

```
x = df_concated['Total consumption']
y = df_concated['Total emissions']
```

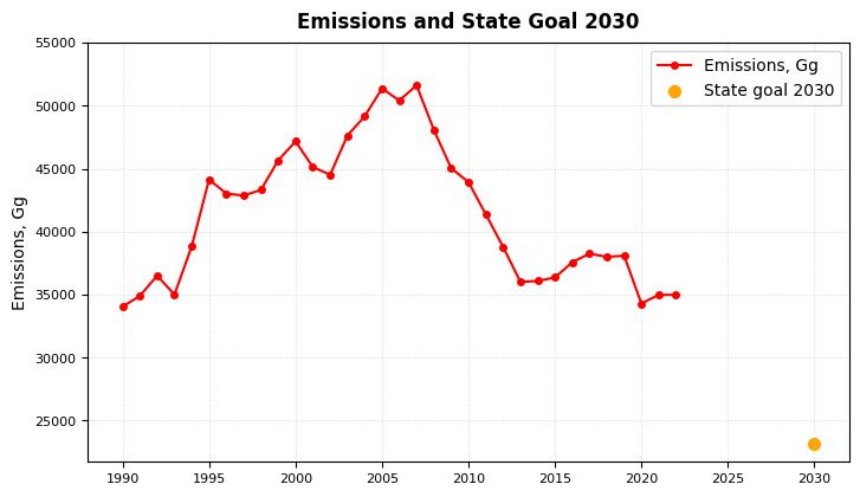
```
equation: y = 1.10x + 16458.06

slope: 1.10
intercept: 16458.06
standart error: 0.30

correlation: 0.55467
p-value: 0.00081

Yes, the dependence is significant
```

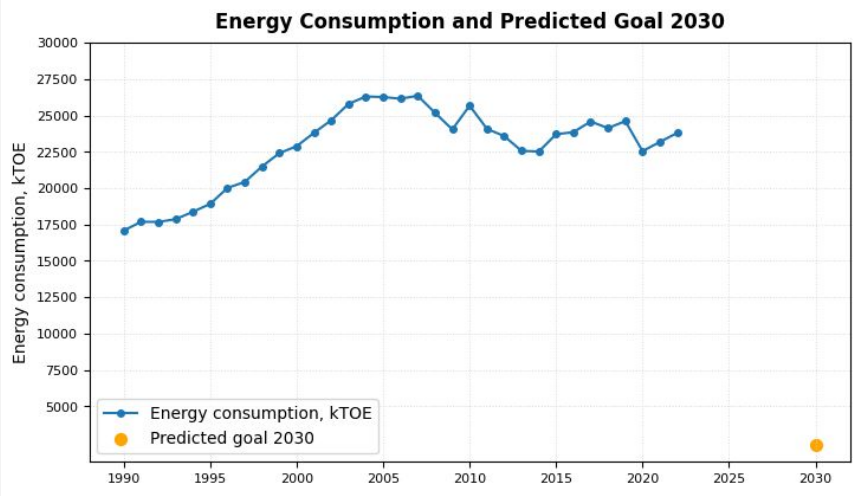
Hypothesis 3: Is it possible to reduce GHG emissions by 32% compared to 1990 levels solely through consumption reduction without increasing renewable energy production?

```
y = 1.10x + 16458.06
```

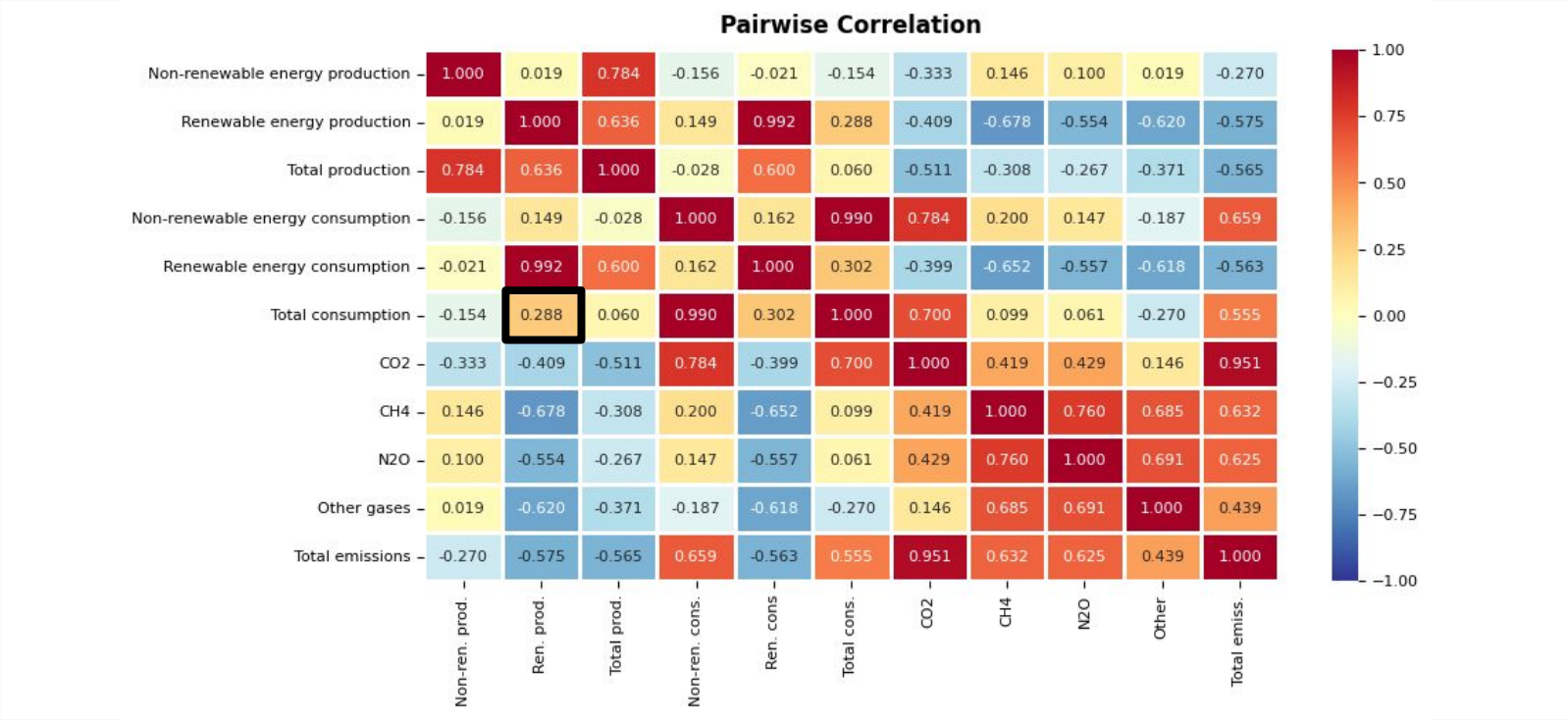
```
based_emissons = df_concated['Total emissions'].iloc[0]
target_emissons = based_emissons * 0.68
```

```
To reduce emissions by 32% compared to 1990 levels,
energy consumption would need to be reduced to: 6113.07
```





Hypothesis 4: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels without reducing consumption?



Hypothesis 4: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels without reducing consumption?

```
from sklearn.linear_model import LinearRegression
import statsmodels.api as sm
from statsmodels.stats.outliers_influence import variance_inflation_factor
```

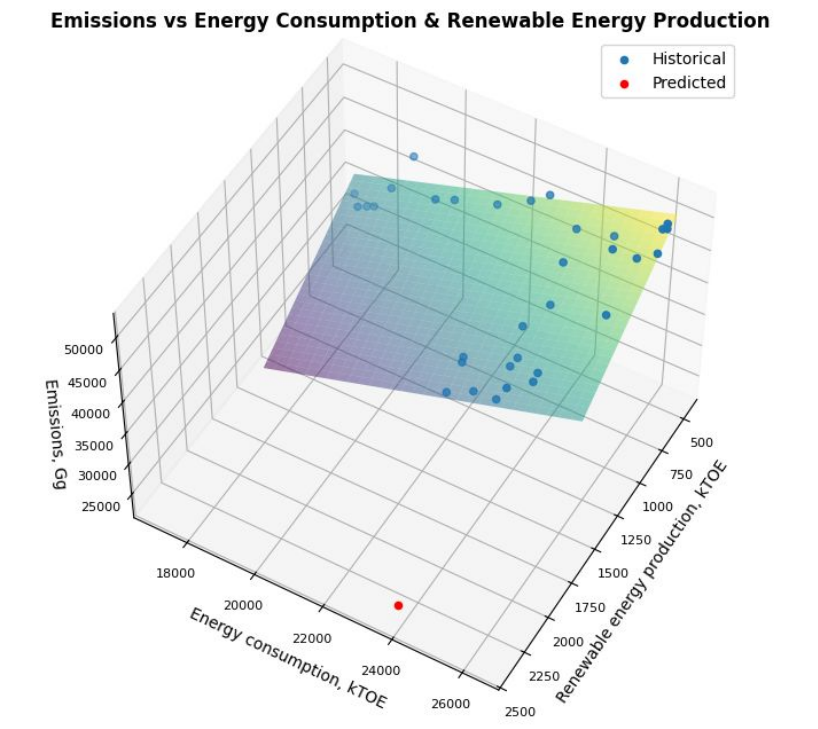
```
X = df_concated[['Renewable energy production', 'Total consumption']]
y = df_concated['Total emissions']
```

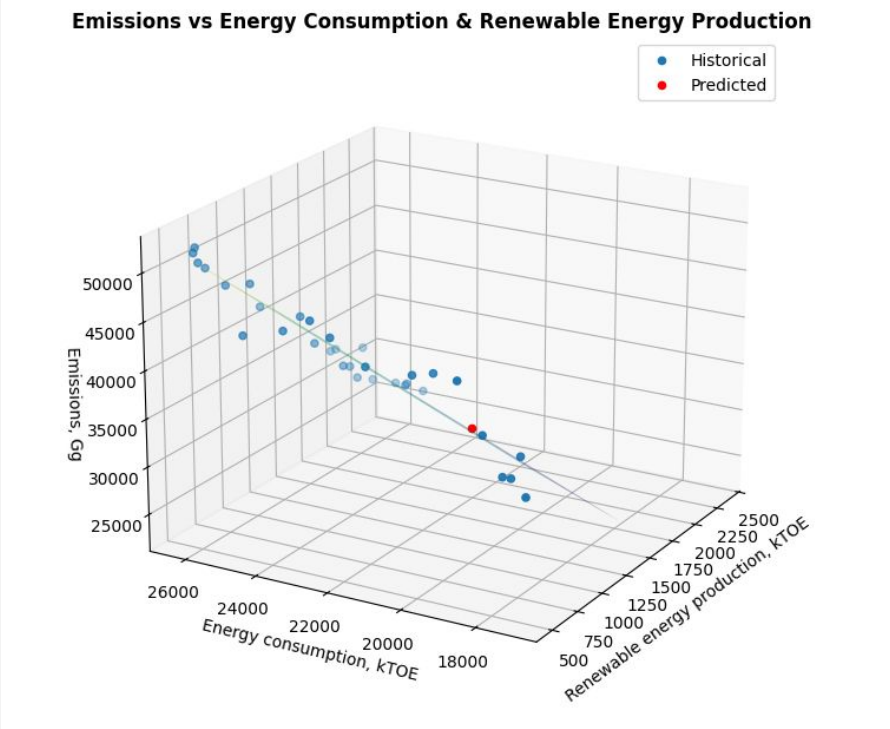
```
equation: y = -12.91x1 + 1.55x2 + 16918.61

intercept (beta_0): 16918.6109
coef of Renewable energy production (beta_1): -12.9108
coef of Consumption (beta_2): 1.5523
correlation: 0.89664
```

	Variable	VIF
0	const	69.561114
1	Renewable energy production	1.090719
2	Total consumption	1.090719

```
                            OLS Regression Results
==============================================================================
Dep. Variable:        Total emissions   R-squared:                       0.897
Model:                            OLS   Adj. R-squared:                  0.890
Method:                 Least Squares   F-statistic:                     130.1
Date:                Sun, 09 Feb 2025   Prob (F-statistic):           1.64e-15
Time:                        21:53:35   Log-Likelihood:                -293.22
No. Observations:                  33   AIC:                             592.4
Df Residuals:                      30   BIC:                             596.9
Df Model:                           2
Covariance Type:            nonrobust
================================================================================================
                                   coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------------------------
const                        1.692e+04   2662.125      6.355      0.000    1.15e+04    2.24e+04
Renewable energy production   -12.9108      0.987    -13.075      0.000     -14.927     -10.894
Total consumption               1.5523      0.121     12.819      0.000       1.305       1.800
==============================================================================
Omnibus:                        1.529   Durbin-Watson:                   1.117
Prob(Omnibus):                  0.465   Jarque-Bera (JB):                0.552
Skew:                          -0.077   Prob(JB):                        0.759
Kurtosis:                       3.615   Cond. No.                     1.92e+05
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 1.92e+05. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Hypothesis 4: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels without reducing consumption?





Hypothesis 4: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels without reducing consumption?

$$y = -12.91x1 + 1.55x2 + 16918.61$$

```
X = df_concated[['Renewable energy production', 'Total consumption']]
y = df_concated['Total emissions']
```

```
current_consumption = df_consumption['Total consumption'].iloc[32]
```

```
To reduce emissions by 32% compared to 1990
levels without reducing consumption, renewable
energy production needs to increase to: 2377.61
```

```
reduced_consumption = current_consumption * 0.9
```

```
If consumption is reduced by 10%, renewable
energy production needs to increase to: 2091.54
```

result of the previous model:

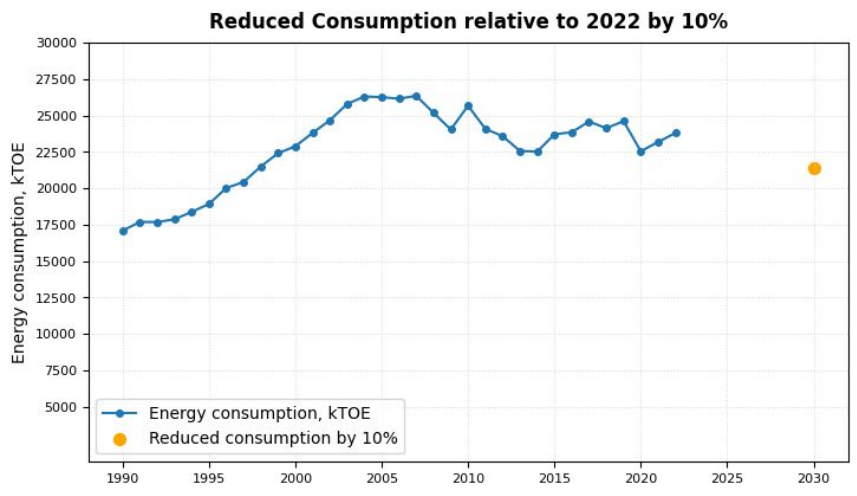
```
To reduce emissions by 32% compared to 1990 levels,
renewable energy production needs to increase to: 2815.20
```

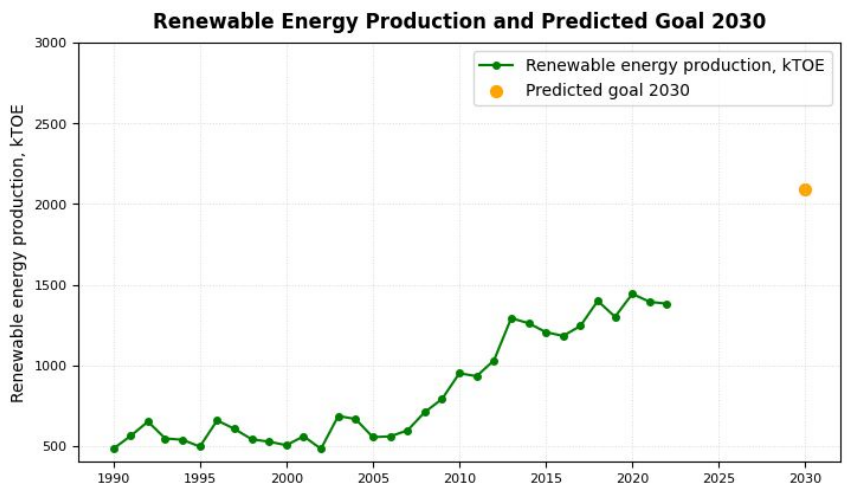
Hypothesis 4: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels without reducing consumption?

```
X = df_concated[['Renewable energy production', 'Total consumption']]
y = df_concated['Total emissions']
```

```
If consumption is reduced by 10%, renewable
energy production needs to increase to: 2091.54
```

```
y = -12.91x1 + 1.55x2 + 16918.61
```

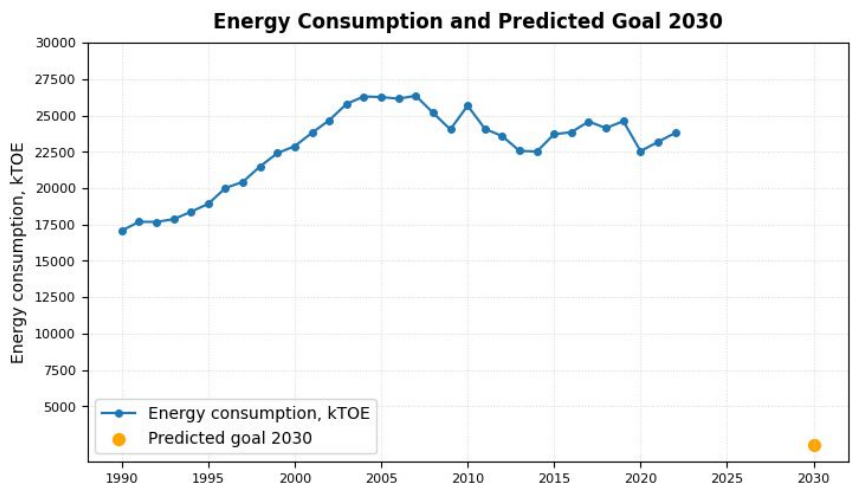




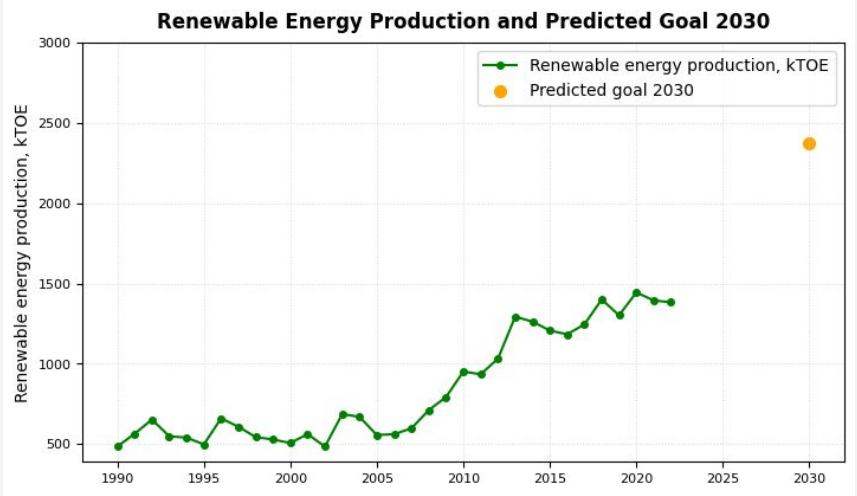
Hypothesis 4: How much renewable energy needs to be produced in Catalonia to reduce GHG emissions by 32% compared to 1990 levels without reducing consumption?

results of the previous models:

`y = 1.10x + 16458.06`



`y = −9.26x + 49225.32`



Conclusions

Catalonia has set ambitious climate goals, aiming for a 32% reduction in greenhouse gases emissions by 2030 and a full transition to renewable energy by 2050.

This study demonstrates that achieving these targets is possible through a combined strategy of increasing renewable energy production and optimizing energy consumption.

References

- Dades obertes Catalunya. (2025, January 29). Emissions de GEH a Catalunya.
- Instituto Catalán de Energía. (2024, December 4). Balance energético de Cataluña.
- Generalitat de Catalunya. (2023, June 13). Prospectiva Energètica de Catalunya 2050.
- Gobierno de España. (2024, Sept. 24). Plan Nacional Integrado de Energía y Clima.

Thank you! Do you have any questions?

- linkedin.com/in/olga-kalugina
- github.com/leocareer