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The development of European Green Energy sector: descriptive statistics and impacts on decarbonization

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ABSTRACT

In recent years climate change has emerged as one of the most pressing issues Humanity has ever faced. Its effects on the ecosystem are now becoming severe and permanent. To ensure Earth's survival, immediate action is required, and this necessity cannot be further ignored. Over the years, the European Union has taken the lead in directing and coordinating Member States' efforts toward a sustainable economy and energy transition. Recently, the European Commission has introduced the European Green Deal, which provides a roadmap to drive the EU towards a path of sustainable development.

Cleantech companies (private companies that focus on the development of sustainability solutions) play a critical role in addressing environmental challenges such as climate change, pollution and resource depletion. The EU supports Cleantech through different financial and technological initiatives.

My thesis focuses on three technological categories of Cleantech companies, that work with Sustainable energy production, Sustainable fuels and Energy-efficient industrial technologies, and that are generally referred to as Green Energy.

Firstly, I have analyzed in depth the composition of the Green Energy sample. I have described different aspects of the companies collected in the dataset, from technological category classification to geographical distribution, from financial data to patents ownership, from year of incorporation to Venture Capital investments. The elaboration of these descriptive statistics allowed us to understand better the sample and gave us a complete picture of Green Energy's current state. Then, I have summarized what is stated by academic literature regarding environmental degradation, studying the correlation that links it to economic growth, the impact that renewable energy has on Carbon Dioxide emissions and how policies could foster a solid and wide Green Energy ecosystem. I have analyzed the different initiatives undertaken by the European Union to help renewable energy diffusion, and the trends that the EU is experiencing in decreasing greenhouse gases emissions and fossil fuels usage.

In the end, I carried out a preliminary analysis to understand if and to what extent there is a correlation between a given country's CO2 emissions and the financial performance of its Green Energy companies, represented by Sales and Total Assets aggregated by country. I repeated this analysis on seven countries, performing multiple linear regressions between country-level aggregated CO2 emissions and financial metrics. No clear pattern among all the countries analyzed was found.

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1 | INTRODUCTION

The tragic consequences of global warming, the massive pressures the planet is living, and the threats climate change poses to Human and animal life, have always concerned me deeply, especially during my studies. For this reason, I decided to complete my academic path focusing on the European Green Energy sector, that plays a crucial role in achieving decarbonization and fostering sustainability.

I report here a summary of the content and the structure of my work.

Chapter 2 identifies the Green Energy industry at large and its importance in addressing the environmental issues we face, then briefly defines the rationale and the scope of the research project that has delivered the Cleantech company database we have worked on, explaining which methodology was adopted to build the dataset. Then, we introduce the technological categories and ecosystem segments in which Cleantech companies have been classified.

Chapter 3 analyzes in depth the composition of the Green Energy companies sample. From financial information to patent ownership, from regional distribution to technology category classification, we will discuss several important aspects of the businesses gathered in the dataset. The refinement of these descriptive statistics will enable us to view the sample from a more comprehensive standpoint, as a prelude to the examination of the upcoming chapters.

Chapter 4 provides a summary of the academic literature on environmental degradation, its relationship to economic growth, the effect of renewable energy on carbon dioxide emissions, and the ways in which laws and policies could support a solid green energy ecosystem. We also thoroughly examine the many measures the EU has taken to promote the spread of renewable energy as well as the patterns the EU is experiencing in terms of lowering greenhouse gas emissions and the use of fossil fuels.

Chapter 5 reports the analysis we carried out to understand if and to what extent there is a correlation between a given country's CO2 emissions and the financial performance of its Green Energy companies, represented by Sales and Total Assets aggregated by country. We repeated this analysis on the seven countries that have the widest Green Energy sector (France, Germany, Italy, Spain, Poland, Sweden and Austria). We report the data sources adopted, the methodology of the analysis, and the results obtained.

2 | IDENTIFICATION AND CLASSIFICATION OF GREEN ENERGY COMPANIES

In this Chapter we identify the Green Energy sector and describe the methodology used to record Green Energy companies in the database. We then explain how those companies have been classified into technological categories and into ecosystem segments.

2.1 | The importance of Cleantech

The European Union (EU) has long been at the forefront of crafting policies aimed at addressing climate change and global warming. One of the milestones in this action is represented by the European Green Deal, a comprehensive plan to steer the EU towards a trajectory of sustainable development. Through the Green Deal, the EU Institutions commit to achieve a broad array of environmental objectives, the most important of which is reaching carbon neutrality by 2050. The importance of green innovations and the role of private companies in developing sustainable solutions (Cleantech, also commonly referred to as Greentech) is clearly stated by the European Green Deal, that provides guidelines, criteria and funds to sustain and drive the growth of these firms.

In particular, Cleantech companies are at the heart of EU strategic plans both for the critical role they play in addressing environmental challenges (such as climate change, pollution and resource depletion) and both for their strong economic and social potential. Cleantech companies can drive long term economic growth by creating new jobs, attracting investment and enhancing Europe’s competitive position on global markets.

In order to direct European investments efficiently towards Cleantech companies is fundamental to well define them. This becomes particularly difficult since there isn’t any universally accepted definition of what constitutes Cleantech. Existing classification methods based upon industry labels (i.e., NACE codes) have proven to be inefficient in properly identifying Cleantech firms, as they are not able to capture the cross-cutting nature of the sector. Other classification approaches, such as the EU Taxonomy are too rigid and risk not considering the dynamic nature of the sector.

Finding a viable alternative to classify Cleantech companies has been the main goal of the project “The Cleantech industry in the European Green Deal: policy challenges and the finance landscape for SMEs”, commissioned by the European Investment Fund and carried out by a research group formed by the universities of Politecnico di Torino, Politecnico di Milano and Università degli Studi di Bologna. The research group developed a robust and fully replicable methodology to identify European Cleantech companies in the Orbis database, a large company-level database commercialized by Bureau Van Dijk, through the use of a supervised machine learning (ML) algorithm applied to the extended business description of European companies.

2.2 | Three steps methodology to classify Cleantech

The method followed by the research group first implied to manually identify the Cleantech nature of a relatively small set of companies. Then, this manually classified dataset was used to let a machine learn the link between a company description and its Cleantech status. By letting the machine learn this mapping, it is possible to predict the classification of non-manually classified companies.

The subsequent classification of the Cleantech companies was carried out following these three main steps:

1. Supervised machine learning (ML) algorithm applied to each company’s extended business description retrieved from Orbis.

2. Computer-aided filter of false positive Cleantech instances (based on keywords using functions embedded in the Stata software) applied to each company labelled as Cleantech in the previous step.

3. Manual checks, ecosystem segmentation, technological classification, and definition of the role of Cleantech companies in the Cleantech ecosystem.

The research group applied the methodology to the entire sample of companies available in Orbis (a dataset that includes financial information on over 40 million companies worldwide), after having applied some filters and after that just the companies that met all the following criteria had been selected:

1. Companies located in Europe.

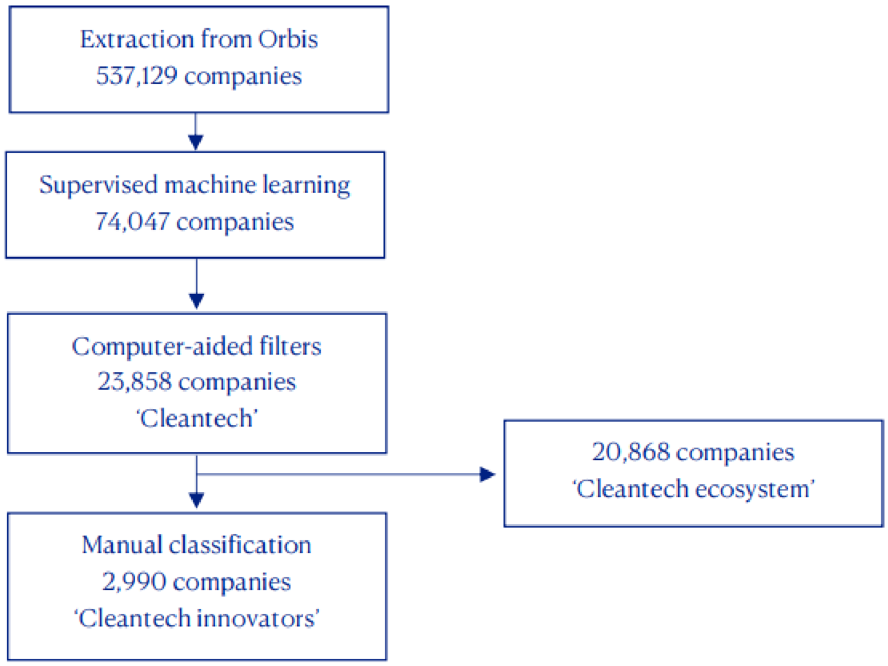
2. Companies which have recorded accounting data for at least one business year.

3. Companies with an available extended business description.

After applying the above criteria, 537,129 companies remained. The sample was reduced to 74,047 companies after running the ML algorithm and to 23,858 companies after applying computer aided filters of false positive.

The third and final step of the methodology adopted was carried out manually to classify the 23,858 companies obtained after step two. The research group assigned each Cleantech company to one or more technological categories and then distinguished each Cleantech company into “Cleantech ecosystem” (i.e., referring to companies that adopt Cleantech technologies, sell services based on Cleantech technologies, or provide inputs for the development of Cleantech technologies) and “Cleantech innovators” (i.e., referring to companies committed to develop clean technologies). Figure 2.1 provides the graphical representation of the three steps methodology used to filter Cleantech companies.

FIGURE 2.1: Graphical representation of the methodology used to screen Cleantech companies



2.3 | Cleantech Classifications

2.3.1 | Classification of Cleantech companies into technological categories

The first classification regards the technological categories. Each Cleantech company was classified into seven different technological categories and sub-categories reflecting the pillars of the European Green Deal and the EU Taxonomy. The structure of the seven technological categories (and subcategories) is presented below:

1) Environmental management

    1.1 Air/water/soil pollution abatement/remediation

    1.2 Waste management

2) Resources preservation

    2.1 Water conservation/availability

    2.2 Sustainable agri-food technologies

    2.3 Sustainable raw materials

3) Industrial energy management

    3.1 Sustainable energy production

    3.2 Sustainable fuels

    3.3 Energy-efficient industrial technologies

4) Capture, storage, sequestration or disposal of GHG

5) Sustainable modes of transport

6) Sustainable buildings

7) Other categories

2.3.2 | Classification of Cleantech companies into ecosystem segments

The second classification acknowledges the complexity of the supply chain structure of the Cleantech ecosystem and divides the 23,858 Cleantech companies into:

1. “Cleantech innovators”: these companies create (and eventually use) the clean technology as their core business. They are at the center of the supply chain.

2. “Cleantech ecosystem”: these companies adopt clean technologies, sell services based on clean technologies, or provide inputs for the development of clean technologies. This broad family includes the following sub-groups:

- I. Experimenters: companies involved in performing experimental tasks that can lead to discoveries.

- II. Manufacturers: companies that deal with manufacturing, fabrication, and production of necessary and auxiliary components or raw materials to the clean technology.

- III. Distributors: companies that only distribute Cleantech products or technologies.

- IV. Integrators: companies that deal with engineering, installation, procurement, design, conception, and planning.

- V. Operators: companies involved in the Cleantech supply chain that deals with the construction, implementation, and maintenance of facilities where clean technology is used.

2.4 | Our Focus

This thesis will be focused on the third category, “Industrial energy management”, that includes technologies for energy production and energy efficiency. In particular:

- the sub-category 3.1 “Sustainable energy production”, that includes clean energy generation technologies such as wind, solar thermal, photovoltaic, geothermal, marine, and hydroelectric. Other types of power generation considered were new nuclear technologies, fuel cells and co-generation technologies.
- the sub-category 3.2 “Sustainable fuels”, that includes fuels from renewable sources that minimize the environmental impact, e.g. fuels deriving from renewable biomass or from waste.
- the sub-category 3.3 “Energy-efficient industrial technologies” includes battery storage, capacitor, and thermal storage. This class also includes technologies related to superconductors, pressurized fluid, mechanical & pumped, recyclable products, and reduction of materials in manufacturing.

In the next chapters we will start our analysis on Green Energy companies.

Firstly, our aim is to analyze the database to gain a meaningful understanding of Green Energy sector: in Chapter 3 we will report some descriptive statistics regarding ecosystem segment, geographical distribution, sector, year of incorporation, patent data, financial KPIs, Venture Capital data. Then, in Chapter 4 we analyze the current trends in the Green Energy sector, with a focus on the EU policies and initiatives, and we review the literature findings. In Chapter 5 we analyze the multiple linear regressions between some financial metrics and country-level aggregated CO_2 emissions.

3 | MACRO-ANALYSIS OF GREEN ENERGY IN EUROPE

In this Chapter we will analyze in depth the composition of the Green Energy companies sample. We will describe different aspects of the companies collected in the dataset, from technological category classification to geographical distribution, from financial data to patents ownership. The elaboration of these descriptive statistics will allow us to look at the sample from a broader and accurate perspective and is propaedeutic to the deeper analysis of the following chapters.

3.1 | Descriptive statistics on Green Energy companies

3.1.1 | By status

The sample of Green Energy company comprises 11.221 companies. Of these, 10.154 are still active and running in 2023 (the year of data downloading), 1.034 have failed in the past years and 33 show a complex status: they have been taken over, or are active but dormient, or inactive but not yet failed. Table 3.1 shows this classification.

Given that even a failed or a taken over company can contribute to understand the composition, the evolution and the overall picture of the Green Energy landscape, we will include companies with “Failed” or “Other” status in the scope of our work, and thus in the following descriptive analysis.

TABLE 3.1: Classification of Green Energy companies by status

Status	#Companies	%
Active	10154	90,5%
Failed	1034	9,2%
Other	33	0,3%
Total	11221	100%

3.1.2 | By ecosystem segment and technological category

The sample of Green Energy companies collects 11.221 companies, 1.911 of which are Cleantech innovators (17%) and 9.310 of which are Cleantech Ecosystem (83%). Table 3.2 reports the distribution of sample companies according to the segmentation described in Section 2.3.2. Within the Green Energy ecosystem group, companies are mainly distributed among Operators (25,6%), Integrators (24,5%), and Manufacturers (20,1%). The two remaining groups, Distributors and Experimenters, account of 12,5% and 0,3%, respectively.

TABLE 3.2: Classification of Green Energy companies into different ecosystem segments

Ecosystem Segment	#Companies	%
Innovators	1911	17,0%
Ecosystem	9310	83,0%
Experimenters	29	0,3%
Manufacturers	2253	20,1%
Distributors	1403	12,5%
Integrators	2747	24,5%
Operators	2875	25,6%
Total	11221	100%

The distribution of Green Energy companies in the sample according to the different technological subcategories described in Section 2.3.1, is reported in Table 3.3. Some companies have been classified in more than one technological category inside the "Industrial energy management" group (3): this is the case for 1244 companies. Considering also the double or triple classified companies, the biggest subcategory is Sustainable energy production (3.1) (57,2%), followed by Energy-efficient industrial technologies (3.3) (40,1%), while Sustainable fuels (3.2) is the least populated subcategory with just 13,8% of the sample.

If we focus just on the 1.911 Innovators, we can appreciate how a broad majority (quite three quarters of the group) belongs to the subcategory Sustainable energy production (3.1), that seems to be definitely the field in which innovation is more concentrated. On the opposite side, Sustainable fuels (3.2) represents less than the 10% of the innovators, being the least innovative subcategory. As far as Ecosystem companies, the broad majority is classified either in subcategory 3.1 or 3.2. Table 3.3 shows these results. We would like to underline that 1244 companies show a double or triple classification and thus the percentages and the sums in the columns are not equal to the amount shown in the last row.

TABLE 3.3: Classification of total Green Energy companies, Innovators and Ecosystem companies into different technological categories, considering also double classifications

Technological categories	#Companies	%	#Innovators	%	#Ecosystem	%
Sustainable energy production (3.1)	6421	57,2%	1419	74,3%	5002	53,7%
Sustainable fuels (3.2)	1547	13,8%	158	8,3%	1389	14,9%
Energy-efficient industrial technologies (3.3)	4497	40,1%	451	23,6%	4046	43,4%
#Companies in the sample	11221		1911		9310	

Furthermore, the sample presents many cross-sector companies that are active in other sustainability-oriented fields. Due to the complexity of their business and to the broad range of activities they run, these companies are classified also under other technological categories, beyond the “Industrial energy management” classification group. Table 3.4 shows all the different subcategories to which these companies belong. The overlapping companies are 4083 (36,4% of the sample analyzed) and half of them belong to the technological category Waste management (1.2). This astonishing result underlines the strong link between waste management and industrial energy production that is one of the pillars of the new Circular Economy paradigm. Other important subcategories are Air/water/soil pollution (1.1) that represents 21,4% of the overlapping companies, and Sustainable buildings (6) with the 15,4%. These results show how Green Energy production also means a cleaner way to produce and manage Energy, and the increasing importance of energy efficient facilities.

TABLE 3.4: Green Energy companies belonging to other technological categories

Technological categories	#Companies	%
Air/water/soil pollution (1.1)	874	21,4%
Waste management (1.2)	2068	50,6%
Water conservation / availability (2.1)	217	5,3%
Agri-food (2.2)	63	1,5%
Sustainable raw materials (2.3)	88	2,2%
Capture, storage, sequestration or disposal of GHG (4)	14	0,3%
Sustainable modes of transport (5)	132	3,2%
Sustainable buildings (6)	627	15,4%
Other categories (7)	0	0,0%
Total	4083	100%

3.1.3 | By geography

We now focus on examining the geographical distribution of Green Energy companies across the European continent. This analysis helps in identifying clusters, highlighting national strengths, evaluating industrial effectiveness, and understanding correlations between relevant metrics and company distribution, if any. The last point is the main focus of this thesis and will be deeply analyzed in the following chapters. Thus, having a geographical map of companies' distribution is an essential component of our research.

Table 3.5 shows the national distribution of the 11221 companies collected in the sample. More than half of them (60,3%) are located in just four countries: Germany (19,7%), Italy (17,0%), France (13,6%), and Spain (10,1%), with the remaining companies distributed over the other European countries. No significant differences appear in the geographical distribution when taking into account the Ecosystem segmentation: even roughly 60% of Green Energy Innovators and Green Energy Ecosystem are located in those four countries.

TABLE 3.5: Geographical distribution of Green Energy companies, Innovators and Ecosystem

Country	Sample Companies		Innovators		Ecosystem	
	#Companies	%	#Companies	%	#Companies	%
Albania	1	0,0%	1	0,1%	0	0,0%
Austria	299	2,7%	54	2,8%	245	2,6%
Belgium	298	2,7%	54	2,8%	244	2,6%
Bosnia and Herzegovina	2	0,0%	0	0,0%	2	0,0%
Bulgaria	151	1,3%	21	1,1%	130	1,4%
Croatia	58	0,5%	14	0,7%	44	0,5%
Cyprus	2	0,0%	1	0,1%	1	0,0%
Czech Republic	292	2,6%	50	2,6%	242	2,6%
Denmark	165	1,5%	38	2,0%	127	1,4%
Estonia	33	0,3%	9	0,5%	24	0,3%
Finland	248	2,2%	45	2,4%	203	2,2%
France	1522	13,6%	209	10,9%	1313	14,1%
Germany	2212	19,7%	355	18,6%	1857	19,9%
Greece	126	1,1%	29	1,5%	97	1,0%
Hungary	185	1,6%	20	1,0%	165	1,8%
Iceland	14	0,1%	1	0,1%	13	0,1%
Ireland	12	0,1%	0	0,0%	12	0,1%
Italy	1902	17,0%	316	16,5%	1586	17,0%
Latvia	40	0,4%	3	0,2%	37	0,4%
Lithuania	53	0,5%	9	0,5%	44	0,5%
Luxembourg	41	0,4%	6	0,3%	35	0,4%
Malta	8	0,1%	2	0,1%	6	0,1%

Montenegro	3	0,0%	0	0,0%	3	0,0%
Netherlands	189	1,7%	39	2,0%	150	1,6%
North Macedonia	16	0,1%	1	0,1%	15	0,2%
Norway	337	3,0%	47	2,5%	290	3,1%
Poland	562	5,0%	92	4,8%	470	5,0%
Portugal	222	2,0%	29	1,5%	193	2,1%
Romania	190	1,7%	25	1,3%	165	1,8%
Serbia	77	0,7%	7	0,4%	70	0,8%
Slovakia	103	0,9%	15	0,8%	88	0,9%
Slovenia	60	0,5%	17	0,9%	43	0,5%
Spain	1135	10,1%	252	13,2%	883	9,5%
Sweden	405	3,6%	88	4,6%	317	3,4%
Switzerland	29	0,3%	3	0,2%	26	0,3%
Turkey	9	0,1%	3	0,2%	6	0,1%
United Kingdom	220	2,0%	56	2,9%	164	1,8%
Total	11221	100%	1911	100%	9310	100%

Table 3.6 shows the geographical distribution of Green Energy companies when divided for technological subcategories. Even in this case the distribution shows the same pattern: roughly the 60% of the companies of each subcategory is located in Germany, France, Italy and Spain.

In particular, Italy represents the most highly populated Country as far as the technological subcategory Energy-efficient industrial technologies (3.3), hosting 838 companies (18,6% of that subcategory).

TABLE 3.6: Geographical distribution of Green Energy companies by technological subcategory

Country	Sustainable Energy		Sustainable Fuels		Energy efficiency	
	#Companies	%	#Companies	%	#Companies	%
Albania	1	0,0%	0	0,0%	0	0,0%
Austria	150	2,3%	72	4,7%	110	2,4%
Belgium	186	2,9%	36	2,3%	108	2,4%
Bosnia and Herzegovina	0	0,0%	0	0,0%	2	0,0%
Bulgaria	68	1,1%	14	0,9%	84	1,9%
Croatia	32	0,5%	1	0,1%	29	0,6%
Cyprus	1	0,0%	1	0,1%	0	0,0%
Czech Republic	133	2,1%	46	3,0%	144	3,2%
Denmark	110	1,7%	30	1,9%	45	1,0%
Estonia	18	0,3%	8	0,5%	12	0,3%
Finland	115	1,8%	41	2,7%	130	2,9%
France	859	13,4%	150	9,7%	665	14,8%
Germany	1376	21,4%	359	23,2%	761	16,9%
Greece	79	1,2%	18	1,2%	42	0,9%
Hungary	96	1,5%	22	1,4%	89	2,0%
Iceland	7	0,1%	1	0,1%	6	0,1%
Ireland	8	0,1%	1	0,1%	6	0,1%
Italy	1053	16,4%	222	14,4%	838	18,6%
Latvia	16	0,2%	11	0,7%	19	0,4%
Lithuania	25	0,4%	12	0,8%	22	0,5%
Luxembourg	26	0,4%	8	0,5%	13	0,3%
Malta	6	0,1%	1	0,1%	2	0,0%

Montenegro	1	0,0%	0	0,0%	2	0,0%
Netherlands	110	1,7%	37	2,4%	67	1,5%
North Macedonia	8	0,1%	1	0,1%	8	0,2%
Norway	209	3,3%	31	2,0%	118	2,6%
Poland	268	4,2%	93	6,0%	268	6,0%
Portugal	139	2,2%	31	2,0%	70	1,6%
Romania	97	1,5%	18	1,2%	97	2,2%
Serbia	29	0,5%	11	0,7%	41	0,9%
Slovakia	43	0,7%	12	0,8%	57	1,3%
Slovenia	34	0,5%	4	0,3%	23	0,5%
Spain	758	11,8%	154	10,0%	342	7,6%
Sweden	203	3,2%	68	4,4%	175	3,9%
Switzerland	19	0,3%	4	0,3%	7	0,2%
Turkey	6	0,1%	1	0,1%	3	0,1%
United Kingdom	132	2,1%	28	1,8%	92	2,0%
Total	6421	100%	1547	100%	4497	100%

The following maps (from Figure 3.1 to Figure 3.10) reports the geographical distribution for all the companies collected in the sample, for each technological subcategories and for each ecosystem segment. This will allow us to have a clear and immediate picture of the geographical diffusion of Green Energy firms, so to help our understanding of local trends and clusters.

FIGURE 3.1: Geographic distribution of all the Green Energy companies in the dataset

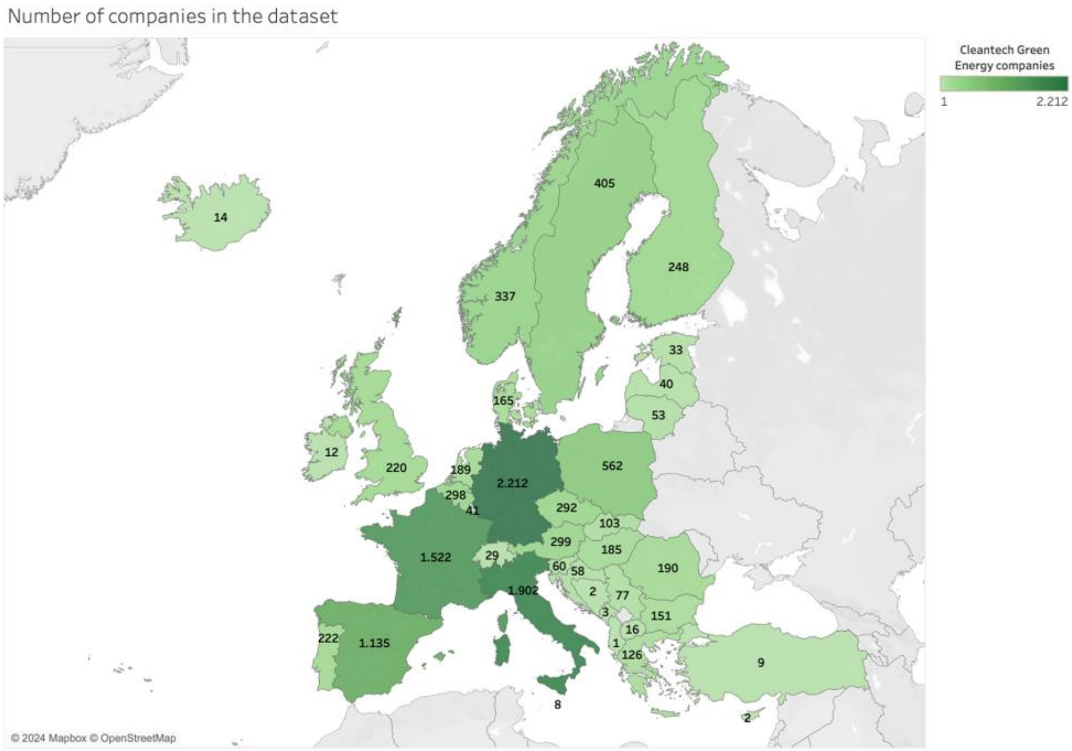


FIGURE 3.2: Geographic distribution of Sustainable Energy producers (3.1)

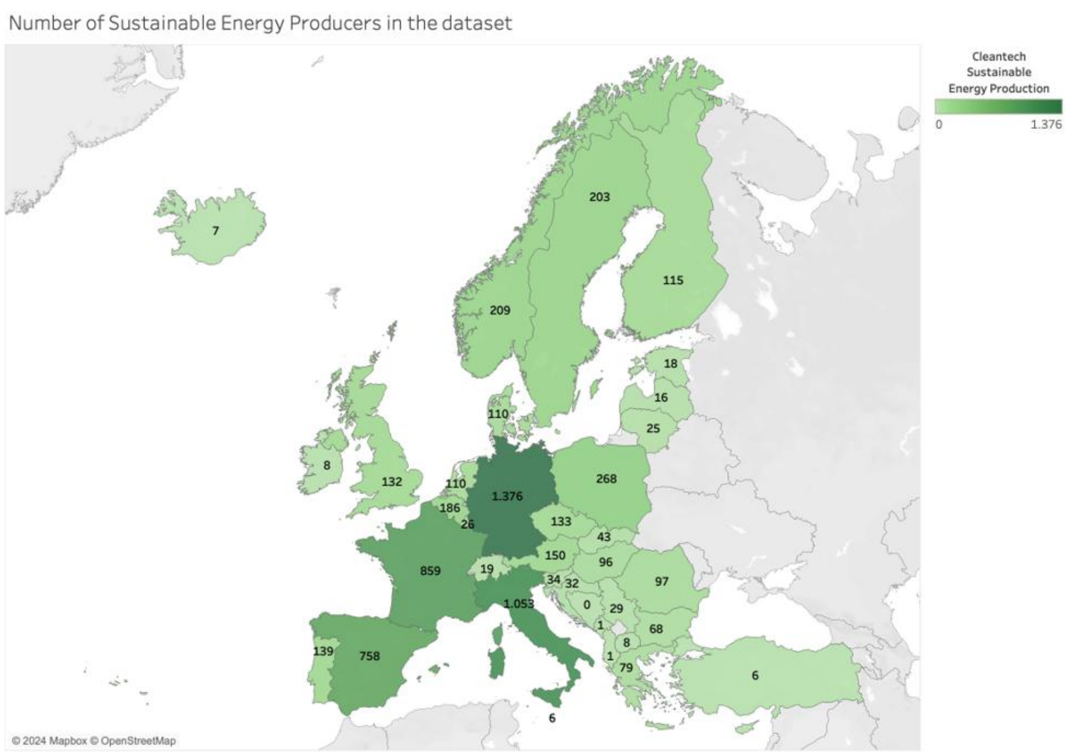


FIGURE 3.3: Geographic distribution of Sustainabel Fuel producers (3.2)

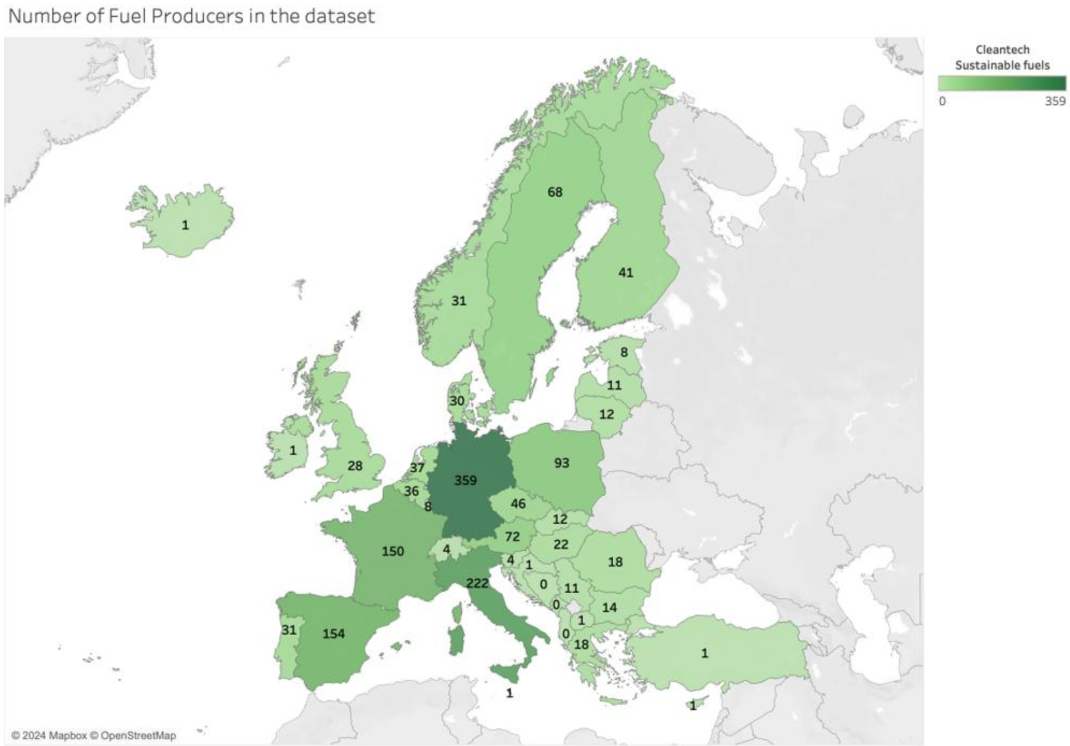


FIGURE 3.4: Geographic distribution of Energy Efficiency companies (3.3)

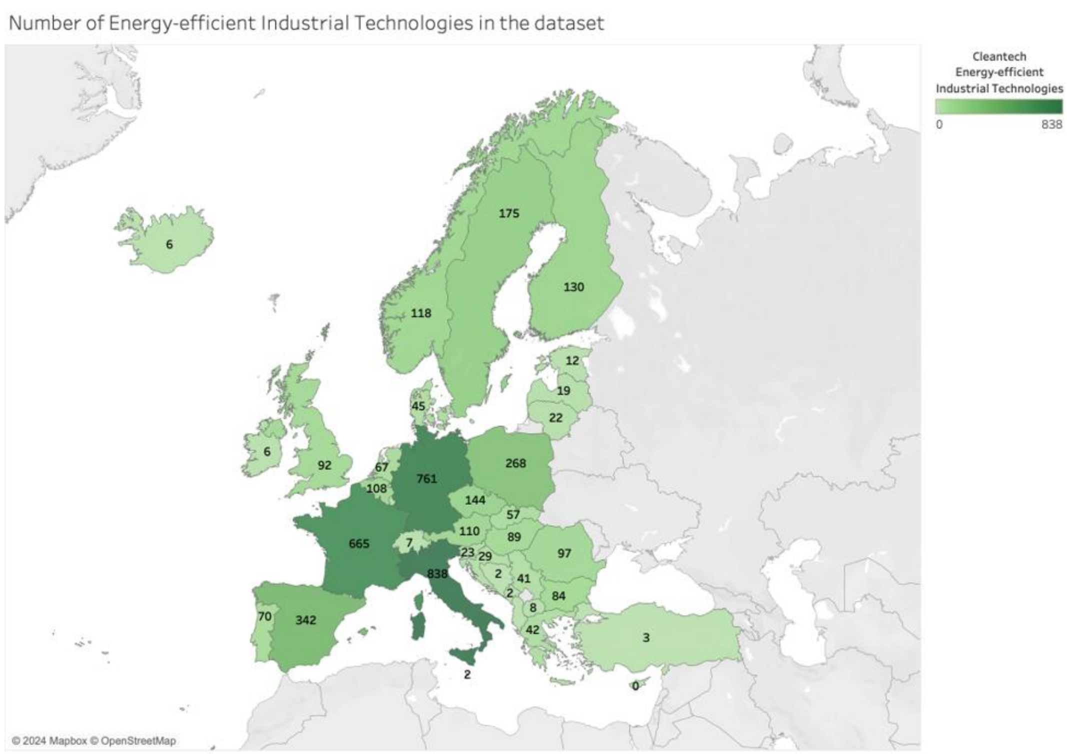


FIGURE 3.5: Geographic distribution of Green Energy Innovators

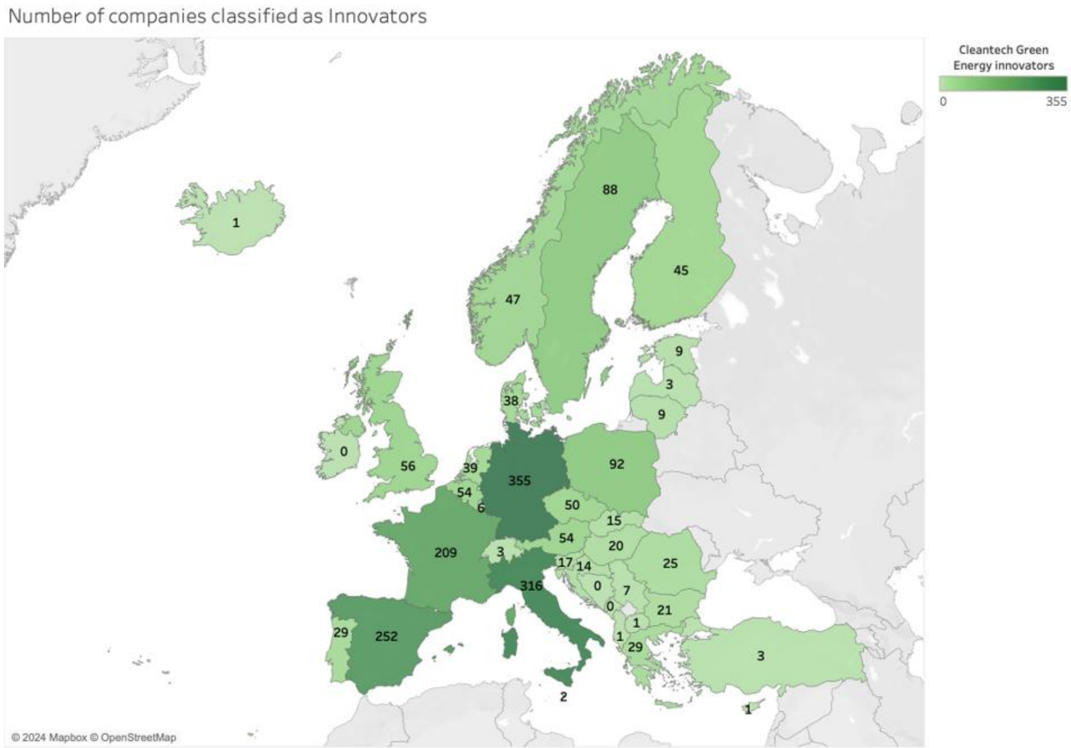


FIGURE 3.6: Geographic distribution of Green Energy Researchers

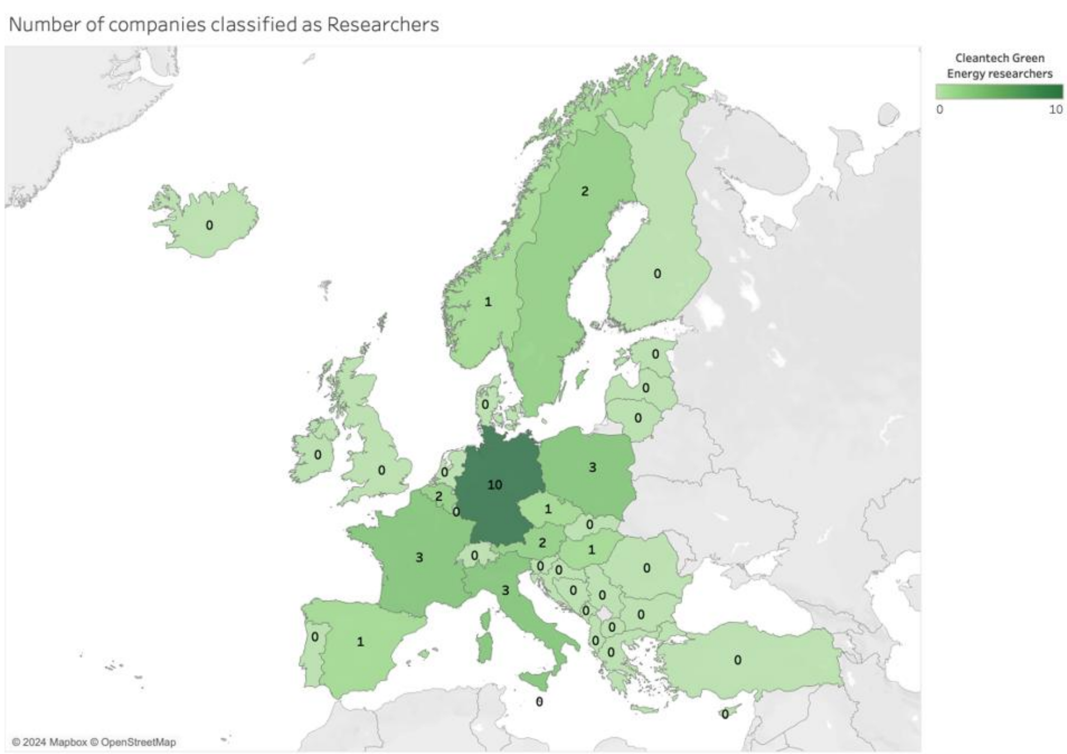


FIGURE 3.7: Geographic distribution of Green Energy Manufacturers

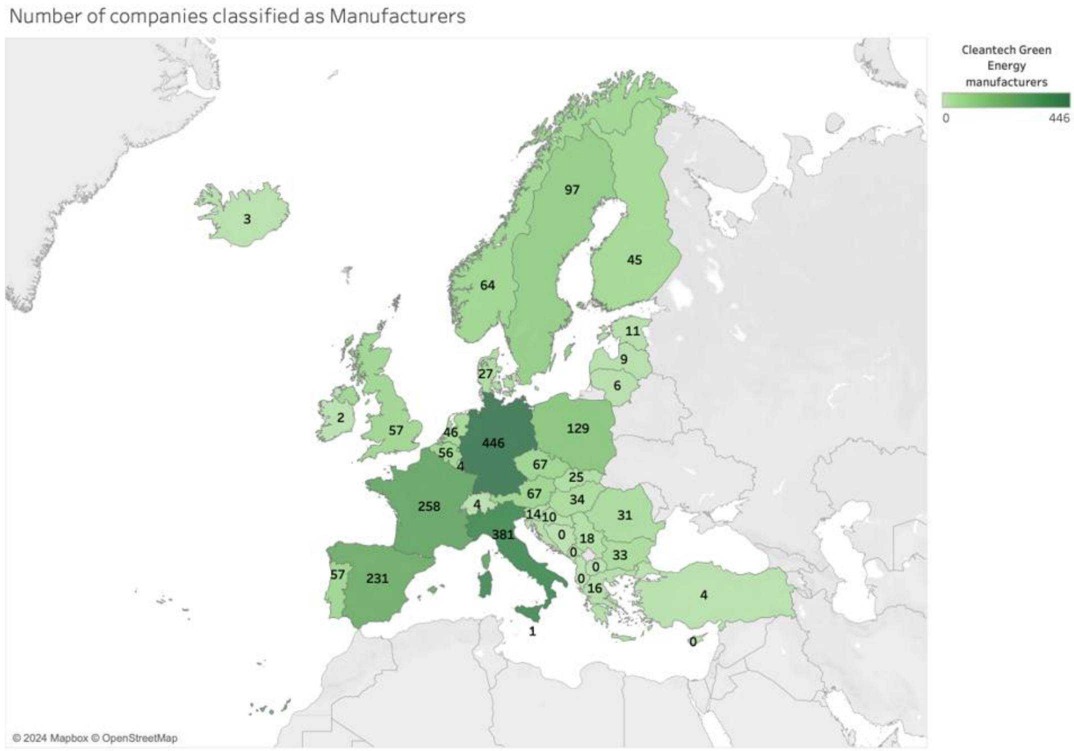


FIGURE 3.8: Geographic distribution of Green Energy Distributors

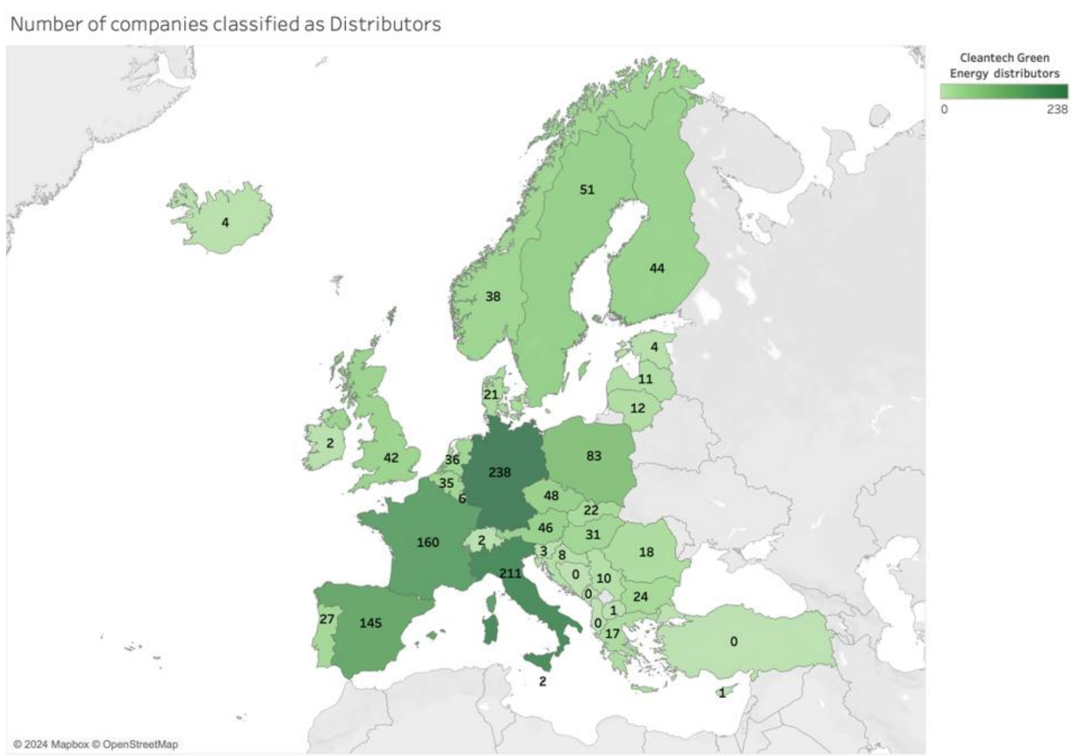


FIGURE 3.9: Geographic distribution of Green Energy Integrators

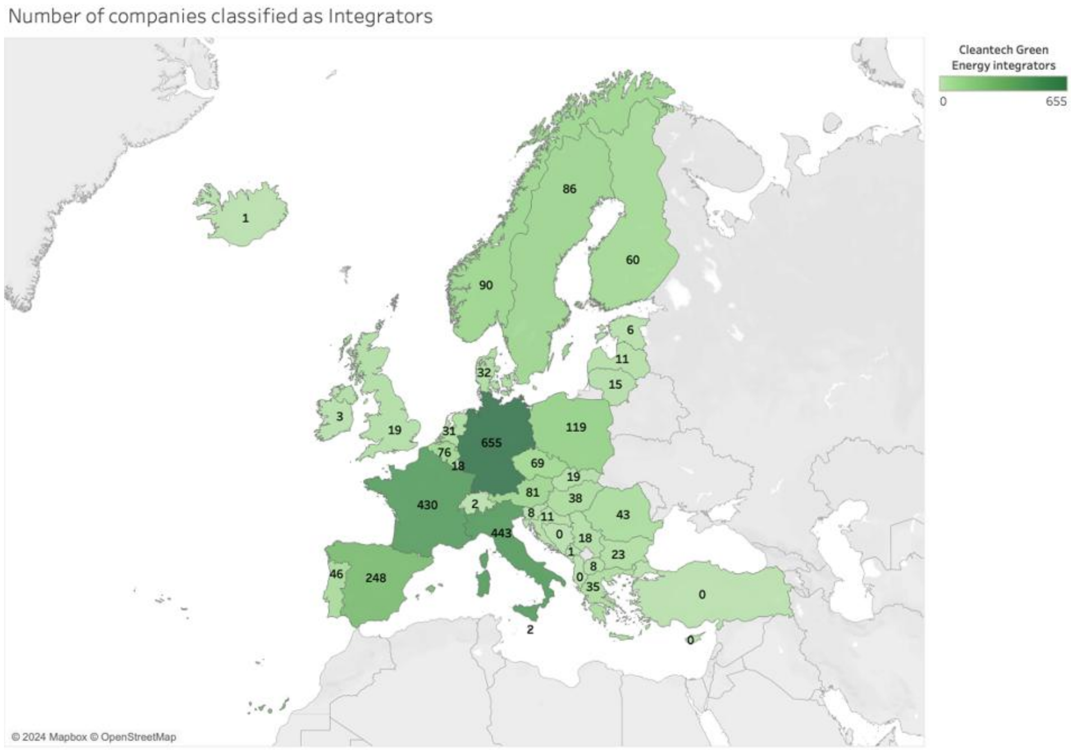
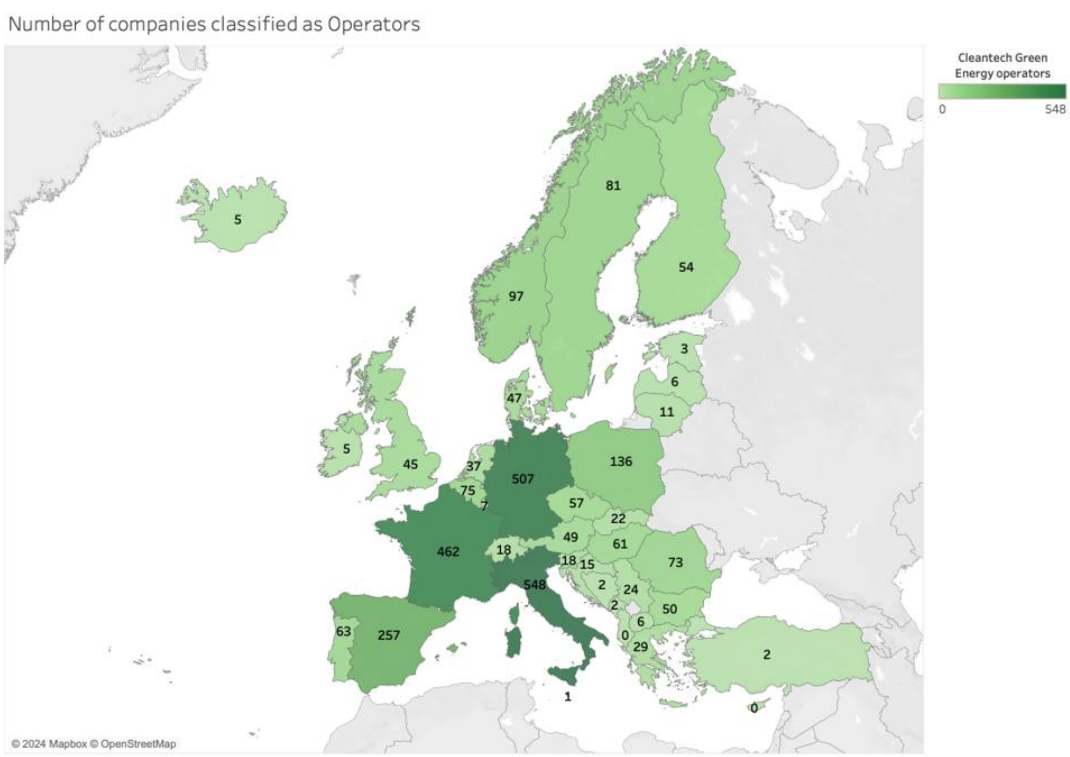


FIGURE 3.10: Geographic distribution of Green Energy Operators



As we can see from the maps, Germany almost always ranks first across the different categories and ecosystem segments, followed by Italy, France and Spain. Just two cases (Energy Efficiency companies (3.3) and Green Energy Operators), Italy overcomes Germany. The other countries with a significant presence of Green Energy companies are Poland, Sweden and Austria.

3.1.4 | By sector

This section illustrates the cross-sectoral nature of Green Energy, by describing the distribution of companies over the different NACE rev.2 section. The NACE classification (Statistical Classification of Economic Activities in the European Community) is a sectoral classification system used to categorize economic activities and industries within the EU. Green Energy companies are indeed active across a wide range of sectors and some interesting conclusions regarding sectoral concentration can be drawn from this analysis.

If we consider the entire sample (Table 3.7, columns 2 and 3), the majority of Green Energy companies operate in the manufacturing (C) (22,8%), wholesale and retail trade (G) (17,3%), Electricity, gas, steam and air conditioning supply (D) (14,7%), water supply and waste management (E) (14,1%), and construction (F) (12,9%). These results are confirmed even when taking into consideration just the company classified as Ecosystem.

When considering only Green Energy innovators (Table 3.7, columns 4 and 5), there is a significantly stronger concentration in manufacturing (42,9%), which indicates that innovation occurs predominantly in capital-intensive sectors.

We want to highlight that 18 companies in the sample (5 classified as Innovators and 13 classified as Ecosystem) don't report any data as their NACE classification and thus they are not reported in Table 3.8.

Table 3.8 illustrates the sectoral distribution (according to the NACE rev.2 classification) of the sample of Green Energy companies for the three technological subcategories defined in section 2.3.1.

As far as companies belonging to Sustainable energy production (3.1), the biggest subcategory, they are predominantly active in the NACE sector Electricity, gas, steam and air conditioning supply (D) (21,7%), while companies belonging to Sustainable fuels (3.2) are mostly active in the manufacturing (C) (26,9%) and quite half of the companies belonging to Energy-efficient industrial technologies (3.3) are active in water supply and waste management (E) and wholesale and retail trade (G).

TABLE 3.7: Distribution of Green Energy companies by industry (NACE rev. 2)

NACE rev.2 section	Sample companies		Innovators		Ecosystem	
	#Companies	%	#Companies	%	#Companies	%
A - Agriculture, forestry and fishing	65	0,6%	9	0,5%	56	0,6%
B - Mining and quarrying	73	0,7%	7	0,4%	66	0,7%
C - Manufacturing	2555	22,8%	735	38,6%	1820	19,6%
D - Electricity, gas, steam and air conditioning supply	1643	14,7%	324	17,0%	1319	14,2%
E - Water supply; sewerage, waste management and remediation activities	1576	14,1%	26	1,4%	1550	16,7%
F - Construction	1449	12,9%	178	9,3%	1271	13,7%
G - Wholesale and retail trade; repair of motor vehicles and motorcycles	1941	17,3%	191	10,0%	1750	18,8%
H - Transportation and storage	143	1,3%	10	0,5%	133	1,4%
I - Accommodation and food service activities	30	0,3%	5	0,3%	25	0,3%
J - Information and communication	101	0,9%	21	1,1%	80	0,9%
K - Financial and insurance activities	289	2,6%	77	4,0%	212	2,3%
L - Real estate activities	135	1,2%	18	0,9%	117	1,3%
M - Professional, scientific and technical activities	850	7,6%	261	13,7%	589	6,3%
N - Administrative and support service activities	256	2,3%	32	1,7%	224	2,4%
O - Public administration and defence; compulsory social security	7	0,1%	1	0,1%	6	0,1%
P - Education	8	0,1%	0	0,0%	8	0,1%
Q - Human health and social work activities	25	0,2%	3	0,2%	22	0,2%
R - Arts, entertainment and recreation	11	0,1%	0	0,0%	11	0,1%
S - Other service activities	46	0,4%	8	0,4%	38	0,4%
Total	11203	100%	1906	1	9297	100%

TABLE 3.8: Distribution of Green Energy companies by industry (NACE rev. 2) and technological subcategories

NACE rev.2 section	Sustainable Energy		Sustainable Fuels		Energy efficiency	
	#Companies	%	#Companies	%	#Companies	%
A - Agriculture, forestry and fishing	27	0,4%	40	2,6%	12	0,3%
B - Mining and quarrying	46	0,7%	14	0,9%	17	0,4%
C - Manufacturing	1351	21,1%	416	26,9%	1004	22,4%
D - Electricity, gas, steam and air conditioning supply	1388	21,7%	312	20,2%	186	4,1%
E - Water supply; sewerage, waste management and remediation activities	638	10,0%	76	4,9%	1060	23,6%
F - Construction	928	14,5%	176	11,4%	530	11,8%
G - Wholesale and retail trade; repair of motor vehicles and motorcycles	787	12,3%	279	18,0%	1042	23,2%
H - Transportation and storage	84	1,3%	18	1,2%	52	1,2%
I - Accommodation and food service activities	24	0,4%	2	0,1%	8	0,2%
J - Information and communication	53	0,8%	7	0,5%	53	1,2%
K - Financial and insurance activities	194	3,0%	46	3,0%	82	1,8%
L - Real estate activities	73	1,1%	12	0,8%	67	1,5%
M - Professional, scientific and technical activities	594	9,3%	107	6,9%	247	5,5%
N - Administrative and support service activities	163	2,5%	29	1,9%	93	2,1%
O - Public administration and defence; compulsory social security	4	0,1%	2	0,1%	1	0,0%
P - Education	4	0,1%	1	0,1%	4	0,1%
Q - Human health and social work activities	13	0,2%	3	0,2%	13	0,3%
R - Arts, entertainment and recreation	7	0,1%	0	0,0%	5	0,1%
S - Other service activities	31	0,5%	7	0,5%	15	0,3%
Total	6409	100%	1547	100%	4491	100%

3.1.5 | By year of incorporation

Sustainability is certainly a main concern of contemporary days and attention for topics as renewable energy and energy efficiency has experienced a strong rise in recent years. Main drivers of this rise are the enhancing of common concerns towards climate change and regulatory evolutions.

Despite this, green energy is not a new phenomenon and precedes the current business expectations and regulatory shift. This is confirmed by our data, as illustrated in Table 3.9 and Figure 3.11, which illustrates the distribution of Green Energy companies by year of incorporation and shows that the majority (68,3%) of the companies were founded before 2005, prior to the broad and capillary diffusion of modern environmental concerns.

The drastic decline in the number of Green Energy companies founded after 2010 can be explained both by a financial reason (the aftermath of the Great Financial Crisis led to reduced investment and funding opportunities for sustainability-oriented innovative companies, an event known as “cleantech crash”), both by the methodological approach used to collect of the initial sample that censored the most recent companies.

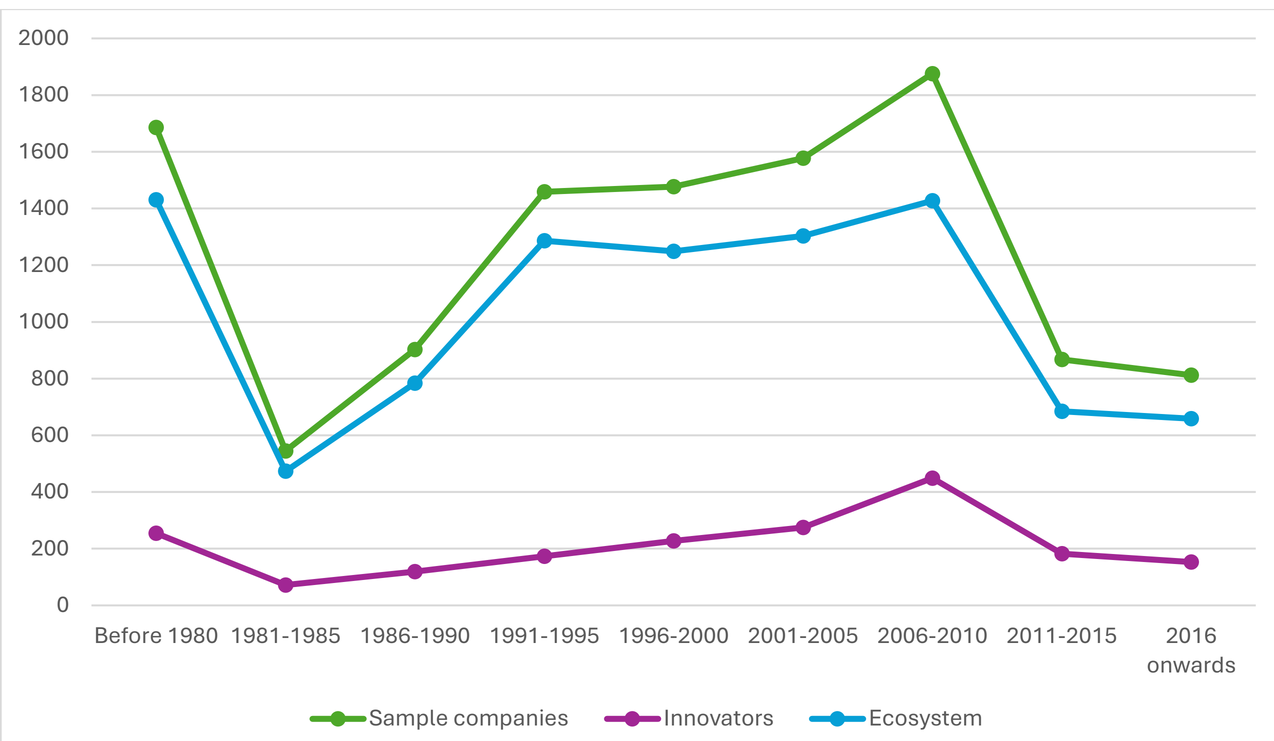
Things change if we consider just the Green Energy innovators: indeed, a big share of these companies (41,1%) has been founded since 2006 till nowadays. This shows how, even if green energy companies have always been existing, a large amount of innovation has coming up recently thanks to regulatory evolutions and global warming concerns.

We want to highlight that 18 companies of the sample (5 classified as Innovators and 13 classified as Ecosystem) don’t report any data as their Year of Incorporation and thus they not reported in Table 3.9 and Figure 3.11.

TABLE 3.9: Distribution of Green Energy companies by year of incorporation

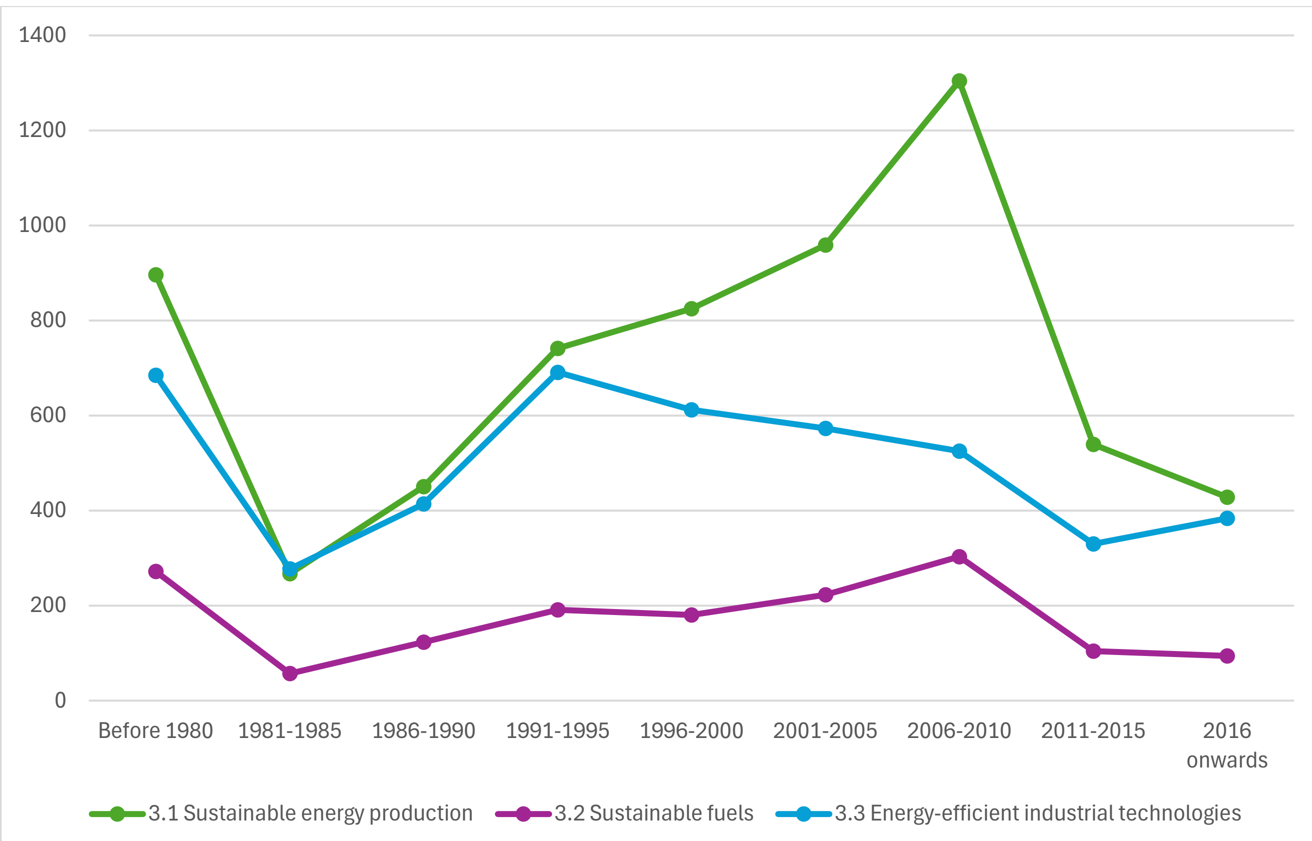
Year of Incorporation	Sample Companies		Innovators		Ecosystem	
	#Companies	%	#Companies	%	#Companies	%
Before 1980	1686	15,0%	255	13,4%	1431	15,4%
1981-1985	545	4,9%	72	3,8%	473	5,1%
1986-1990	903	8,1%	119	6,2%	784	8,4%
1991-1995	1459	13,0%	173	9,1%	1286	13,8%
1996-2000	1477	13,2%	228	12,0%	1249	13,4%
2001-2005	1578	14,1%	275	14,4%	1303	14,0%
2006-2010	1876	16,7%	449	23,6%	1427	15,3%
2011-2015	867	7,7%	182	9,5%	685	7,4%
2016 onwards	812	7,2%	153	8,0%	659	7,1%
Total	11203	100%	1906	100%	9297	100%

FIGURE 3.11: Distribution of Green Energy companies by year of incorporation



By plotting the evolution of Green Energy new-born companies by technological subcategory, Figure 3.12 reveals diverging trends in the emergence of technological-specific start-ups. Indeed, the declining trend in the number of Cleantech firm births initiated after 2010 for two categories, Sustainable Energy production (3.1) and Sustainable Fuels (3.2), while for Energy-efficient industrial technologies (3.3) the decline started at the beginning of 1990s.

FIGURE 3.12: Evolution of newly founded Green Energy start-ups by technological category (1981-2015)



3.2 | Financial KPIs

We collected and analyzed information on several essential financial KPIs from the database Orbis to construct a more detailed overview of the average scale of the Green Energy companies in our sample (Table 3.10). We analyzed 108.384 data points relating to 11.221 Cleantech companies over the period 2009 until 2022, to obtain the following results.

TABLE 3.10: Descriptive statistics for selected financial KPIs for the full sample of Green Energy companies

	Green Energy companies					
	#obs	Mean	Median	St. dev.	Min	Max
Sales	10,863	135.874 €	6.755 €	135874,6	0 €	159.000.000 €
Total Assets	10,531	115.629 €	6.995 €	1133765	0 €	72.500.000 €
Net profit	10,614	6.600 €	101 €	146675	-1.133.000 €	12.900.000 €
EBITDA	9,668	17.899 €	470 €	335614,6	-339.000 €	26.700.000 €
#Employees	7,354	451	39	5508,5	0	2,60E+05

In Table 3.11, we report the mean values of the main financial KPIs selected, separately for Green Energy innovators and ecosystem companies. We also reported the differences between their values, in order to highlight the diversity between the two clusters of companies, if any. Cleantech innovators typically operate at a larger scale, compared to their ecosystem counterparts, as the higher mean values of Sales, Total Assets, and Number of Employees show. We also performed a t-test comparison, as reported in the last columns of the table below: only Total Asset showed a difference with a significance level lower than 5%, while all the other financial metrics showed a significance level higher than 10%.

TABLE 3.11: Mean values for selected financial KPIs, Innovators vs Ecosystem

	Green energy Innovators	Green energy Ecosystems	Difference	Significance-level *
Sales	203.975 €	122.042 €	81.933 €	
Total Assets	167.230 €	105.183 €	62.047 €	(**)
Net profit	3.792 €	7.176 €	-3.384 €	
EBITDA	16.713 €	18.137 €	-1.425 €	
#Employees	661	408	253	

* (**) and (***) indicate significantly different means at the 5%- and 1%-level respectively

Table 3.12 shows the evolution of some aggregated financial KPIs across the period analyzed (from 2009 to 2021). Thanks to the data collected from Bureau Van Dick, we computed the total amount of Sales, EBITDA, Total Asset, Tangible Fixed Asset and Long-Term Debt aggregating for all the companies in the dataset. We analyzed the percentual variation and the CAGR over the aforementioned time span of 13 years to point out potential trends. In particular, a strong increasing trend across all the KPIs analyzed is noticeable: Sales have tripled, Total Asset and Tangible Asset have more than doubled, Long Term Debt has increased 8-fold. These results highlight the increasing importance that green energy companies play in the EU economy, the huge optimism that leads firm leaders to invest in assets, and the broader sense of trust that allows banks and financial players to borrow money to these companies.

TABLE 3.12: Financial KPIs' trends from 2009 to 2021

KPIs	Total value 2009 (€)	Total value 2021 (€)	Variation %	CAGR
Sales	180 B€	554 B€	207,14%	9 %
EBITDA	6,8 B€	82 B€	1109,49%	21,1%
Total Asset	735 B€	1680 B€	128,25%	6,6%
Tangible Asset	139 B€	289 B€	107,25%	5,8%
Lond Term Debt	8,9 B€	72,8 B€	721,63%	17,6%

3.3 | Patent data

Patents play a crucial role in explaining and analyzing the innovative potential of Green Energy companies, providing valuations and understanding of their technological power and competitive advantage. Examining patterns in their patenting activity allows us to assess the capacity to develop new solutions, thereby addressing environmental challenges and driving sustainable transition.

Starting with the identified sample of 11.221 Green Energy companies, we matched firm-level data with patent data in the Orbis Intellectual Property (Orbis IP) database by using the Bureau van Dijk company identifiers. We selected all patent applications filed by our sample companies at the European Patent Office (EPO) to ensure that the data is comparable across countries. Table 3.13 illustrates the distribution of EPO patenting Green Energy companies when considering the division between innovators and ecosystem companies. The findings show that over 1.200 companies (11,5% of the sample) filed at least one EPO patent. Furthermore, it seems that Innovators companies patent inventions at a significantly higher rate than the ecosystem companies: indeed, 21,3% of the formers figured out as EPO patenting company, while just the 8,7% of the latters did the same.

TABLE 3.13: EPO patenting activity of Green Energy companies

	Sample Companies		**Innovators**		**Ecosystem**	
	#companies	%	#companies	%*	#companies	%**
At least one in any field	1219	11,5%	407	21,3%	812	8,7%

*Of all Green Energy Innovators companies
*Of all Green Energy Ecosystem companies

The patenting intensity of specific technology categories typically depends on a number of factors, such as the technological content, its market potential, the intellectual property landscape typical of that market segment, regulations and policies considerations, or strategic reasons. Novel and disruptive technologies with commercial potential are more likely to be eligible for patents.

Table 3.14 reports the distribution of EPO patenting firms by technological category for the two sub-samples of companies belonging to Cleantech innovators and to the Cleantech ecosystem, respectively.

The technological category with the largest share of patenting companies is by far the one of Sustainable Energy production (3.1) in both groups, followed by Energy-efficient industrial technologies (3.3). These results are partially justified by the fact that technologic subcategories 3.1, 3.2 and 3.3 are the most represented in the collected sample, while the other categories are just occasionally covered by a few large and diversified companies that fall also in other technological categories. Given that each company can be associated with multiple technological categories, the totals are not the sum of the row values.

TABLE 3.14: Distribution of EPO patenting Green Energy companies by technological category and by ecosystem segment

Technological Category	**Innovators**		**Ecosystem**	
	# companies	%	# companies	%
Air/water/soil pollution abatement/remediation (1.1)	24	5,9%	102	12,6%
Waste management (1.2)	11	2,7%	85	10,5%
Water conservation/availability (2.1)	5	1,2%	30	3,7%
Sustainable agri-food technologies (2.2)	1	0,2%	6	0,7%
Sustainable raw materials (2.3)	4	1%	11	1,4%
Sustainable energy production (3.1)	264	64,9%	435	53,6%
Sustainable fuels (3.2)	26	6,4%	150	18,5%
Energy-efficient industrial technologies (3.3)	139	34,2%	312	38,4%
Capture, storage, sequestration or disposal of GHG (4)	1	0,2%	1	0,1%
Sustainable modes of transport (5)	11	2,7%	15	1,8%
Sustainable buildings (6)	44	10,8%	29	3,6%
Others (7)	0	0%	0	0%
Total	407	22,8%	812	9,2%

The innovative capacity of the local Green Energy ecosystem differs widely between countries. This depends on the local green policies, national culture towards environmental concerns, availability of green energy resources and knowledge, and presence of skilled researchers and workers. According to Table 3.15, Germany is the leader both when considering the whole Green Energy sample, both when considering the division between Innovators and Ecosystem. Even Italy and France show up a clear patenting leadership, followed by Spain and Sweden, countries with a clear abundance of clean energy resources potentially available in their territory.

TABLE 3.15: Distribution of EPO patenting Green Energy companies, Innovators and Ecosystem by country

Country	Sample Companies		Innovators		Ecosystem	
	#Companies	%	#Companies	%	#Companies	%
Germany	371	30,4%	116	28,5%	255	31,4%
Italy	225	18,5%	66	16,2%	159	19,6%
France	116	9,5%	31	7,6%	85	10,5%
Spain	92	7,5%	34	8,4%	58	7,1%
Poland	20	1,6%	7	1,7%	13	1,6%
Sweden	88	7,2%	34	8,4%	54	6,7%
Czech Republic	13	1,1%	4	1,0%	9	1,1%
Belgium	32	2,6%	12	2,9%	20	2,5%
Norway	29	2,4%	10	2,5%	19	2,3%
Austria	58	4,8%	19	4,7%	39	4,8%
Others	175	14,4%	74	18,2%	101	12,4%
Total	1219	100%	407	100%	812	100%

The following Figures 3.13, 3.14, 3.15 shows the geographical map of European green energy companies that filed at least an EPO patent. Figure 3.13 reports all the companies without distinction for business segments, Figure 3.14 reports just the Innovators and Figure 3.15 just the companies belonging to the Ecosystem.

FIGURE 3.13: Geographical distribution of patenting companies

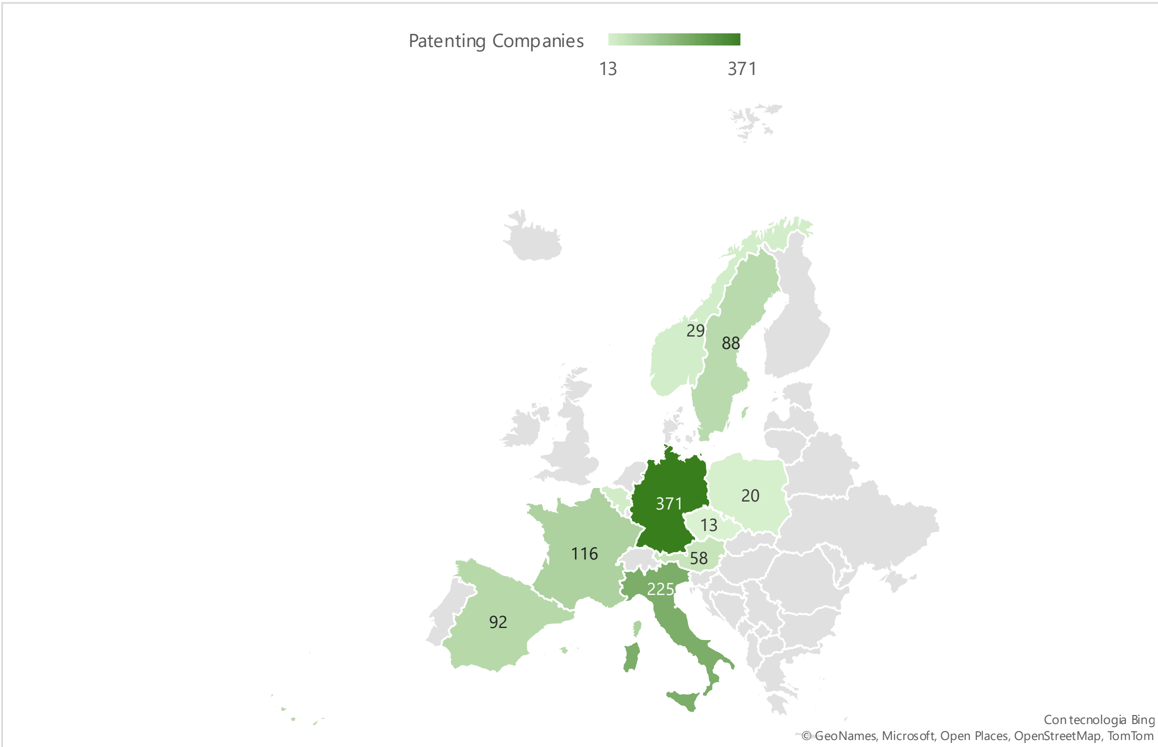


FIGURE 3.14: Geographical distribution of patenting Innovators

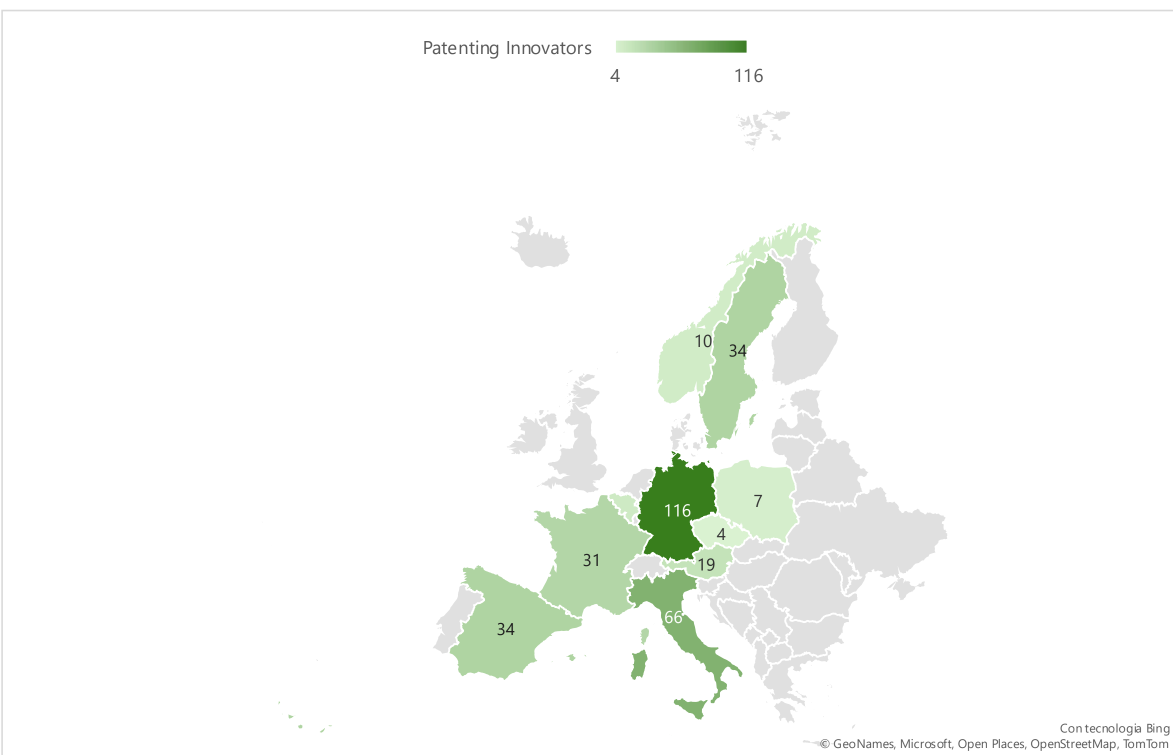
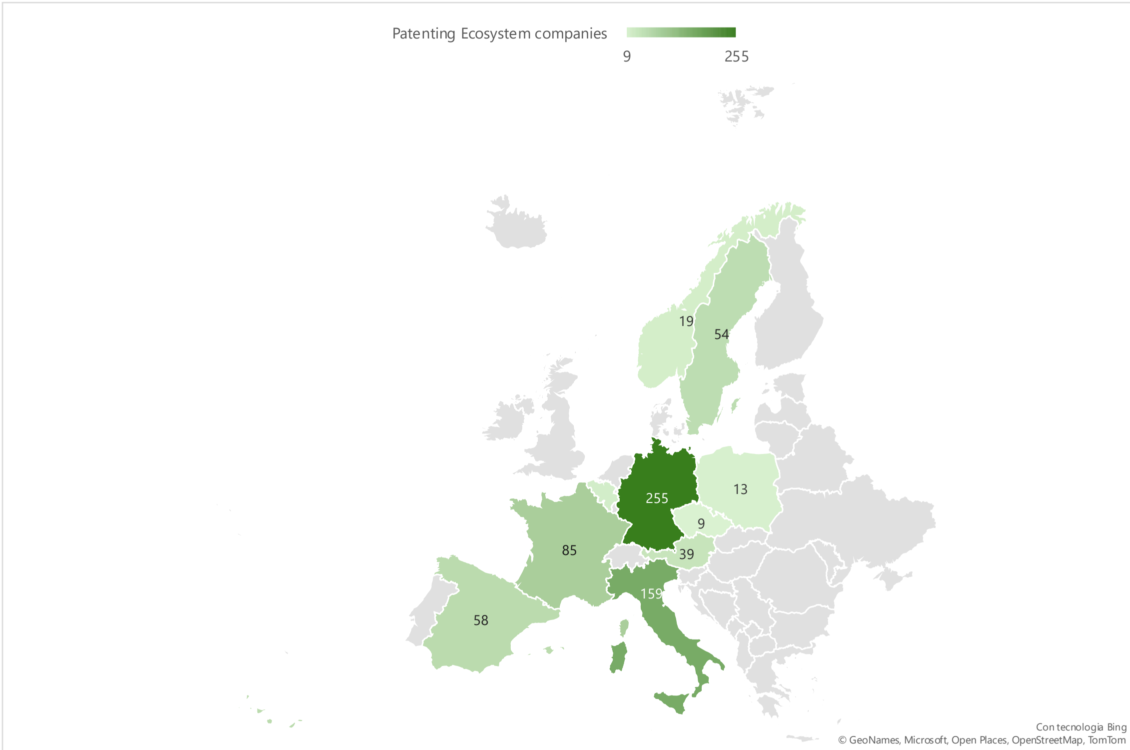


FIGURE 3.15: Geographical distribution of patenting Ecosystem companies



Finally, patenting intensity also differs depending on the ecosystem segments identified in section 2.3.2. Unsurprisingly, Experimenters engage most intensely in patenting activity (37,9%). They are followed by Manufacturers (21,5%) and Innovators (21,3%). Table 3.16 shows these results.

TABLE 3.16: Distribution of EPO patenting Green Energy companies by ecosystem segment

Ecosystem Segment	At least one EPO patent in any field	
	#Companies	%*
Innovators	407	21,3%
Experiments	11	37,9%
Manufacturer	484	21,5%
Distributors	64	4,5%
Integrators	132	4,8%
Operators	121	4,2%

*Of the related Ecosystem Segment companies

We have analyzed the cumulative number of patents that each company has filed, still considering the split into the different Ecosystem segments (Table 3.17). We have considered three ranges of companies: those that own between 1 and 5 patents, those that own between 6 and 20 patents, and those that own more than 20 patents. Across all the segments, the first range of companies is by far the biggest, while almost a quarter of Innovators and Manufacturer have filed between 6 and 20 patents, and little more than 20% of Innovators has filed more than 20 patents.

TABLE 3.17: Distribution of EPO patenting Green Energy companies by ecosystem segment, for different ranges of patents

Ecosystem Segment	#Companies with at least one EPO Patent	Between 1 and 5 EPO Patents		Between 6 and 20 EPO Patents		More than 20 EPO Patents	
		#Companies	%	#Companies	%	#Companies	%
Innovators	407	206	50,6%	109	26,8%	92	22,6%
Experiments	11	8	72,7%	2	18,2%	1	9,1%
Manufacturer	484	281	58,1%	128	26,4%	75	15,5%
Distributors	64	50	78,1%	10	15,6%	4	6,3%
Integrators	132	96	72,7%	22	16,7%	14	10,6%
Operators	121	97	80,2%	14	11,6%	10	8,3%

Then, we analyzed the trend in patent activity, focusing in particular on the period that we are analyzing, going from 2009 to 2021 (Table 3.18). We have analyzed the number of companies that have at least an EPO Patent and seen how this number changed over the time period of interest. The number of companies having registered at least an EPO Patent has slightly increased from 2009 to 2021 of +4%. We have analyzed the number of total patents registered by the companies in the dataset and seen how this number evolved between 2009 and 2021. The total number of patents have highly increased over the timespan analyzed, rising by 85,6%. The almost doubled number of patents compared to almost same number of companies filing patents shows us an important increase in the patenting activities of green energy companies.

TABLE 3.18: Evolution of patenting activity from 2009 to 2021

KPIs	2009	2021	Variation %
#Companies with at least a patent	1173	1219	+3,9%
#Patents	30129	55926	+85,6%

3.4 | Venture capital investment in Green Energy companies

Venture Capital financing (VC) is one of the most important sources of external funding for Green Energy start-ups. Innovations often require significant upfront investments in research and development, prototype design, and scaling up production. Venture capitalists are able to provide the funds needed to support such high-cost activities, which for their high-cost nature may hardly obtain financing from other traditional sources. In addition, Green Energy companies often face longer time horizons for commercialization and profitability, due to regulatory complexities, market adoption challenges, and technological advancements. VC investors, with their risk-tolerant approach and longer investment horizons, are well positioned to provide patient capital and support the company's growth over the long term.

Matching our data on Green Energy companies from the Orbis database with data on VC investment from VICO 4.0 (a pan-European dataset on VC investment activity developed by the RISIS2 EU-funded Horizon 2020 project, that contains more than 54.910 European VC investment deals), will allow us to develop a better understanding of the role of VC in European Green Energy development. Table 3.19 illustrates the involvement of VC investors in the Cleantech companies identified in Orbis.

A total of 251 companies (2,2% of the 11.221 companies in the sample) received at least one VC investment. Unsurprisingly, VC involvement is substantially larger for Green Energy innovators (4,9%), compared to the ecosystem companies (1,7%), due to the higher technologic content of the formers.

TABLE 3.19: Distribution of VC-backed Green Energy companies

	Sample Companies		Innovators		Ecosystem	
	#Companies	%	#Companies	%	#Companies	%
#VC-backed companies	251	2,2%	93	4,9%	158	1,7%
Total #Companies	11221		1911		9310	

Table 3.20 reports the distribution of VC-backed companies by technological category for the two groups of companies classified as Green Energy innovators and ecosystem, respectively. In both groups, the

category with the highest share of VC backed companies is Sustainable energy production (3.1), followed by Energy-efficient industrial technologies (3.3). These results are partially justified by the fact that technologic subcategories 3.1, 3.2 and 3.3 are the most represented in the collected sample, while the other categories are just occasionally covered by a few large and diversified companies that fall also in other technological categories. These findings show how Green Energy-related start-ups are highly supported by European Venture Capital and Private Equity investment activity. Furthermore, the centrality of Green Energy VC investment underlines the strong importance of this industry in addressing climate change and global warming. Each company can be associated to multiple technological categories, and thus the sum in the columns can exceed the total amount of the classification.

TABLE 3.20: Distribution of VC-backed Green Energy companies by technological category

Technological category	**Innovators**		**Ecosystem**	
	#Companies	%	#Companies	%
Air/water/soil pollution abatement/remediation (1.1)	1	1,1%	12	7,6%
Waste management (1.2)	1	1,1%	15	9,5%
Water conservation/availability (2.1)	0	0%	3	1,9%
Sustainable agri-food technologies (2.2)	0	0%	0	0%
Sustainable raw materials (2.3)	1	1,1%	2	1,3%
Sustainable energy production (3.1)	64	68,8%	102	64,6%
Sustainable fuels (3.2)	8	8,6%	25	15,8%
Energy-efficient industrial technologies (3.3)	24	25,8%	51	32,3%
Capture, storage, sequestration or disposal of GHG (4)	1	1,1%	0	0%
Sustainable modes of transport (5)	0	0%	4	2,5%
Sustainable buildings (6)	5	5,4%	8	5,1%
Other cathegories (7)	0	0%	0	0%
Total	93	4,9%	158	1,7%

Patents are important for investors as they protect the intellectual property rights of innovative technologies, thereby ensuring a competitive advantage and improving growth prospects for invested companies. Patents also enhance the attractiveness of companies to potential investors, by signaling the innovative potential of the patenting company. This holds true also for green technologies, as our data confirm. Table 3.21 presents the distribution of EPO patenting Green Energy firms categorized by their VC-backed status. Among the VC-backed firms, 39,8% of the companies have filed at least one EPO patent in any field, highlighting the strong innovative content of these firms.

TABLE 3.21: Distribution of EPO patenting Green Energy companies by VC-backed status

	At least one EPO patent in any field	
	#Companies	% of relative group
VC-backed firms	100	39,8%
Non VC-Backed firms	1119	10,2%
Total	1219	11,5%

Table 3.22 reports the distribution of VC-backed Green Energy companies by country. Among the VC-backed companies, the 25,5% is located in France, followed by Germany (13,5%), and Belgium (10,8%). The geographical distribution holds the same even when considering the division between Green Energy innovators and Ecosystem: unsurprisingly, France and Germany confirm to be leaders in VC investments, due to their highly developed system of incubators, accelerators and other facilities that connect start-ups to investors. Figure 3.16 shows the geographical map.

TABLE 3.22: Distribution of VC-backed Green Energy companies by country

Country	Sample Companies		Innovators		Ecosystem	
	#Companies	%	#Companies	%	#Companies	%
Germany	34	13,5%	15	16,1%	19	12,0%
Italy	10	4,0%	3	3,2%	7	4,4%
France	64	25,5%	21	22,6%	43	27,2%
Spain	17	6,8%	4	4,3%	13	8,2%
Poland	7	2,8%	2	2,2%	5	3,2%
Sweden	20	8,0%	9	9,7%	11	7,0%
Czech Republic	1	0,4%	1	1,1%	0	0,0%
Belgium	27	10,8%	12	12,9%	15	9,5%
Norway	11	4,4%	2	2,2%	9	5,7%
Austria	6	2,4%	1	1,1%	5	3,2%
Others	54	21,5%	23	24,7%	31	19,6%
Total	251	100%	93	100%	158	100%

FIGURE 3.16: Geographical distribution of VC-backed companies

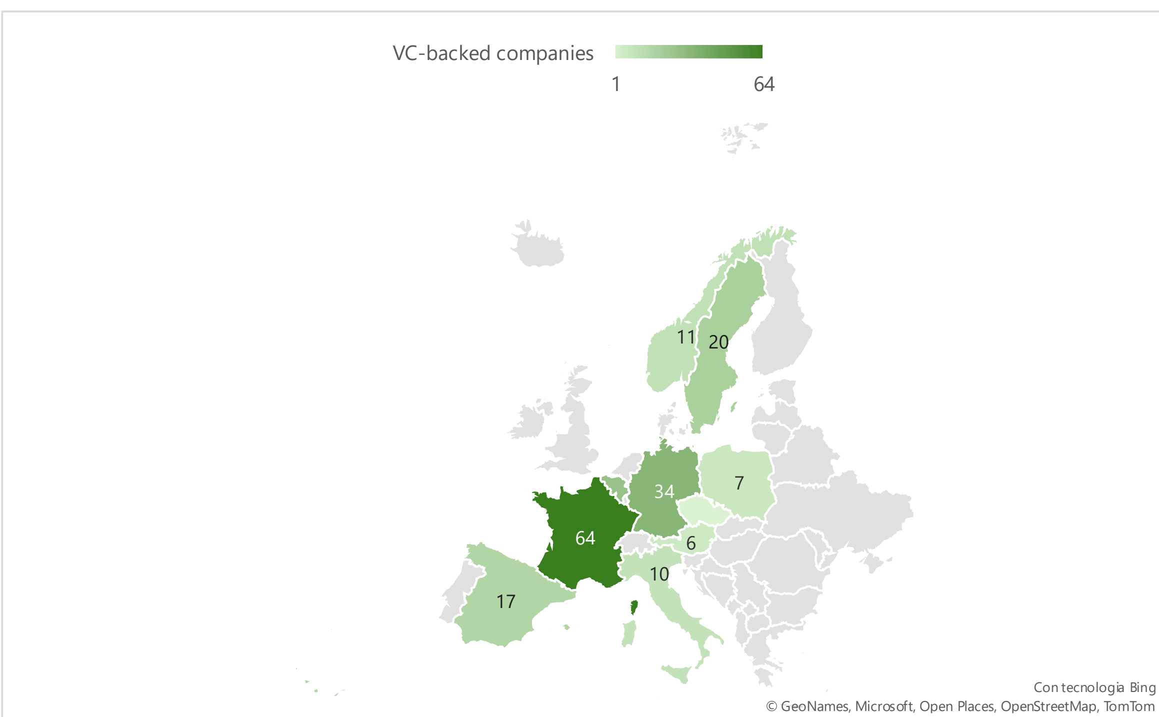


Table 3.23 reports the distribution of VC-backed Green Energy companies by ecosystem segment. The findings confirm that VC investors typically look for highly innovative companies with maximum growth potential. Indeed, 37,1% of VC-backed companies were classified as Innovators, followed by Manufacturers (25,1%) and Integrators (16,3%).

TABLE 3.23: Distribution of VC-backed Green Energy companies by ecosystem segment

Ecosystem Segment	**Sample Companies**		**Innovators**		**Ecosystem**	
	#Companies	%	#Companies	%	#Companies	%
Innovators	93	37,1%	93	100%	0	0,0%
Experiments	2	0,1%	0	0%	2	1,3%
Manufacturers	63	25,1%	0	0%	63	39,9%
Distributors	21	8,4%	0	0%	21	13,3%
Integrators	41	16,3%	0	0%	41	25,9%
Operators	31	12,4%	0	0%	31	19,6%
Total	251	100%	93	100%	158	100%

Then, we analyzed the trend in VC activity, focusing in particular on the period that we are analyzing, going from 2009 to 2021 (Table 3.24). We have analyzed the number of companies classified as Innovators and as Ecosystem that are VC-backed and seen how this number changed over the period of interest. The number of Innovators that are VC-backed has increased from 2009 to 2021 of +16,25%. While the number of Ecosystem companies that are VC-backed has increased from 2009 to 2021 of +16,7%. The two percentage changes are almost the same, showing there is no distinction between Innovators and Ecosystem when comes to attractiveness of venture capital investment opportunity. Furthermore, the rate of increase is quite important, showing increasing commitment by VC funds in the green energy sector.

TABLE 3.24: Evolution of VC-backed Innovators and Ecosystem companies from 2009 to 2021

VC-backed companies	2009	2021	Variation %
#Innovators	80	93	+16,25%
#Ecosystem	135	158	+17%

4 | LITERATURE REVIEW AND CURRENT TRENDS

In this Chapter we summarize what is stated by academic literature regarding environmental degradation, the correlation that links it to economic growth, what is the impact that renewable energy has on Carbon Dioxide emissions and how policies and legislative frameworks could help foster a solid and wide green energy ecosystem. We also analyze in detail the different initiatives undertaken by the European Union to help renewable energy diffusion, and the trends that the EU is experiencing with regards to reduction in greenhouse gases emissions and fossil fuels usage.

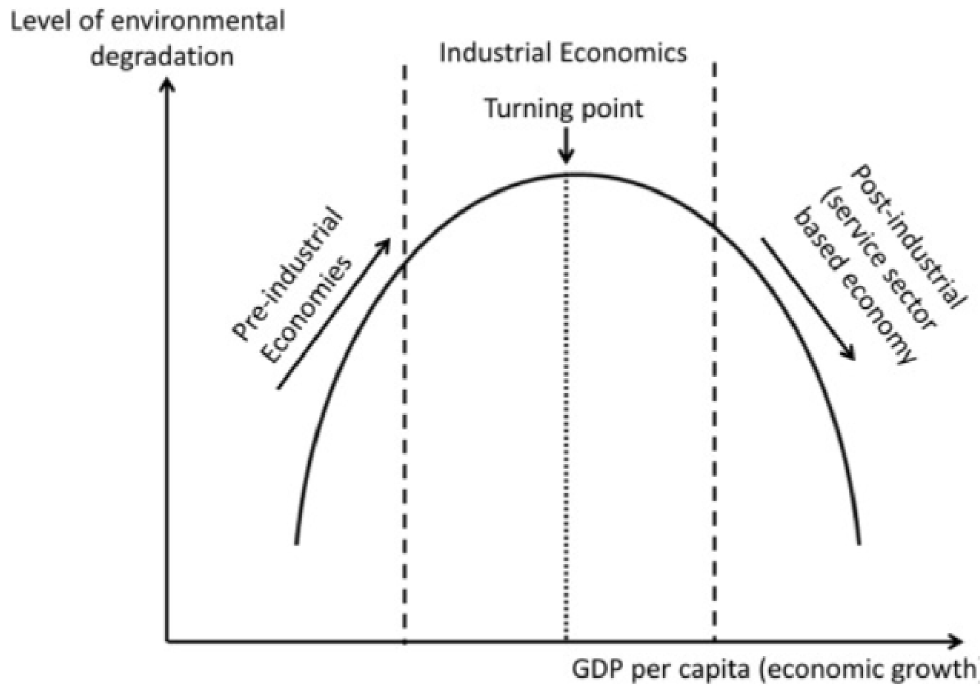
4.1 | The Environmental Kuznets Curve for CO2 Emissions

The Environmental Kuznets Curve (EKC) is an important economic theory that postulates an inverse U-shaped relationship between several environmental variables and per capita income. According to this theoretical model, environmental pollution would rise during the early phases of an economy, peak, and then decline as a nation's wealth increases, because it becomes able to purchase greener technologies and more sensible environmental regulations.

In 1991, Grossman and Krueger introduced the EKC concept, which bears the name of the economist Simon Kuznets, who previously proposed a comparable correlation between economic progress and income inequality. The study focused on the environmental effects of the North American Free Trade Agreement (NAFTA) and confirmed the U-shaped features of the proposed correlation. EKC has been tested on several contaminants, such as particulate matter, CO2, and SO2. Some studies showed that the EKC's general application may differ based on the kind of pollution taken into account as well as the unique socioeconomic and environmental features, and policy circumstances of the nation being studied.

Figure 4.1 reports the Environmental Kuznets Curve, as elaborated by Stern (2004).

FIGURE 4.1: The Environmental Kuznets Curve



As shown in the picture, the EKC can be divided into 3 main stages:

- Initial economic development: in the first decades of the evolution of a new economy, the pressure on the economic actors, companies and individuals to produce more and to increase their level of wealthiness is higher than the environmental concerns arising from these dirty economic activities. The only way to substantially increase national GDP seems to be degrading the environment. This is mostly true in the industrializing phase of an economy, because this process is highly supported by polluting and cheaper forms of energy: this was the case of Western Countries during the first and second Industrial Revolution and this is the case nowadays for fossil-based emerging countries, as Eastern Europe, Middle East, India and China.

- Environmental turning point: this is the most important component of the EKC, where the income level at which environmental degradation peaks and then starts declining is reached. After a country has reached a critical wealth level, economic growth stabilizes, and use of dirty economic activities and energy resources start declines due to the rising environmental concerns of market players. The higher level of income lets investors, businesses, and consumers pay more attention to environmental issues and pollution, so that sustainability-oriented policies and activities start to be carried out.

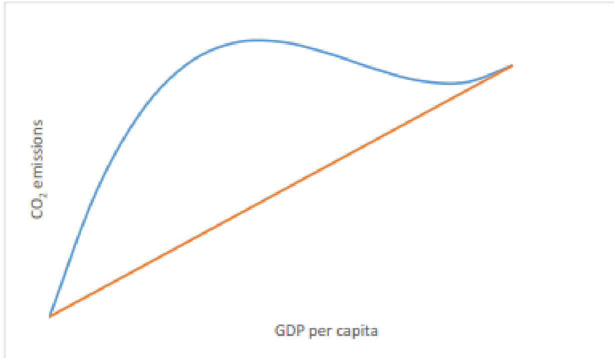
- Advanced development: eco-friendly consciousness increase, and general reduction of environment degradation occur at a higher pace. Another important force that pushes advanced economies to reduce pollution is the awareness that it is not possible anymore to further increase their own income level without paying more attention to the planet and to the consumption of resources. The industrial manufacturing activities are not anymore the locomotive of the economy as advanced countries are shifting towards a service economy. Demand for sustainable products booms and companies are deeply involved in decarbonization to meet customer needs.

Considering the figures reported above and the past evolution of the European Union economy, it is clear that the continent has already passed the Environmental turning point and has started the process of post-industrial service-based development. Thus, according to this model, if the EU wants to keep increasing its average per capita income level it needs to foster pollution reduction and sustainability.

The relationship between CO2 emissions and the Environmental Kuznets Curve EKC has been studied across the years by several researchers. This relationship was proved to be complex and depending on a multitude of factors, including the level of economic development, technological advancements in energy efficiency, and governmental eco-friendly policies. However, recent studies have shown that a solid correlation can be found for developed countries.

Indeed, Hannesson (2022) showed that, in rich countries, the Environmental Kuznets Curve based on CO2 emissions is valid but with CO2 emissions per unit of GDP falling at a declining rate and asymptotically reaching a constant level. This can be explained by the fact that rich countries have largely outsourced the production of CO2-intensive goods to developing countries. Thus, Hannesson proposed an EKC that sees CO2 emissions first declining and then slightly increasing towards an asymptote after the turning point (Figure 4.2). In any case, this shows that right after the environmental turning point, a reduction in CO2 emissions is absolutely necessary in order to sustain economic growth.

FIGURE 4.2: The Environmental Kuznets Curve based on CO2 emissions, proposed by Hannesson



The same result was achieved by Bilgili, Koçak and Bulut (2015). Their analysis came to the conclusion that there is a classic EKC relationship, showing an inverted U-shaped curve, where CO2 emissions first rise with GDP per capita and subsequently fall as GDP continues to climb. Moreover, the study shows that the usage of renewable energy has a negative influence on CO2 emissions, meaning that using it can successfully lower emissions and promote environmental sustainability. According to the research, policies that favor renewable energy can play a critical role in both reducing global warming and fostering economic expansion.

4.2 | The role of green energy in reducing CO2 emissions

How the Environmental Kuznets Curve for Carbon Dioxide emissions suggest, to increase GDP per capita a decrease in CO2 emissions is fundamental to such developed and rich economy as the one of European Union.

One of the most important methods for lowering CO2 emissions and slowing down climate change is to use renewable energy. Renewable sources of energy (including solar, wind, hydropower, and biomass) produce electricity with very little emissions of greenhouse gases. Indeed, the energy conversion processes for renewables usually produce little to no CO2. Renewable energy sources reduce the total amount of greenhouse gases in the atmosphere by displacing the demand for carbon-intensive energy sources. This immediately slows down global warming and promotes the development of sustainable energy sources.

There are several studies at every level that state how using green energy allows for important reductions in CO_2 emissions.

Mirziyoyeva (2023) analyzed the multidimensional relationship between economic growth, renewable energy, globalization, and climate change, using CO_2 emissions as a proxy for air pollution, and focusing on the 50 most globalized countries. It was found that renewable energy and globalization decrease CO_2 emissions. In particular, a 1 percentage point increase in the share of renewable energy in total energy consumption leads to a 0,26% decrease in CO_2 emissions per capita. This study also found that GDP per capita has an inverted U-shaped link with CO_2 emissions. Thus, it confirmed the presence of the EKC hypothesis for highly globalized countries.

Moutinho and Madaleno (2018) studied the main factors affecting CO_2 emissions with a focus on the top 23 countries for renewable energy consumption, carrying out an LMDI decomposition application. The model proposed breaks down carbon dioxide emissions into six main effects: carbon trade intensity, the trade of fossil fuels effect, fossil fuels intensity, renewable sources productivity, electricity financial power effect, and the financial development effect. The study examines data from 1985 to 2011 to determine which of these factors plays the bigger role in explaining the variations in CO_2 emissions over the period. The results coming from the analysis showed different positive and negative impacts in the behavioral change of CO_2 emissions throughout Europe as compared to the rest of the world. In particular, in Europe the productivity of renewable sources and the financial development effect in renewable electricity generation per GDP come out as the main responsible for the total and negative changes of CO_2 emissions in the last decades, underlining the leading role of green energy sector in lowering carbon footprint and how financial measures helping the development of this sector become more and more crucial to foster decarbonization.

Hdom (2019) explored the impact of electricity production broken down by energy sources (fossils and renewables) on carbon dioxide emissions in South America over the la decades. The research was focused on the relationship between carbon dioxide emissions, the energy mix in electricity generation and its implications for economic growth. The analysis verifies the presence of a positive relationship between renewable energy production, CO_2 reduction, and gross domestic product growth in a panel of 84 countries, between 1991 and 2012.

Other proofs of renewable energy's positive impact on CO_2 emissions at a global scale come from Bhattacharya and Churchill (2017). They have shown that additional factors, such as the role of public institutions, play a significant role in fostering the adoption of green forms of energy. In this study, they have examined the impact that renewable energy consumption and institutions had on economic output and CO_2 emissions across 85 developed and developing countries around the world, using annual data from 1991 to 2012, and employed alternative panel econometric techniques.
The results suggest that the role of institutions and renewable energy consumption has a significant positive and negative impact on the economic output and CO_2 emissions across the countries analyzed, respectively. Therefore, a significant presence of institutions and the use of renewable energy will strengthen the growth process and enhance environmental quality. For instance, countries with higher institutional quality give higher priority to sustainable economic development.

Kaur and Sandhu (2021) studied through multiple regression techniques what are the main drivers of the green energy sector development. The researchers have collected and analyzed Indian data from 2009 to 2019 and investigated 3 main green energy drivers: energy security, CO_2 emission, and social & economic development. Furthermore, the study emphasizes the critical role that renewable energy plays in fostering the growth of the green energy sector. Indeed, the study revealed that the most impactful independent variables on Green Energy development are renewable energy consumption per capita, energy usage per capita, and fossil fuel energy consumption.
They also discovered that the relationship between renewable energy and CO_2 emissions still holds even in countries that highly rely on fossil fuels: even in these cases, CO_2 has negative correlation with renewable energy consumption (on per capita basis).

If till now we have seen mostly proof of huge benefits deriving by green energy consumption when considering and analyzing a global perspective, there are plenty of specific studies focused on European countries that analyze renewable sources positive impacts on the EU economy.

For example, Albulescu and Artene (2019) examined the relationship between CO_2 emissions, renewable energy consumption, and environmental regulations within the European Union (EU). In particular, they analyzed the factors explaining the decrease of CO_2 emissions in the European Union (EU), focusing on 12 European countries and carrying out a panel data analysis over the period 1990 to 2017. They have

investigated mainly two factors: the impact of renewable energy share in energy production and the role of EU environmental regulations in explaining the reducing level of CO_2 emissions.
They have found out that the increase in renewable energy consumption significantly contributes to the reduction of CO_2 emissions, highlighting its crucial role in mitigating environmental impact. Furthermore, they have discovered that the impact of the EU's 2020 climate and energy regulation shows a positive effect on reducing emissions, validating the important role played by EU policymaking and Institutions in addressing climate change.
As a collateral result of their analysis, it has been confirmed that the Environmental Kuznets Curve hypothesis for EU countries still holds, demonstrating that CO_2 emissions initially increase with GDP but eventually decline as income jumps over the turning point.

Similar results have been found by Bayar and Gavriletea (2021). They have explored the combined effects of two main sustainability factors (municipal waste recycling and renewable energy) on the environment sustainability proxied by CO_2 emissions in EU member states over the period from 2004 to 2017, through panel cointegration and causality analyses. Their findings indicate that while the recycling of municipal waste has a partial negative impact on CO_2 emissions, the consumption of renewable energy confirms to be a major driver of CO_2 emissions reductions. Even this study supports the Environmental Kuznets Curve (EKC) hypothesis for EU countries.

4.3 | Current trends in the European Union

The European Union seems to have passed over the turning point of the Environmental Kuznets Curve by more than two decades, after the ratification of Kyoto Protocol in 1997. Considering that Carbon Dioxide emissions can be used as a proxy for environmental degradation (how demonstrated by aforementioned studies), the emissions of this gas by members of the European Union have been declined since the first years of 2000s, according to the data reported by different European Institutions, such as European Commission, Eurostat and European Environment Agency.

It can be affirmed that European Institutions and policymakers have correctly understood the implications of Environmental Kuznets Curve, or the fact that an advanced service-oriented economy, like the European one, cannot keep growing without a drastic reduction in environmental degradation, pollution and GHG emissions.

Indeed, driven by extensive legislation, strategic efforts, and ambitious goals aimed at lowering carbon emissions and combatting climate change, the European Union (EU) is increasingly shifting towards the adoption of renewable sources of energy. These actions are in line with the ambitious European Union's objective to become carbon neutral by 2050.

In the past years, European Institutions have launched different initiatives to foster CO2 emissions decrease for each Member State, undertaking a massive political and economic effort in order to reach the carbon neutrality goal. Here we summurize the main directives, packages, and plans adopted by the EU in its legislative framework:

- The Renewable Energy Directive (RED II), which was updated in 2018, establishes an obligatory renewable energy target for the EU. By 2030, the EU must source at least 32% of its energy from renewable sources. In a recent proposal for modifications by European Commissions, the target was shifted to 40% of renewable sources. RED II has promoted actions to increse the use of renewable energy sources, such as streamlined processes for smaller-scale projects and improved compensation guidelines for communities that use renewable energy.

- The European Green Deal (Figure 4.3), which was introduced in December 2019, is a plan for converting the EU into a modern, competitive, and resource-efficient economy. This all-encompassing framework of policies lays forth aggressive goals for cutting greenhouse gas emissions, with a particular emphasis on boosting the use of renewable energy sources. By 2050, there should be no net emissions of greenhouse gases, economic growth should be independent of resource use, and none of the Member States should be left behind.

- The Fit for 55 package, which is a partial modification of the European Green Deal launched in 2021, intends to enhance and amend existing EU laws in order to guarantee a minimum 55%

decrease in net greenhouse gas emissions by 2030 as compared to 1990 levels. The package also includes proposals to expand the EU Emissions Trading System (ETS) to enhance energy efficiency and renewable energy use. These changes will impact mainly the construction, land use, and transportation sectors.

- National Energy and Climate Plans (NECPs): in order to reach the energy and climate targets for 2021–2030, European Commission requires each Member State to develop a National Energy and Climate Plan clarifying the initiatives that each of them aims to undertake. These programs address five areas: energy security, the domestic energy market, energy efficiency, decarbonization, and research, innovation, and competitiveness. The NECPs are essential to understand each nation's plan to promote and consume more renewable energy.

- Horizon Europe: with a budget of about €95.5 billion for 2021–2027, this is the main funding initiative for research and innovation inside the European Union. A portion of its money is allocated to research and innovation in the green energy sector, promoting technological advancements that may result in greater use of renewable energy throughout Europe.

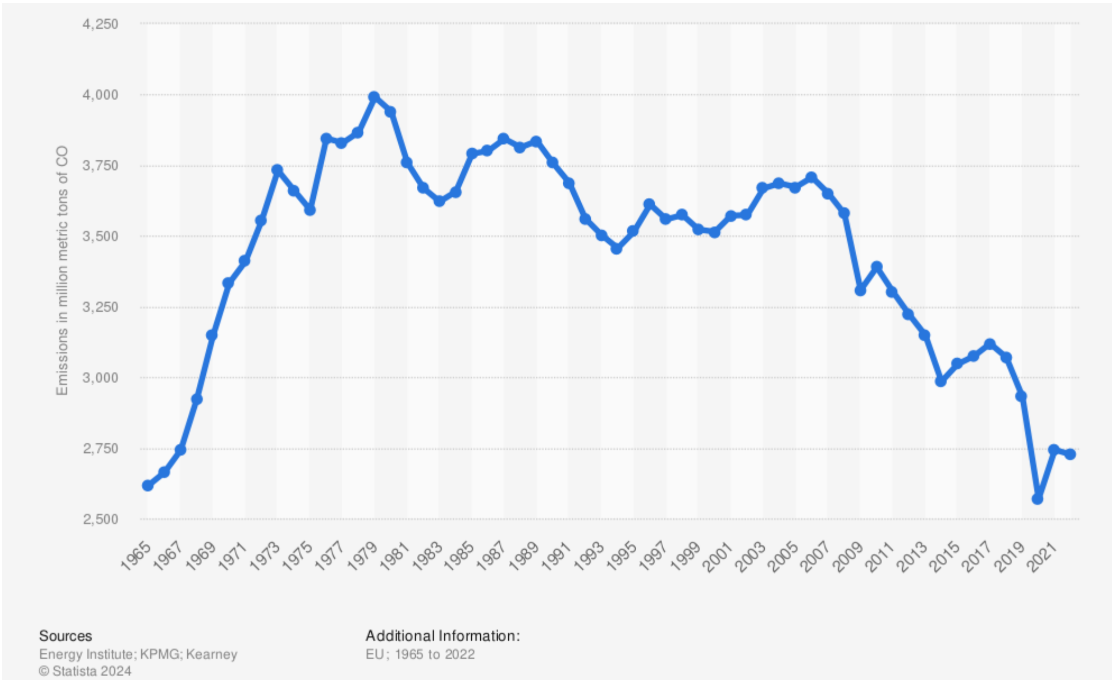
- REPowerEU: due to the geopolitical tensions resulting from Russia's invasion of Ukraine in 2022, the European Union launched this initiative to address the concurrent energy crisis. The main goal of REPowerEU is to fast-track the switch to renewable energy sources and diversify the energy mix in order to lessen the EU's reliance on Russian fossil fuels. Enhancing energy efficiency, increasing the generation of renewable energy (particularly solar and wind power), and encouraging energy savings in all the areas are the different lines of action of this initiative. The plan calls for actions to boost renewable hydrogen production and imports, upgrade energy infrastructure, and expedite the approvals process for renewable energy projects.

FIGURE 4.3: The European Green Deal

We are now trying to quantify the results that all EU's initiatives are delivering. Different data and analysis by Eurostat, Statista and a recently published report by the European Environment Agency reveals important insights as far as renewable energy adoption by European Countries.

As shown by Figure 4.4, in recent decades, the EU-27 has reduced net emissions of greenhouse gas (GHG) by almost one third. In 2021, net GHG emissions, including international aviation, decreased by 30% compared to 1990 levels. Estimates for 2022 indicate that net GHG emissions decreased by a further 2% compared to 2021 levels, resulting in an overall reduction of 31% since 1990.

FIGURE 4.4: Carbon dioxide emissions in the European Union from 1965 to 2022



In the last decades, renewable energy adoption boomed. Several data recorded by different European Institutions show a steady increase in green energy consumption from the first years of 2000s. As reported in Figure 4.5, the share of renewable energy use in total energy consumption was just 10,2% in 2005, while in 2021 it reached the 21,8%: this equals an average annual linear growth of 0,7%. According to the European Environment Agency this quantity is estimated to have risen to 22,5% in 2022, reaching a historical high and confirming the unstoppable adoption of green energy sources.

However, the increase in green energy consumption, even if it seems to be booming at a formidable rate, is still below the required average annual growth needed to achieve the 2030 targets. Figure 4.6 demonstrates that the effort still required to EU Member Countries is very high. Several aforementioned EU initiatives go in this direction, like the National Energy and Climate Plans.

FIGURE 4.5: Evolution of Renewable Energy share in the EU energy consumptions

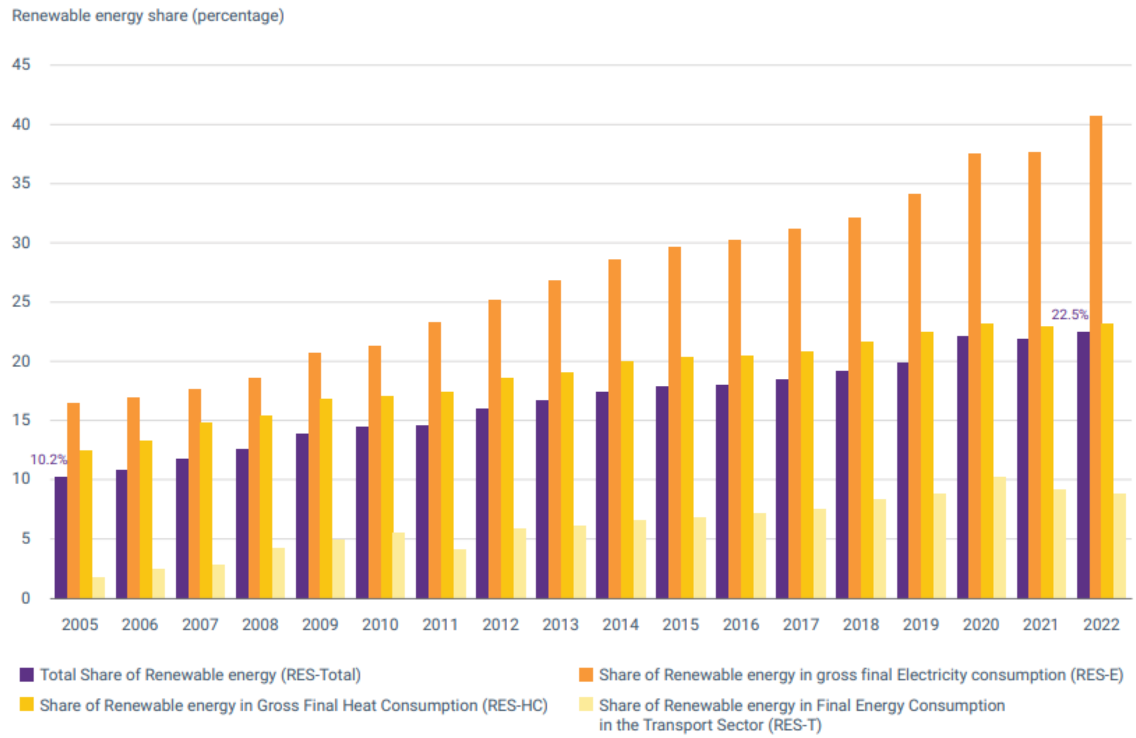
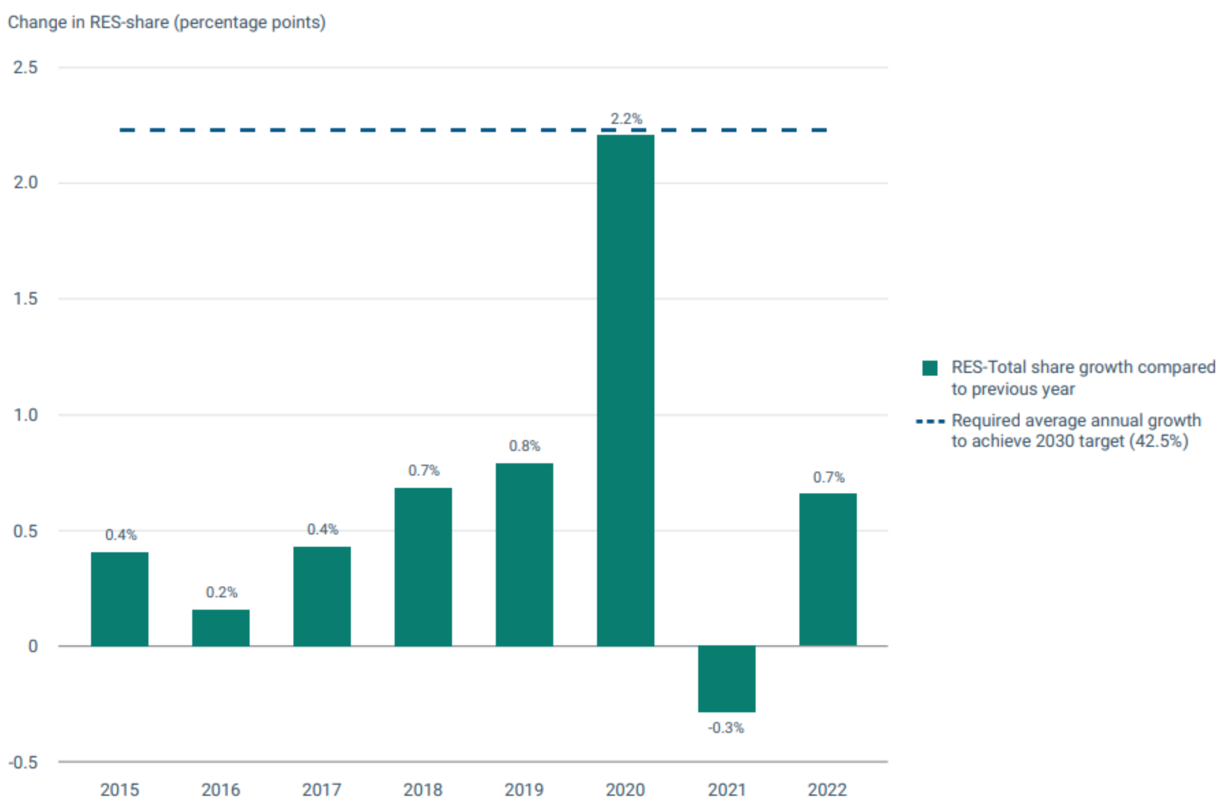


FIGURE 4.6: Recent growth in Renewable Energy shares vs required annual average

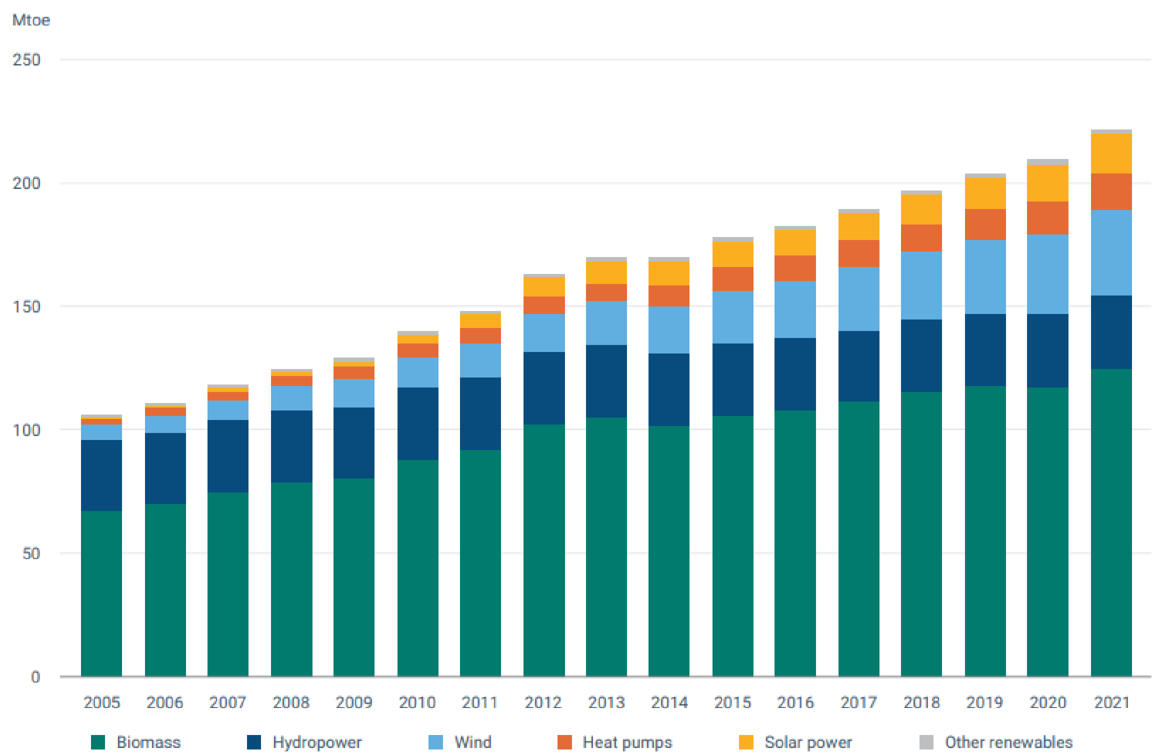


Another evidence of EU's advancements in adopting green energy is given by the changes in primary energy consumptions of the main sources of energy recorded in the last 15 years (measured in megaton of oil equivalent). As reported by Figure 4.7, renewable energy is the very single source that has experienced an increase in consumption while, on the opposite side, fossil fuels, oil and natural gas have seen a sharp decline in their usage. In particular, the largest reductions were experienced by solid fossil fuels, whose primary energy consumption decreased considerably by 40%, then oil and petroleum products were reduced by 23% and natural gas by 17%. The increase in renewable energy is particularly striking over this period, with a doubling of primary energy consumption between 2005 and 2022.

FIGURE 4.7: Changes in primary energy consumption in the last 15 years by sources

Now we analyze the single sources of green energy to understand which technologies are playing a leading role. As reported by Figure 4.8, the overall renewable energy consumption in the EU remains dominated by biomass over the period 2005-2021. Biomass made up 63% of the overall renewable gross final energy consumption in 2005 and stood at 56% in 2021. Hydropower used for generating electricity was the second largest renewable energy source up to 2018, after which wind power overtook its place. Solar power and heat pumps started off as small renewable energy sources in 2005 and have grown in parallel since then, with both standing at 7% of overall renewable energy consumption in 2021.

FIGURE 4.8: Renewable gross final energy consumption by technology in the EU



The huge increase in renewable energy adoption has highly impacted the European energy sector, mostly under the CO2 emissions point of view. The energy sector accounted for a quarter of the total EU-27 greenhouse gas emissions in 2021. However, it is also the sector that has made the most substantial contribution to reducing emissions. Since 2005, emissions have been declining at a rapid pace with multiple annual reductions of more than 5% recorded over the last decade, as shown in Figure 4.9. The replacement of coal by less CO2-intensive natural gas is an important factor in explaining the emission reduction, but in recent decades the roll-out of renewable energy has been the primary driver of this shift.

FIGURE 4.9: Evolution of GHG emissions in the European energy sector

4.4 | The role of EU policies in fostering green energy companies

There is a documented relationship between the expansion of green energy enterprises in the European market and EU environmental legislation. The goal of the European Union's strict environmental laws and programs is to move the Union toward a cleaner economy. The EU's green energy industry is developing and expanding because of this policy-driven transition, which involves significant investments in renewable energy and the advancement of green technologies.

Some aspects of European legislative framework have been crucial for the expansion of this sector. To the aforementioned European Green Deal, National Energy and Climate Plans and Renewable Energy Directive, other economic and financial mechanisms should be added when depicting the regulatory system in which green energy companies operate. These instruments are essential to build an economic landscape in which Cleantech companies can compete and thrive. We will now discuss deeper these mechanisms, how they work and their rationale.

A key component of the EU's green policy is the EU Emissions Trading System (EU ETS), one of the main tools for efficiently cutting industrial greenhouse gas emissions. Established in 2005, it was the first large-scale carbon trading scheme globally and continues to be the largest. The ETS works in this way: a cap is placed on the total quantity of specific greenhouse gases that can be released by facilities covered by the system, in accordance with the "cap and trade" concept. Companies can buy or receive emission allowances under this cap, which they can then exchange for other allowances as needed. The right to emit one ton of CO_2 or the equivalent quantity of other strong greenhouse gases is granted to the holder of each allowance. Over time, the cap is lowered to guarantee a decrease in overall emissions. As confirmed by the European Commission, ETS has revealed itself to be a particularly effective measure to encourage companies to reduce emissions by investing in more sustainable technologies.

The promotion of renewable energy has been greatly aided by market integration within the European Union since it has facilitated cross-border collaboration and energy trading among Member States. A unified energy market, which enables the smooth transmission and distribution of energy across national borders, optimizes the allocation of energy resources, lessens reliance on conventional fossil fuels, and facilitates this integration. The EU stabilizes prices and increases the security of the energy supply by tying together various energy markets, thereby reducing regional differences in energy supply and demand. Additionally, market integration helps the continent's renewable energy supply to aggregate, which is especially helpful for balancing discontinuous sources like solar and wind power. By increasing the efficiency and dependability of renewable energy, this strategic pooling speeds up its adoption and makes a substantial contribution to the EU's sustainability goals. A framework like this has been proved to promote economic growth and technological innovation in the green energy industry and to encourage investments in renewable infrastructure.

Other main legislative tools used by European Institutions have been financial and fiscal incentives, granted to both renewable energy producers and consumers. These instruments have long played a clear role in fostering green energy companies' diffusion, as demonstrated by Nicolini and Tavoni (2017). They have investigated the impact of monetary incentives on the production and installation of renewable energy in Europe's five largest countries (France, Germany, Italy, United Kingdom, and Spain) during the years 2000-2010. Their analysis focused on the effectiveness of two main policy instruments: feed-in tariffs (FIT) and tradable green certificates (TGC). The results of their econometric analysis showed a positive correlation between the number of subsidies and both the production of renewable energy and the installed capacity. In particular, a 1% rise in tariffs or incentives results in a 0,4–1% increase in the production of renewable energy. The study concludes that when it comes to encouraging the generation of renewable energy, feed-in tariffs work better than transferable green certificates. The research showed that these EU policies have been effective in promoting renewable energy both in the short (by boosting production) and in the long run (by contributing to increased installed capacity).

All these legislative actions and economic incentives have effectively shaped the European renewable energy sector in the last decades, benefiting not only the environment and the companies operating in this field, but also society in its broader sense. Different have been the positive outcomes that EU policies have produced on workforce, well before that the current mainstream actions have been released, as shown by Markandya and Arto (2016). Their study clarifies the role communitarian green policies had on job creation in the years 1995–2009, a topic that had been long debated by scholars and researchers. They used a multi-regional input–output model and the World Input–Output Database to monitor even the net employment impacts coming from spill-over effects between different sectors and countries. The period analyzed (1995–2009) saw the EU's energy structure going through a significant shift, taking the distance for the first time from the more carbon intensive sources and starting the conversion towards gas and renewables. The results showed that the net employment generated from this structural change was equal to at 530.000 jobs in the EU, of which one third is due to trans-boundary effects within the EU (employment generated in one country due to the changes in another). Within the Member States, the main gainers were Poland, Germany, Hungary, Italy and Spain, while the main losers were Ireland, Lithuania, France and Czech Republic.

To enhance energy efficiency, increase the share of renewables in the energy mix, and engage citizens actively in the energy transition, the European Union has considered as an integral part of its strategy the role of prosumers. This concept refers to an individual or entity that both produces and consumes renewable energy: prosumers can generate electricity for their own consumption, reduce their dependence on the traditional fossil-based power grid, and even feed surplus energy back into the grid. Their virtuous behavior is supported by the aforementioned mechanisms, such as feed-in tariffs. The role of prosumers is emphasized in several EU policies and directives, which advocate decentralized energy production and encourage the involvement of individuals in the energy market. Ines and Guilherme (2020) have analyzed the regulatory challenges and opportunities that collective renewable energy prosumers face across nine EU Member States. The research analyzed the legal frameworks and constraints influencing the deployment of collective renewable energy initiatives, such as energy communities and cooperatives. The study also illustrates how different national policies impact the possibility for collaborative prosumer projects. In particular, France, Germany, the Netherlands, and the United Kingdom provide more favorable regulatory conditions: in order to encourage communities to participate more actively in the production and distribution of renewable energy, these nations have implemented different support and connection systems. On the other hand, the research highlights that in Spain and Portugal more accommodative legislative frameworks that promote group renewable energy projects have just lately replaced restrictive ones.

All these examples show that, in the European Union, clear and strict environmental policies combined with different kinds of effective financial incentives have heavily and positively impacted the renewable energy sector and its employment, the green energy production and the installed capacity, the final consumption and the overall CO_2 emissions, the attitude and the activities of prosumers. All these results have been giving an important push to the development and the diffusion of the green energy sector, and to Cleantech in general.

These conclusions are not true only in the European context but have been proven to be valid worldwide. As shown by two OECD reports (2015 and 2023), policies and regulations have a crucial role in promoting renewable energy adoption at a global level. The analysis employed the OECD Environmental Policy Stringency (EPS) index to examine data from 30 OECD nations across 50 industries. The results imply that lower emissions are correlated with stricter environmental regulations: a unit rise in the EPS index results in significant reductions in emissions, especially over longer periods (12% reduction after 10 years for sectors with median fossil fuel intensity). Nevertheless, the research showed that sector-specific differences exist, with greater reductions observed in sectors with higher fossil fuel intensity. The report highlights the need for more aggressive policy changes in order to achieve the net-zero emissions targets, pointing out that the energy, industry, and transportation sectors have the greatest potential to reduce emissions.

4.5 | Our analysis

We have analyzed the implications of the Environmental Kuznets Curve for a developed and rich economy as the European one, in the case of environmental degradation approximated by Carbon Dioxide emissions; we have than reported different analysis and literature findings affirming that the consumption of renewable energy is negatively correlated with the CO2 emissions; we have deeply analyzed the current main energy trends in EU and how the several political and economic initiatives promoted by European Institutions are positively impacting the green energy transition; we have discussed how policymaking plays a crucial role in fostering decarbonization and the diffusion of renewable energy consumptions, not only in the EU but on a global scale.

Considering all these elements and starting from the descriptive data on green energy sector analyzed in the previous chapter, we can start our analysis.

We will study if there is a correlation between the evolution of CO2 emissions of a given country and the financial activity of the Green Energy sector of that country, represented by aggregated sales and total assets. The purpose of this analysis is to discover if, as reasonable, there is evidence of negative correlation between those financial and climate metrics and to understand its degree of significance. This analysis will be carried out on a sample of European countries that represent the large majority of the EU Green Energy Ecosystem. This will be discussed in the next chapter.

5 | CORRELATION ANALYSIS BETWEEN CO2 EMISSIONS BY COUNTRY AND LOCAL GREEN ENERGY FINANCIAL METRICS

In this Chapter, we explain the analysis we carried out to understand if and to what extent there is a correlation between a given country's CO2 emissions and the financial performance of its Green Energy companies, represented by Sales and Total Assets aggregated by country. We repeated this analysis on the seven countries with the biggest number of Green Energy companies that, how reported in Table 3.5, are France, Germany, Italy, Spain, Poland, Sweden and Austria. We highlight the sources of data, the procedure and the method adopted, the results coming from the analysis and the conclusions we drafted.

5.1 | Overview at a European level

It is possible to collect data on country-level CO2 emissions from different EU Agencies and Institutions. Our main source was EDGAR, the "European Union Emissions Database for Global Atmospheric Research". It is a global database that monitors greenhouse gas and pollution emissions produced by human activity. Through the consolidation of emissions data from several global sources, EDGAR facilitates scientific investigations and policy making coping with climate change and air quality. The database offers comprehensive datasets that are essential for modeling and assessing the environmental effects of specific gases and pollutants in various locations and time periods.

The dataset on Green Energy Companies we have analyzed in Chapter 3 reports observations from the 1980s to 2022, but some years of data recorded show some inconsistencies or lack completeness. The database offers a good picture of the sector just from 2009 onwards, but some concerns regarding the macroeconomic environment led us to further restrict our time horizon. In particular, we have decided not to include in our analysis the years going from 2009 to 2011, since the economic performance of Green Energy companies (like that of the other industries) was highly impacted by the consequences of the Financial Crisis and by the following European Sovereign Debt crisis. For these reasons those years don't represent correctly the financial results and the potential of the Green Energy sector, indeed they show data and statistics quite different from the ones of the following years. Summing up, our correlation analysis will consider just the financial data of the years going from 2012 to 2021.

From EDGAR, we gathered data concerning each single EU Member State total CO2 emissions over the period of our study, to analyze the overall trend experienced by each country and by the whole Union over this timeframe. Table 5.1 provides these data and shows the variation in CO2 emissions of each country. The EU27 CO2 emissions have seen an overall reduction of 15% over the analyzed period, a great result coming from the wide set of communitarian strategical goals, stringent policies, economic incentives, and financial aids we have analyzed in the previous chapter. This result, that could seem extraordinary if compared with the global trend (worldwide CO2 emissions raised by 20,8% over 2009-2022 period, signaling a terrible ineffectiveness of global initiatives to stop global warming and climate change) is still not in line with the ambitious EU targets of total carbon neutrality by 2050. Thus, further effort in shifting towards renewable sources of energy and towards improving overall energy efficiency is still required to Member States.

Estonia is the nation where CO2 emissions fall most, given that the Baltic country almost halved its emissions over the time horizon analyzed (-47,3%), followed by Malta (-37%). The small size of these countries and the limited dimensions of their energetic demand make it quite simpler to convert the National energy mix. It is quite difficult for bigger countries to get similar astonishing decarbonization results, apart from Greece. Greece reports the third largest reduction, having reduced its CO2 emissions by almost a third (-30,3%). This result is mainly due to the deep and tragic economic slowdown lived by the Aegean country over the past decade, caused by the financial crisis of 2008 and the European Sovereign Debt crisis of 2011, whose negative outcomes impacted on the Hellenic economy over the whole period analyzed. The sharp falling of Greek GDP and economic activities, and the high reduction in internal energy consumption are the main drivers of its emission trend.

Between the larger countries, the greatest reductions are recorded by Finland (-28,1%) and Denmark (-24,5%). Those nations are European champions when talking about the decarbonization of national energy mix, being worldwide known for their massive renewable energy consumption. Indeed, Denmark is one of the leading EU Member States as far as renewable energy production, capacity installed and consumption. In 2023, the 80,8% of Danish electric grid power come from low carbon sources, with solar and wind energy contributing for almost 60%.

TABLE 5.1: Country-level total CO_2 emissions in 2012 and in 2022, and their variation

EDGAR Country Code	Country	CO2 emissions 2012 (MtCO2)	CO2 emissions 2022 (MtCO2)	Variation (%)	Absolute Variation
AUT	Austria	68,9	61,2	-11,2%	-7,7
BEL	Belgium	102,8	90,4	-12,0%	-12,4
BGR	Bulgaria	49,9	50,1	0,5%	0,2
CYP	Cyprus	7,1	7,5	4,8%	0,3
CZE	Czechia	113,5	101,5	-10,5%	-11,9
DEU	Germany	795,7	673,6	-15,3%	-122,1
DNK	Denmark	38,6	29,2	-24,5%	-9,5
ESP	Spain and Andorra	286,6	254,4	-11,3%	-32,3
EST	Estonia	20,6	10,8	-47,3%	-9,7
FIN	Finland	51,9	37,3	-28,1%	-14,6
FRA	France and Monaco	365,2	315,3	-13,7%	-49,9
GRC	Greece	81,5	56,8	-30,3%	-24,7
HRV	Croatia	18,7	17,2	-7,8%	-1,5
HUN	Hungary	47,3	47,3	0,0%	0,0
IRL	Ireland	37,4	37,8	1,0%	0,4
ITA	Italy, San Marino and the Holy See	394,0	322,9	-18,0%	-71,1
LTU	Lithuania	14,5	13,3	-8,4%	-1,2
LUX	Luxembourg	10,9	7,6	-30,2%	-3,3
LVA	Latvia	8,0	6,7	-16,2%	-1,3
MLT	Malta	2,7	1,7	-37,0%	-1,0
NLD	Netherlands	170,5	134,7	-21,0%	-35,8
POL	Poland	319,8	322,0	0,7%	2,1
PRT	Portugal	49,7	41,3	-17,0%	-8,4
ROU	Romania	86,7	77,3	-10,9%	-9,4
SVK	Slovakia	35,8	35,2	-1,7%	-0,6
SVN	Slovenia	15,5	13,9	-10,1%	-1,6
SWE	Sweden	46,9	37,9	-19,3%	-9,0
EU 27		3240,8	2804,8	-13,5%	-435,9
Global Total		35380,0	38522,0	8,9%	3142,0

As far as the seven countries analyzed in our research, Sweden ranks the first, reporting a reduction of -19,3%, followed by Italy (-18%), Germany (-15,3%), France (-13,7%), Spain (-11,3%), Austria (-11,2%), and Poland that is one of the 5 European Countries (with Bulgaria, Cyprus, Hungary and Ireland) which increased the CO_2 emissions over the period analyzed (+0,7%): an astonishing data that shows a counter trend in the decarbonization results achieved by the EU, and that we will explain better later on.

Just Italy, Sweden, Germany and France were able to overcome the EU average of -13,5% reduction recorded over the period, while Spain and Austria fell little behind, and Poland failed completely to reduce emissions. The CO_2 emissions reduction reported by these countries, by far lower than the ones of Estonia, Malta, Greece, Finland, or Denmark are mainly motivated by the complexity and the largeness of their industrial networks, the decisions made on the best energy mix to be adopted, different energetic strategies, the economic and financial contingencies and national regulation limitations.

If we consider the absolute variation of CO_2 emission instead of the relative variation, the ranking changes quite radically and we can observe that the greatest reductions are achieved by the seven countries analyzed in our research. Indeed, Germany is the European leader in absolute CO_2 emission reduction, having reported a negative variation of 122,1 $MtCO_2$. Italy ranks second with a reduction of 71,1 $MtCO_2$, while France takes the third place with a reduction of 49,9 $MtCO_2$.

So, the landscape on which we carried out our correlation analysis is given by a generally large decrease in CO_2 emission by European countries, which occur in a very different magnitude between different states and is motivated by different drivers, factors, and contingencies. We now aim to understand if and to which extent this decrease can be explained by changes in the local green energy sector's economic activity and financial performance (we will use total aggregated revenues and total aggregated assets in a given year for a given country as financial metrics).

We will now carry out this analysis on the seven countries selected (France, Germany, Italy, Spain, Poland, Sweden and Austria) because they represent the biggest portion of European green energy network, in terms of number of companies operating in this sector.

For each country, we have computed from the dataset the total revenues and total assets of green energy companies in each year spanning from 2012 to 2021. Correspondingly, we have collected from EDGAR the amount of total absolute CO_2 emitted (measured in $MtCO_2$), CO_2 emitted per unit of GDP (tCO2/kUSD) that measures the "carbon intensity" of an economic system, and CO_2 emitted per capita (tCO2/cap). We report in the next paragraphs the environmental data for each country, the aggregated financial metrics, and the multiple linear regression between the CO_2 emissions and the country-level aggregate revenues and total assets of the green energy companies, to understand if there is a correlation between them and what intensity does it shows.

The companies' financial data are available in the original dataset on the green energy sector we analyzed in the previous chapters. We excluded the financial data referring to fiscal year 2022 because incomplete and partially inconsistent.

In this analysis we have lagged by 1 year the CO_2 emissions data, because the activity of green energy companies isn't immediately reflected on the country's emissions but rather its effects are delayed. So, we have considered that the financial metrics of Year N are related to the CO_2 emissions of Year N+1: if total sales and total assets go from 2012 to 2021, CO_2 emissions go from 2013 to 2022.

5.2 | Correlation analysis for France

5.2.1 | France's CO2 emissions from 2012 to 2022

Table 5.2 reports the data of total CO2 emissions, CO2 emission per GDP and CO2 emission per capita for France, collected from EDGAR over the period 2012-2022.

Figure 5.1, Figure 5.2, and Figure 5.3 report those data graphically, in order to understand better the evolution and the trends of French CO2 emissions over the analyzed time horizon.

TABLE 5.2: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for France over the period 2012 -2022

Year	Total CO2 (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	365,2	0,130	5,7
2013	359,7	0,127	5,6
2014	326,9	0,115	5,1
2015	331,9	0,115	5,1
2016	335,1	0,115	5,1
2017	338,5	0,114	5,2
2018	327,6	0,108	5,1
2019	321,6	0,104	4,9
2020	286,3	0,100	4,3
2021	324,7	0,107	4,9
2022	315	0,101	4,8
Variations	**-13,7%**	**-22,3%**	**-16,4%**

FIGURE 5.1: France's Total Emissions (MtCO2) over the period 2012-2022

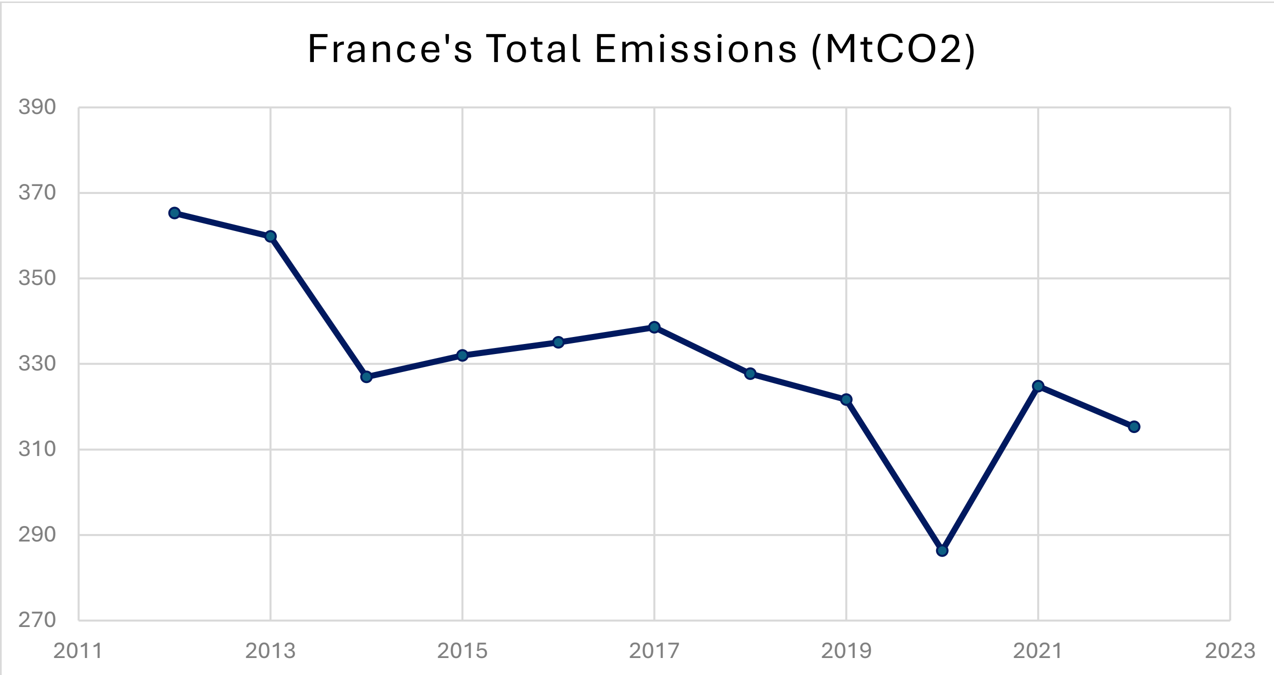


FIGURE 5.2: France's Emissions per GDP (tCO2/kUSD) over the period 2012-2022

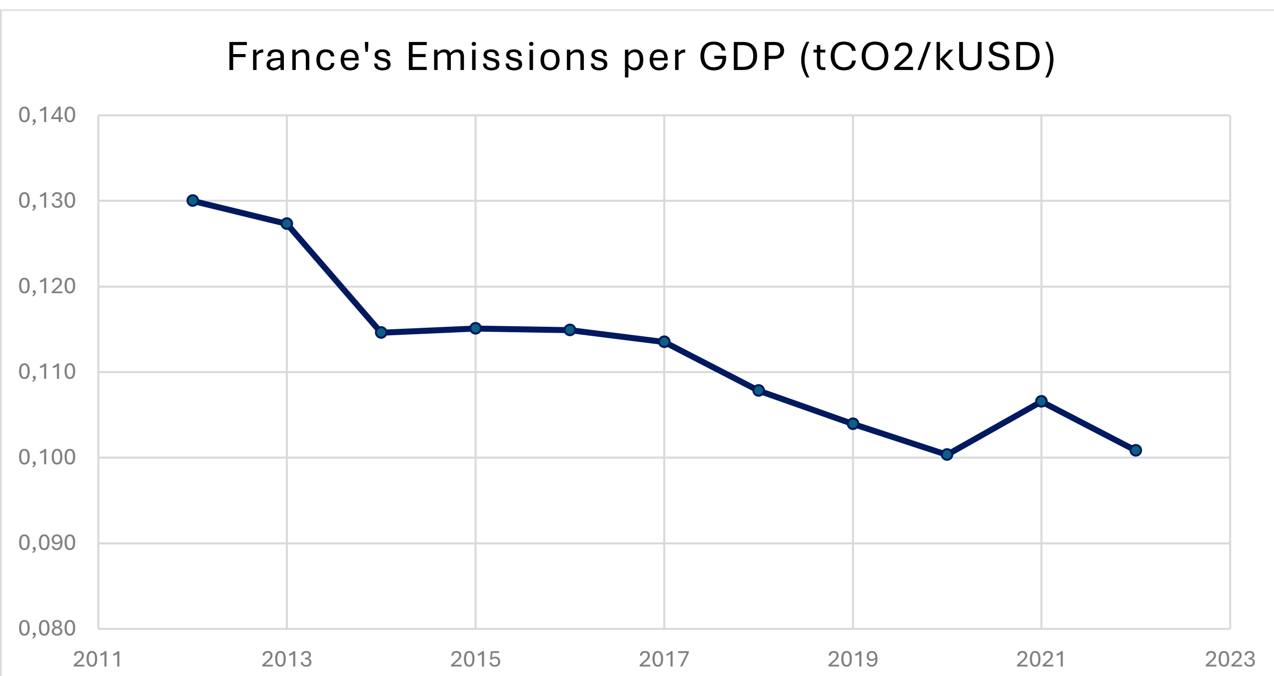
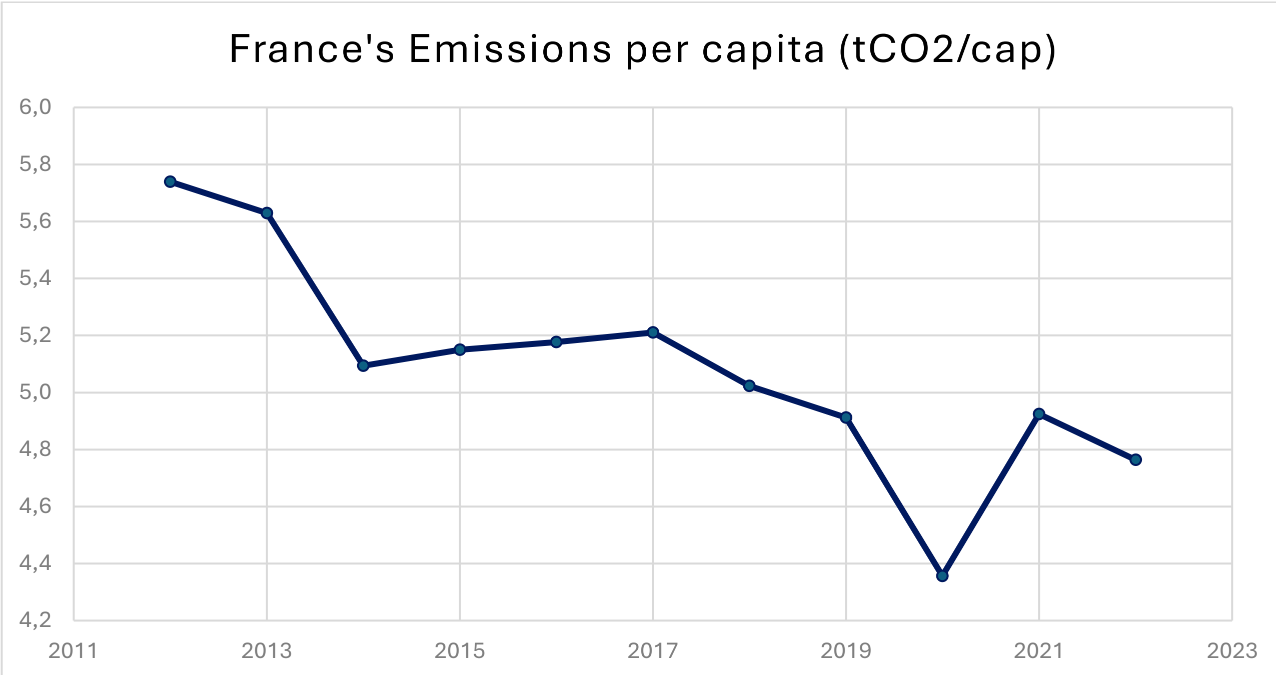


FIGURE 5.3: France's Emissions per capita (tCO2/cap) over the period 2012-2022



Over the period analyzed, France's total emissions have decreased by 13,7%, slightly better than EU average of 13,5%. This reduction could seem small if compared to those of Nordic countries but should not be translated in a negative judgement of French energetic and environmental decisions. Indeed, data from Statista shows that the French power mix is mainly dominated by nuclear (that in 2022 contributed for the 62% of overall electricity production) and hydropower (the second most important energy source, that accounted for 11% of the total electricity produced in 2022). The French energy mix is thus very clean nowadays, and it is more difficult than in other European countries to keep decarbonizing it in a significant way.

As far as absolute emissions, France is the third country in EU for MtCO2 emitted, despite being the second largest economy and having a population of almost 68 million, the second largest in EU. France's Emissions per GDP are a third lower and Emissions per capita are almost a half of the related German emissions respectively, with Germany being the biggest European Country for population and GDP.

The plot of Total Emissions (Figure 5.1) and Emissions per capita (Figure 5.3) show clearly the impact of Covid 19. The pandemic caused the sudden disruption of economic activities and changed significantly the way of living, the everyday activities and the related energy consumption and carbon emissions of millions of people, particularly in the western world. Indeed, the metrics of CO2 emissions report an outlier value in 2020, since it is substantially lower than the value recorded in the other years observed. Thus, to address the potential biased effect that Covid could have on our analysis, we used a dummy variable equal to 1 in 2020 and equal to 0 in all the other years.

5.2.2 | France's Green Energy aggregated financial metrics from 2012 to 2021

We have computed the aggregated sales and aggregated total asset of French Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category "3.1 Sustainable energy production", "3.2 Sustainable fuels", and "3.3 Energy-efficient industrial technologies".

Table 5.3 shows these financial metrics, while Figure 5.4 and Figure 5.5 plot their time series. French Green Energy aggregated sales have increased by 13,67% over the period analyzed, while aggregated total assets have increased by 44,6%.

TABLE 5.3: France's Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	1383	11,70	260,22
2013	1408	12,55	262,76
2014	1424	12,81	280,16
2015	1436	12,94	292,17
2016	1444	13,23	294,91
2017	1448	13,64	295,26
2018	1448	14,33	297,89
2019	1448	14	318,1
2020	1448	13,90	320,8
2021	1448	13,30	376

FIGURE 5.4: France's Green Energy aggregated Sales, from 2012 to 2021

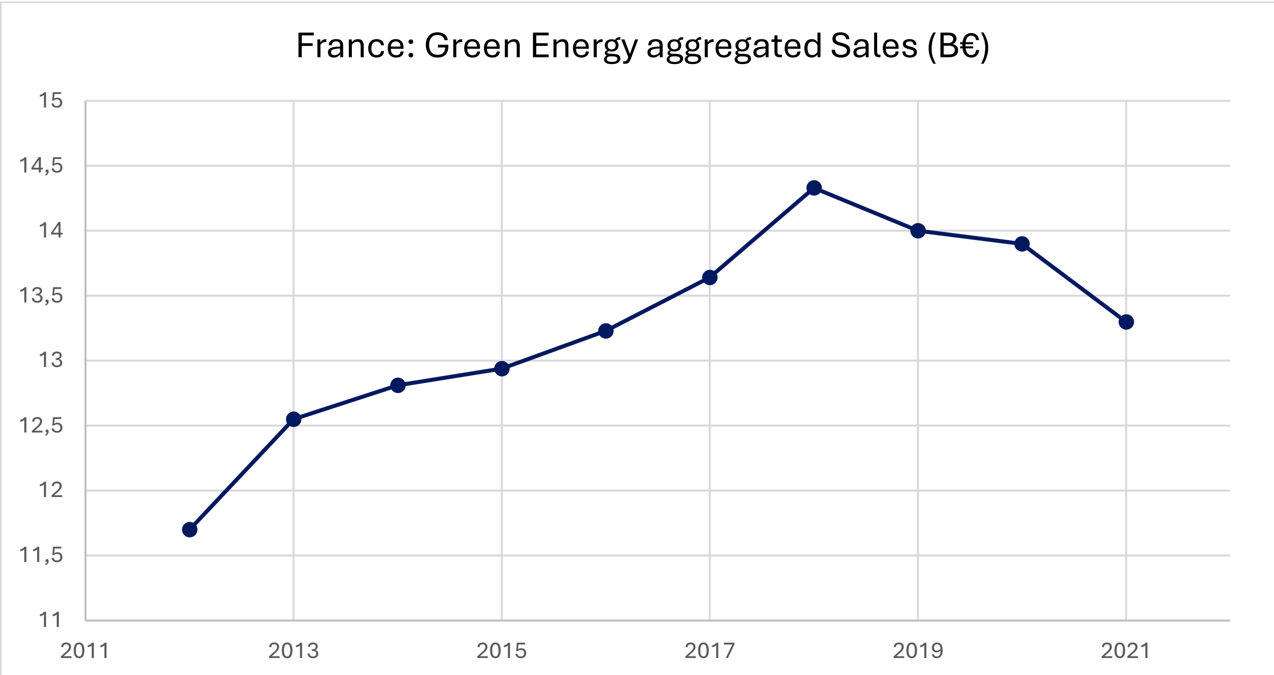
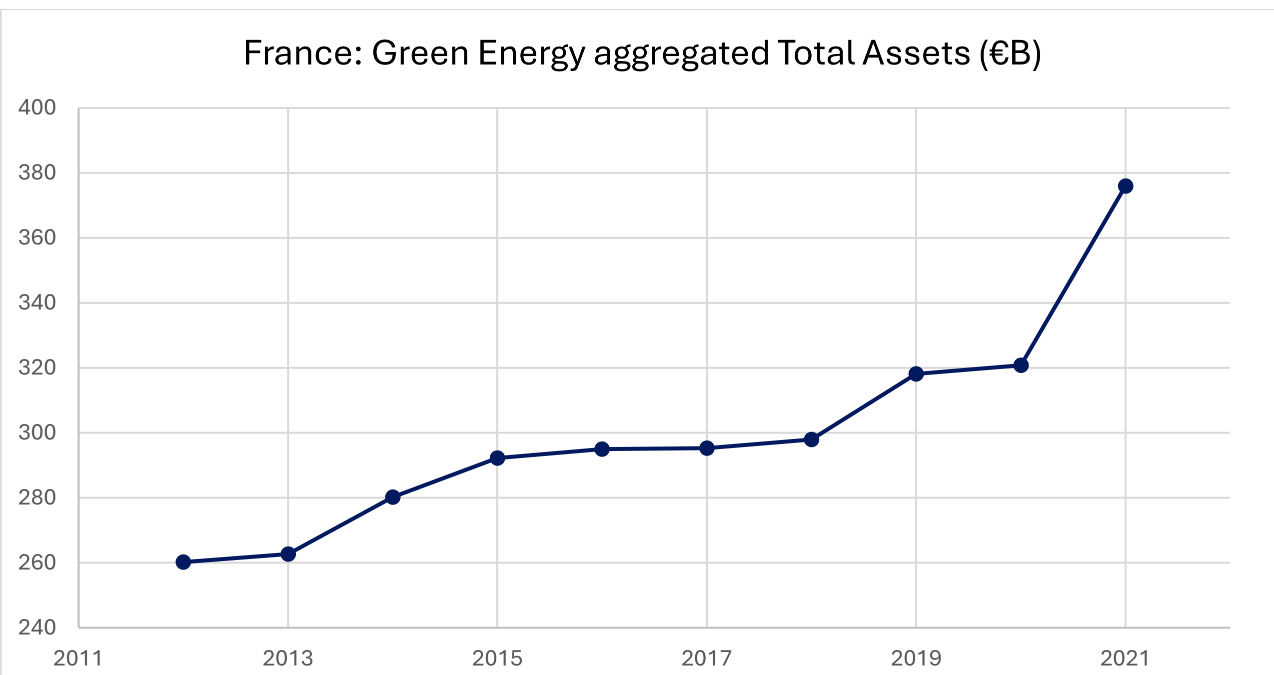


FIGURE 5.5: France's Green Energy aggregated Total Assets, from 2012 to 2021



5.2.3 | Multiple linear regression analysis for France's aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO_2 emissions metrics gathered (Total CO_2 emissions, CO_2 per GDP and CO_2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years.

The following Table 5.4 shows the output of the regressions.

TABLE 5.4: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	-12,3025**	-0,0086***	-0,2367**
Covid Dummy	-34,533**	-0,0044	-0,5889***
Constant	493,069***	0,2253***	8,2039***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) well predict the dependent variables (CO_2 emissions). The coefficient of X1 (Sales) is negative, confirming the reasonable intuition that higher Green Energy Sales lead to lower CO_2 emissions.

Furthermore, the p-value of the overall models and the p-value of each single independent variable is lower than 0,05, meaning that these variables are statistically significant in running each model. The only exception is the variable X2 (Covid dummy) in the regression for CO_2 emissions per GDP that has not a significant p-value, neither if we raise the significance level at 0,10. But this is not a worrying result because Emissions per GDP is a metric that already accounts for the impact of Covid on both emissions and economic activity, making variable X2 irrelevant in this case.

5.2.4 | Multiple linear regression analysis for France's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have also added a dummy variable (independent variable X3) to account for the outlier in the value of 2021 Total Assets that is unreasonable higher than the previous years, due to the impact of governmental grants and subsidies offered to companies to cope with industrial disruption caused by Covid pandemic.

The following Table 5.5 shows the output of the regressions.

TABLE 5.5: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Total Assets	-0,3456	-0,00027**	-0,0078**
Covid Dummy	-36,558**	-0,0048	-0,5887**
2021 Dummy	12,155	0,012	0,3662
Constant	432,812***	0,1924***	7,388***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Total Assets, Covid dummy and Outlier dummy) well explain the dependent variables (CO2 emissions). The coefficient of X1 (Total Assets) is negative, confirming the reasonable intuition that higher Green Energy Total Assets lead to lower CO2 emissions.

Furthermore, the p-value of the models is lower than 0,05, meaning that these models are overall statistically significant in predicting the CO2 Emissions. As far as the p-value of each single independent variable, X1 (Total Assets) and X2 (Covid dummy) are significant in two out of three regressions, and the result wouldn't change if we raised the significance level at 0,10. In particular, Total assets is not significant when related to Total CO2 emissions. On the contrary, X3 (Outlier dummy) is never significant. Anyway, we decided to keep the variable X3 in our regression for the sake of comparability and homogeneity across the different countries.

In conclusion, France's aggregated Sales are highly significant and negative correlated to all the metrics of CO2 Emissions. Total Assets are negatively correlated to emissions too, but lack of significance in explaining Total CO2 Emissions.

5.3 | Correlation analysis for Germany

5.3.1 | Germany's CO2 emissions from 2012 to 2022

Table 5.6 reports the data of total CO2 emissions, CO2 emission per GDP and CO2 emission per capita for Germany, collected from EDGAR over the period 2012-2022.

Figure 5.6, Figure 5.7, and Figure 5.8 report those data graphically, in order to understand better the evolution and the trends of German CO2 emissions over the analyzed time horizon.

TABLE 5.6: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for Germany over the period 2012 -2022

Year	Total CO2 (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	795,7	0,198	9,8
2013	813,1	0,202	10,1
2014	773,2	0,188	9,4
2015	779,7	0,187	9,5
2016	783,9	0,184	9,5
2017	769,1	0,175	9,3
2018	744,5	0,168	9,1
2019	693,5	0,155	8,4
2020	637,3	0,148	7,7
2021	679,2	0,154	8,2
2022	674	0,150	8,2
Variations	**-15,3%**	**-24,4%**	**-16,4%**

FIGURE 5.6: Germany's Total Emissions (MtCO2) over the period 2012-2022

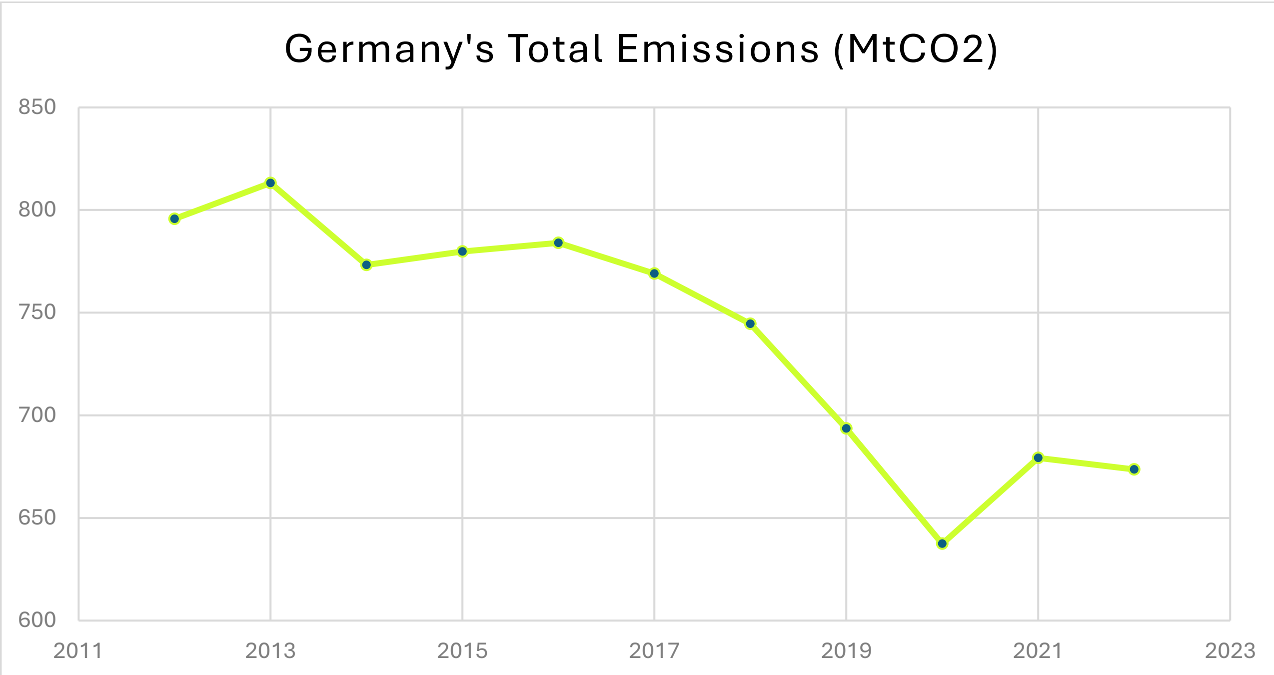


FIGURE 5.7: Germany's Emissions per GDP (tCO2/kUSD) over the period 2012-2022

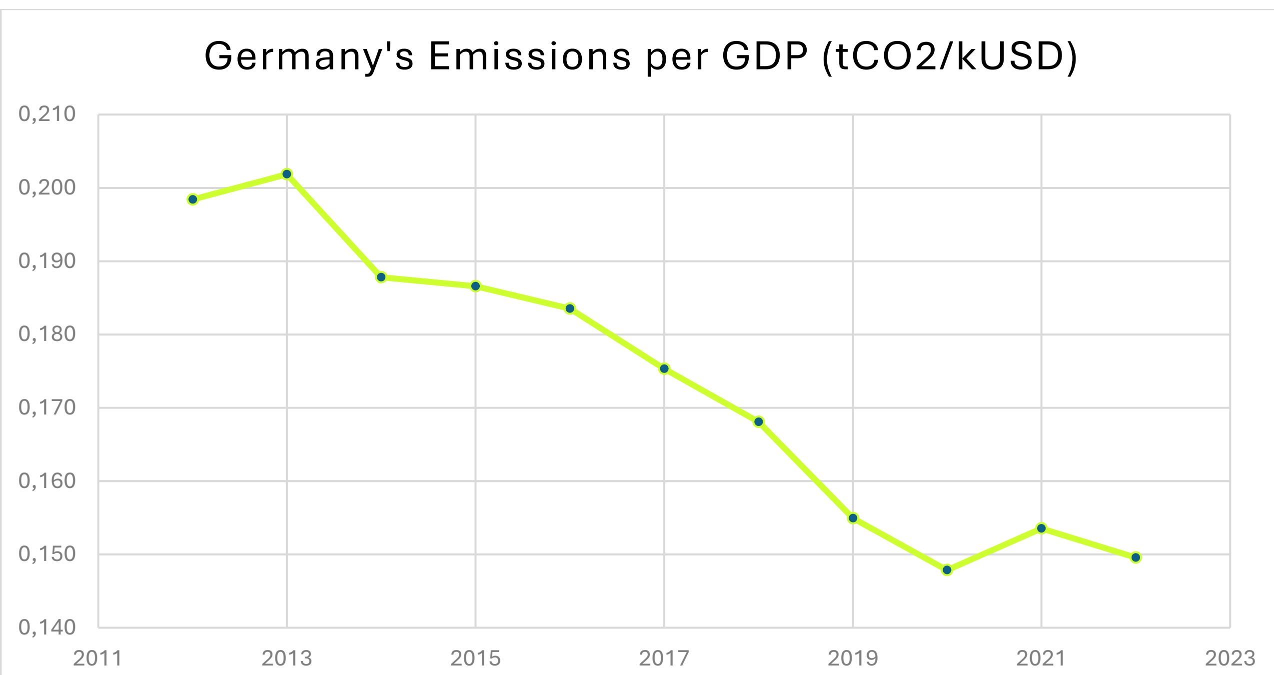
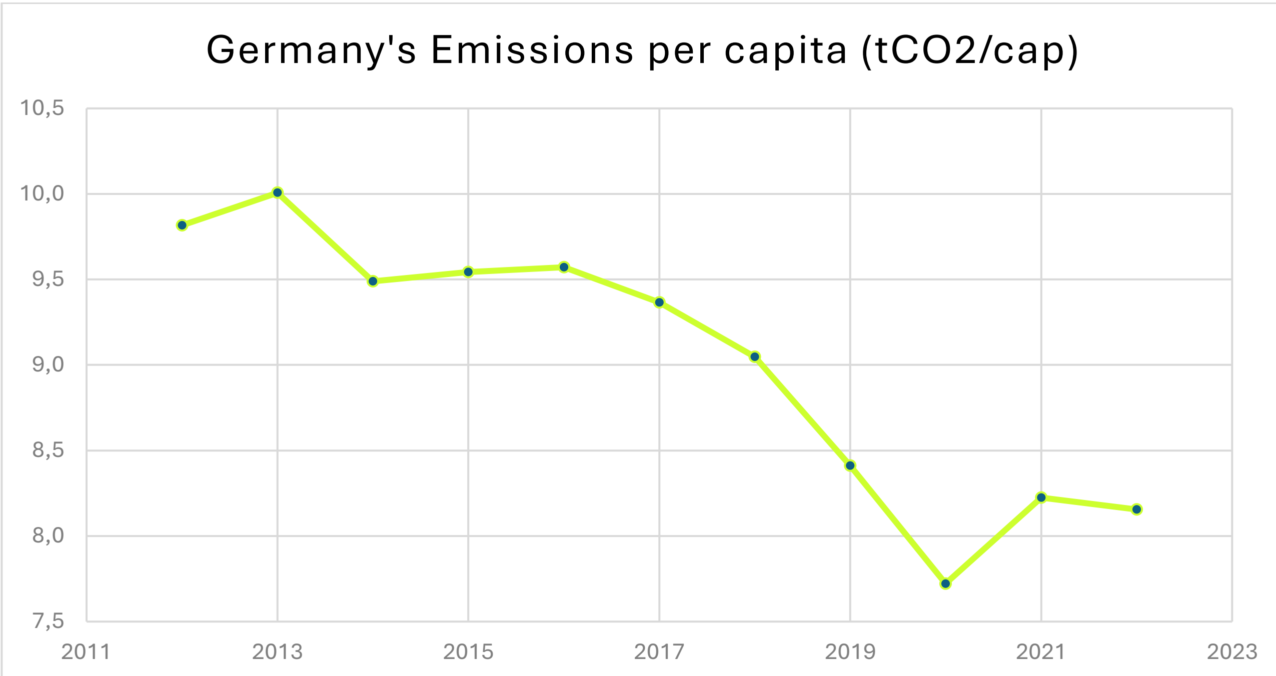


FIGURE 5.8: Germany's Emissions per capita (tCO2/cap) over the period 2012-2022



Over the period analyzed, Germany's total emissions have decreased by 15,3%, quite better than the EU average of 13,5%. This significant reduction is driven by the massive investments made by German government in the past years to increase energy production from renewable sources, to achieve the decarbonization target set by EU commission and to match the environmental goals signed in its National Energy and Climate Plan. Data from Statista shows that the country has allocated large financial resources to increase its wind and solar power capacity, with the aim of reducing its dependency on fossil fuels and nuclear energy. Major initiatives include the construction of offshore wind farms in the North Sea, that now rank among the world's largest, as well as extensive development of solar photovoltaic systems. Furthermore, Germany has invested in updating its energy grid to handle the growing amount of renewable energy, improving both storage capacity and grid integration technology.

However, the country still relies heavily on fossil fuels and the path to reach carbon neutrality is still long. Indeed, in 2022 renewable energy sources accounted for just 17,2% of electricity production. The most important primary energy sources are highly carbon intensive, such as mineral oil (35,3% of the energy mix) and natural gas (23,6% of the energy mix). The strong dependence on Russian natural gas supply for energy production provoked an economic shock in the German energy market in the aftermath of Russian full-scale invasion of Ukraine, with consumer price skyrocketing and being one of the main causes of a persistent inflation. German has been hit heavily by covid pandemic: the consequent economic slowdown has contributed to a sharp decrease in carbon emissions, with a total amount of CO2 emitted fallen by 8% with regards to the 2019 levels; the same reduction has been recorded in CO2 per capita values.

5.3.2 | Germany's Green Enegy aggregated financial metrics from 2012 to 2021

We have computed the aggregate sales of German Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category "3.1 Sustainable energy production", "3.2 Sustainable fuels", and "3.3 Energy-efficient industrial technologies".

Table 5.7 shows the aggregated sales and total assets for German Green Energy companies. Figures 5.9 and 5.10 plot their time series. German Green Energy aggregate sales have increased by 41,3% over the period analyzed, while total assets rose by 45,6%.

TABLE 5.7: Germany's Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	2045	12,17	197,3
2013	2085	13,60	190,3
2014	2105	14,70	172,2
2015	2119	15,91	163,3
2016	2129	17,34	152,9
2017	2130	16,92	160,8
2018	2131	18,12	162
2019	2131	17,70	159,5
2020	2131	16,71	158,8
2021	2131	17,20	287

FIGURE 5.9: Germany's Green Energy aggregated Sales, from 2012 to 2021

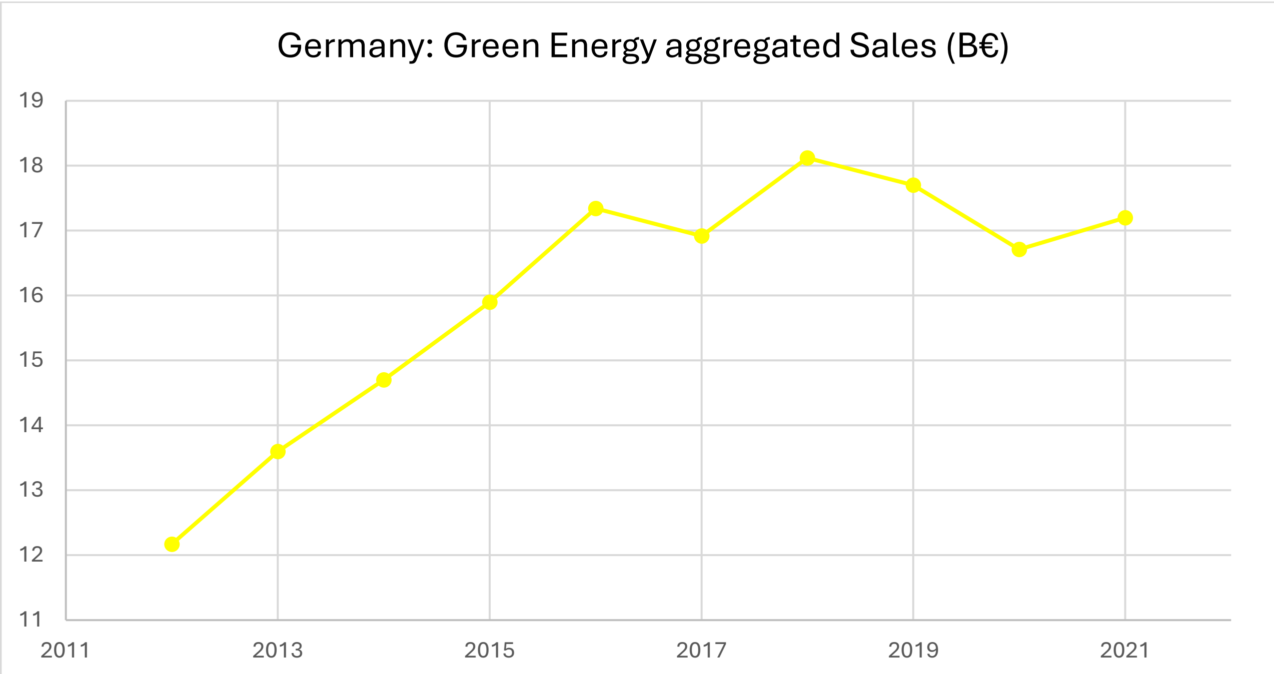
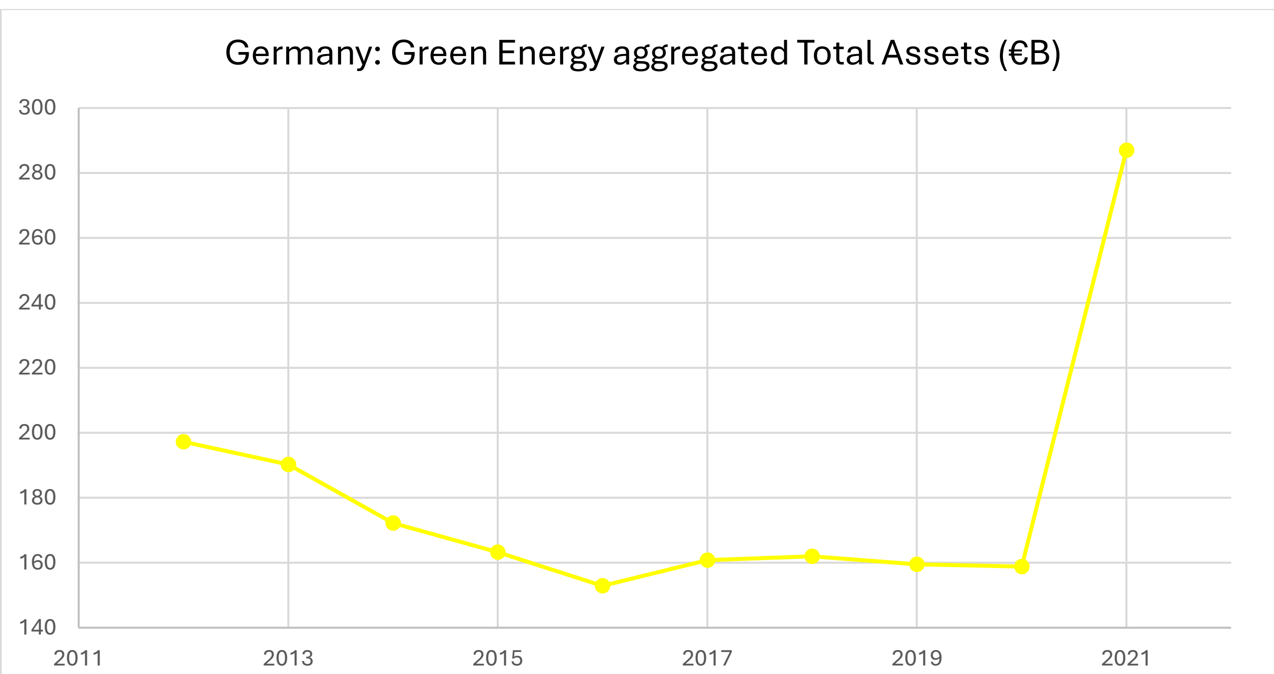


FIGURE 5.10: Germany's Green Energy aggregated Total Assets, from 2012 to 2021



5.3.3 | Multiple linear regression analysis for Germany's aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years.

The following Table 5.8 shows the output of the regressions.

TABLE 5.8: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	-22,843**	-0,0095***	-0,3059**
Covid Dummy	-71,195	-0,0102	-0,8811
Constant	1112,82***	0,3266***	13,995***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) well explain the dependent variables (CO2 emissions). The coefficient of X1 (Sales) is negative, confirming the reasonable intuition that higher Green Energy Sales lead to lower CO2 emissions.

Furthermore, the p-value of the overall models and the p-value of independent variable X1 is lower than 0,05, meaning that this variable is statistically significant in predicting each emissions metric. The opposite holds for the variable X2 (Covid dummy): it never shows a significant p-value (even considering a significance level of 0,10) and thus is not significant in explaining any emission metric. Nonetheless, we have included it in the model for the sake of comparability and homogeneity across countries.

5.3.4 | Multiple linear regression analysis for Germany's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have also added a dummy variable (independent variable X3) to account for the outlier in the value of 2021 Total Assets that is unreasonable higher than the previous years (it is almost double the 2020 Total Assets), due to the impact of governmental grants and subsidies offered to companies to cope with industrial disruption caused by Covid pandemic.

The following Table 5.9 shows the output of the regressions.

TABLE 5.9: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Total Assets	1,6987	0,0008**	0,0248*
Covid Dummy	-99,898*	-0,0203	-1,234*
2021 Dummy	-279,783*	-0,1212**	-3,902**
Constant	466,253*	0,0396	4,97*

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Total Assets, Covid dummy and Outlier dummy) well explain the dependent variables (CO2 emissions). The coefficient of X1 (Total Assets) is slightly higher than zero, showing a positive correlation with CO2 emissions.

The p-value of the models is slightly higher than 0,05 for total emissions and emissions per capita. The same applies for the independent variable X1 (Total Assets) questioning the statistical significance of this variable in the models.

Considering that we are carrying out exploratory research and that our goal is to identify potential relationships, we can use also a softer significance level, equal to 0,10. In this case, all the models will be overall significant, while Total Asset will be significant in predicting Emissions per GDP and per Capita.

The variable X3 (Outlier dummy) shows a p-value lower than 0,10 in all the three regressions, underlining its importance in these models for Germany, that shows a very large 2021 Total Assets outlier.

In conclusion, Germany's aggregated Sales are highly significant and negative correlated to all the metrics of CO2 Emissions. On the contrary, Total Assets are positively correlated to emissions but are less significant in explaining them.

5.4 | Correlation analysis for Italy

5.4.1 | Italy's CO2 emissions from 2012 to 2022

Table 5.10 reports the data of total CO2 emissions, CO2 emission per GDP and CO2 emission per capita for Italy, collected from EDGAR over the period 2012-2022.

Figure 5.11, Figure 5.12, and Figure 5.13 report those data graphically, in order to understand better the evolution and the trends of Italian CO2 emissions over the analyzed time horizon.

TABLE 5.10: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for Italy over the period 2012 -2022

Year	Total CO2 (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	394,1	0,159	6,5
2013	361,3	0,149	6,1
2014	342,9	0,141	5,7
2015	353,6	0,145	5,9
2016	348,9	0,141	5,8
2017	345,3	0,137	5,8
2018	340,3	0,134	5,7
2019	331,7	0,130	5,6
2020	295,1	0,127	4,9
2021	320,7	0,129	5,4
2022	323	0,125	5,5
Variations	**-18%**	**-21,38%**	**-15,38%**

FIGURE 5.11: Italy's Total Emissions (MtCO2) over the period 2012-2022

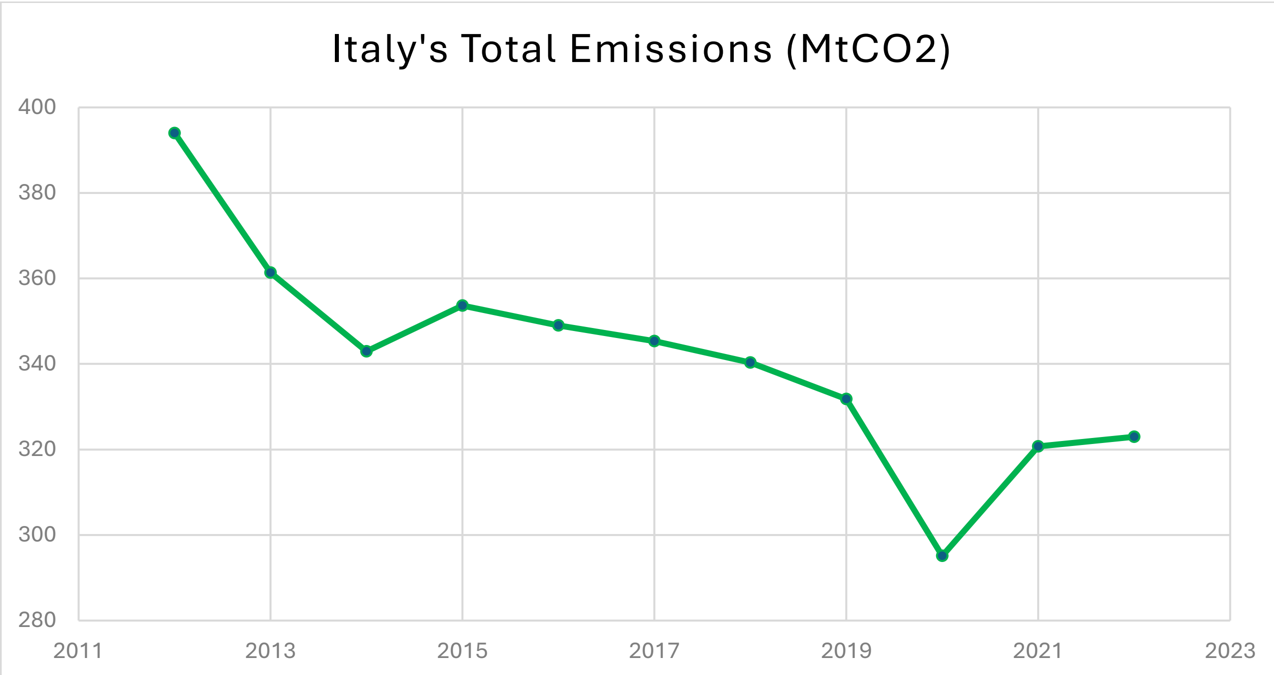


FIGURE 5.12: Italy's Emissions per GDP (tCO2/kUSD) over the period 2012-2022

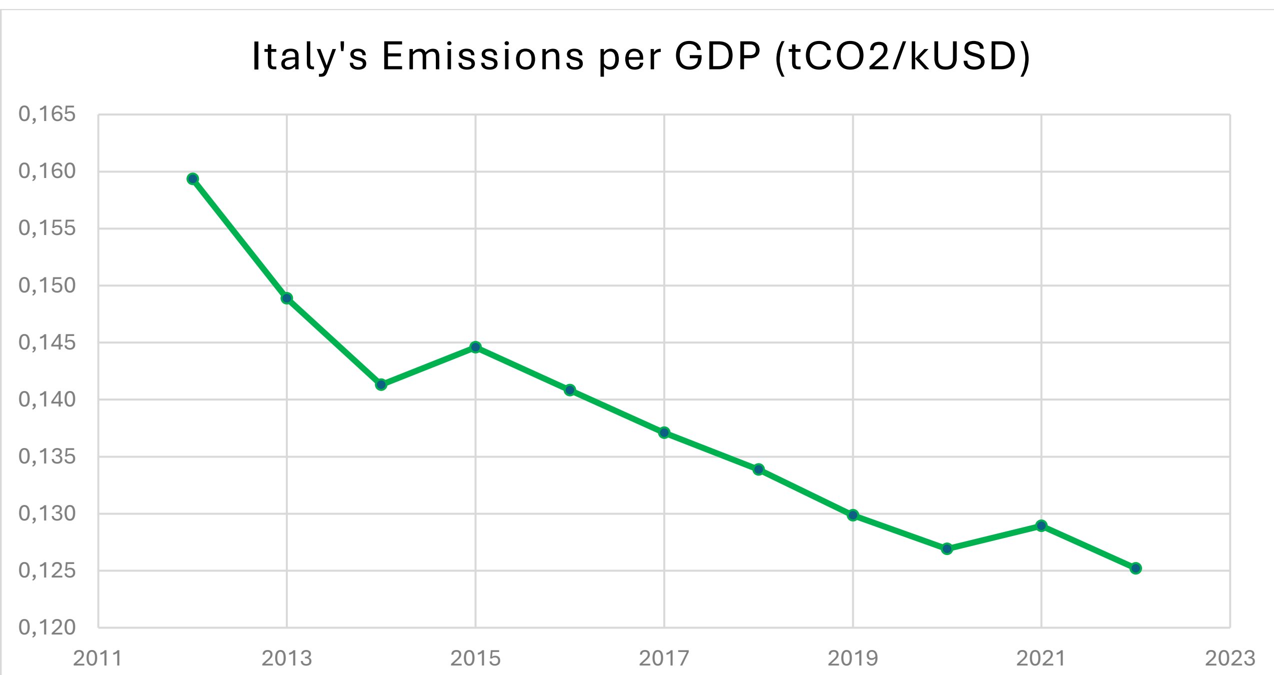
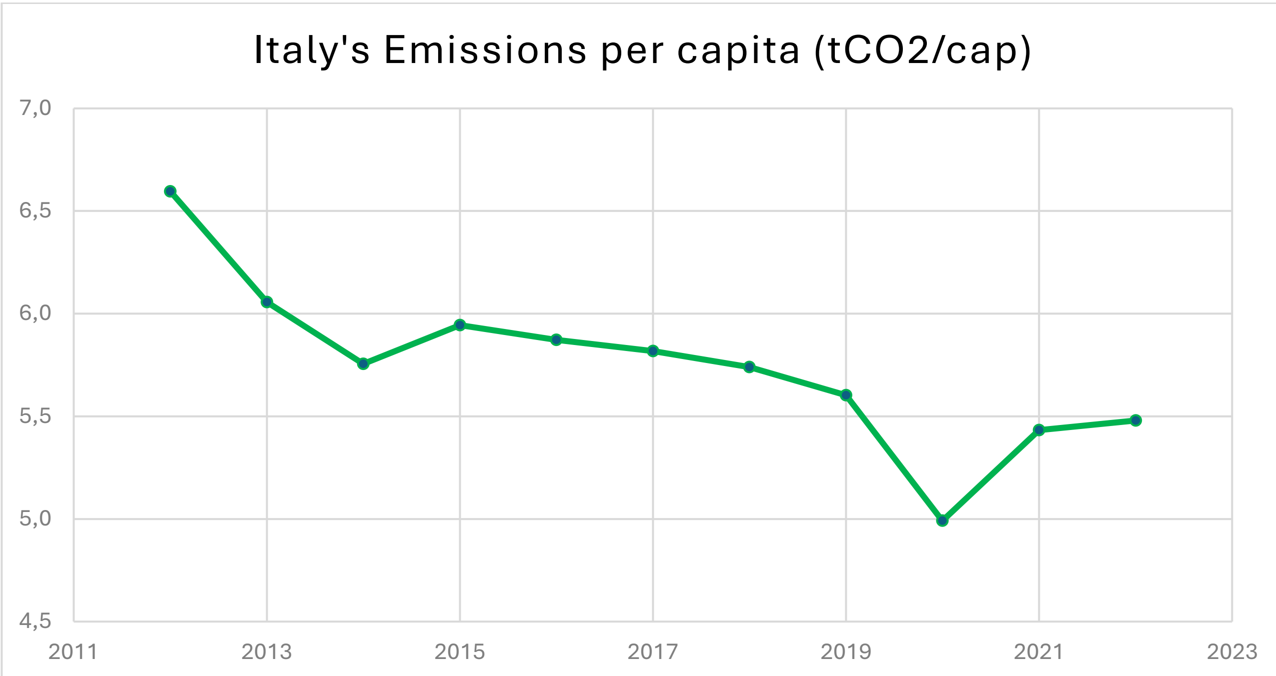


FIGURE 5.13: Italy's Emissions per capita (tCO2/cap) over the period 2012-2022



Over the period analyzed, Italy's total emissions have decreased by 18%, far over the EU average of 13,5%. Italy has boosted dramatically its renewable energy spending in order to satisfy its climate commitments and lessen its reliance on imported fossil fuels. The country has concentrated heavily on increasing its capacity for wind and solar energy. Italy is one of the top producers of solar energy thanks to its strategic initiatives, which include large investments in solar photovoltaic systems supported by tax credits and feed-in tariffs from the government. Moreover, Italy is making investments in the construction of offshore and onshore wind farms, and in the development of geothermal energy projects. Further investments have been directed towards research and development in renewable technologies and the promotion of bioenergy. Due to these coordinated efforts, Italy is now seen as a prominent player in the renewable energy industry, helping to create a robust and sustainable energy landscape.

Over the period analyzed and with regards to absolute CO2 emissions, Italy was repeatedly the second country in EU for MtCO2 emitted (right after Germany); As far as CO2 per unit of GDP (tCO2/kUSD), Italy shows values almost 25% lower than German ones, but still higher than the French. Reports from Statista shows that the current Italian energy mix is mainly relying on fossil fuels: natural gas accounts for 40,5% of total electric energy production, and oil for 35,3%, while renewable resources share is equal to almost 20%.

Covid 19 pandemic hit Italian economy very heavily, causing a significant slowdown of industrial production and energy consumption. This is particularly evident when looking at the value of the 3 metrics of CO2 emissions registered in 2020: total emissions decreased by 11% and CO2 per capita decreased by 12,5%, while CO2 per GDP doesn't show anormal values because of the relative fall in Italian GDP.

5.4.2 | Italy's Green Energy aggregated financial metrics from 2012 to 2021

We have computed the aggregate sales of Italian Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category "3.1 Sustainable energy production", "3.2 Sustainable fuels", and "3.3 Energy-efficient industrial technologies".

Table 5.11 shows the aggregated sales and total assets for Italian Green Energy companies. Figures 5.14 and 5.15 plot their time series. Italian Green Energy aggregate sales have increased by 11,7% over the period analyzed, while total assets rose by 18,3%.

TABLE 5.11: Italy's Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	1803	18,36	194,5
2013	1819	17,50	186,8
2014	1834	17,43	190
2015	1849	17,81	185,5
2016	1865	17,53	179,8
2017	1875	19,14	179,8
2018	1879	18,40	189,2
2019	1879	19	194,6
2020	1879	17,36	186,6
2021	1879	20,50	230

FIGURE 5.14: Italy's Green Energy aggregated Sales, from 2012 to 2021

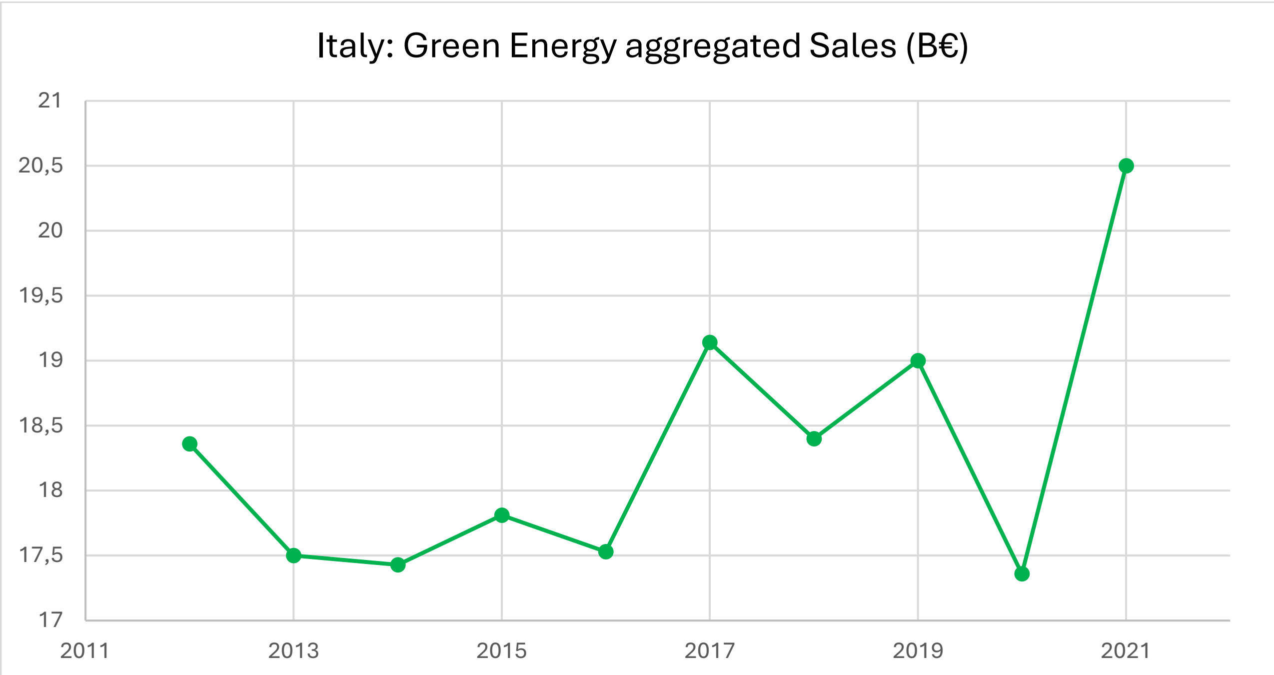
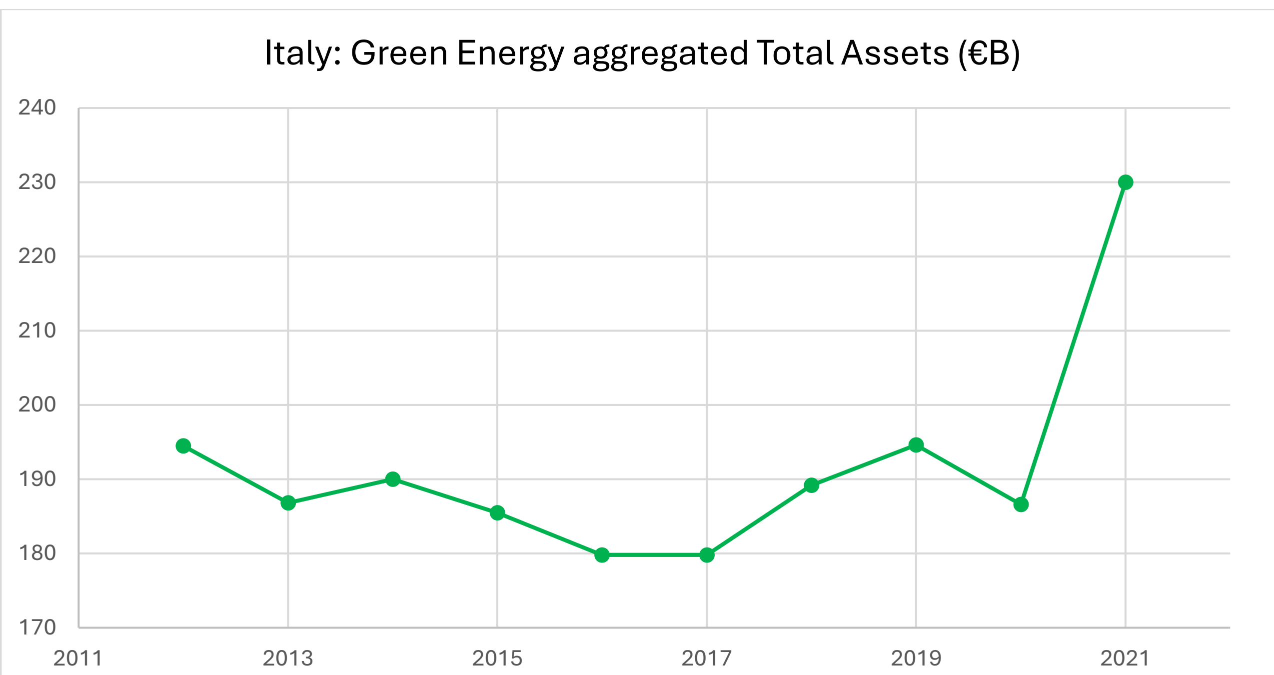


FIGURE 5.15: Italy's Green Energy aggregated Total Assets, from 2012 to 2021



5.4.3 | Multiple linear regression analysis for Italy's aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. Furthermore, Italy's aggregate sales show an outlier in the 2012 data, that is a relative high amount if compared to the other recorded sales: to address this problem we have added a second dummy variable (independent variable X3) equal to 1 in 2012 and to 0 for all the other years.

The following Table 5.12 shows the output of the regressions.

TABLE 5.12: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	-5,0765	-0,0041*	-0,0565
Covid Dummy	-39,1831**	-0,0049	-0,7302***
2012 Dummy	23,7678*	0,0143*	0,4335**
Constant	430,737***	0,2103***	6,7042***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) well explain the dependent variables (CO2 emissions). The coefficient of X1 (Sales) is negative, confirming the reasonable intuition that higher Green Energy Sales lead to lower CO2 emissions.

The p-value of the overall models is lower than 0,05 in two cases, and lower than 0,10 in all cases. Thus, the models are generally significant in predicting the Emissions.

The p-value of independent variable X1 is never significant at a 0,05 level, while at a 0,10 level is significant just for Emissions per GDP: so, aggregated Sales are generally not a good predictor for Italian emissions. The variables X2 (Covid dummy) and X3 (Outlier dummy) are almost always significant at a 0,10 level.

Therefore, for Italy it seems that aggregated sales have a lower statistical significance on the CO2 emissions than France or Germany.

5.4.4 | Multiple linear regression analysis for Italy's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have also added a dummy variable (independent variable X3) to account for the outlier in the value of 2021 Total Assets that is unreasonable higher than the previous years (it is almost double the 2020 Total Assets), due to the impact of governmental grants and subsidies offered to companies to cope with industrial disruption caused by Covid pandemic.

The following Table 5.13 shows the output of the regressions.

TABLE 5.13: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	**CO2 Emissions per GDP**	**CO2 Emissions per capita**
Total Assets	0,8456	0,00069	0,0161
Covid Dummy	-54,816**	-0,0168*	-0,9805***
2021 Dummy	-56,851	-0,0434	-0,9529
Constant	185,354	0,0084	2,734

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

The linear regressions for Total CO_2 Emissions and Emissions per capita report a high level for both R squared and adjusted R squared, and a significant p-value at the 0,05 level, meaning that the independent variables together (Total Assets, Covid dummy and Outlier dummy) well predict the dependent variables. The coefficient of X_1 (Total Assets) is slightly higher than zero, showing a positive correlation with CO_2 emissions. On the contrary, the model for Emissions per GDP is not significant neither at a 0,10 level.

The independent variable X_1 (Total Assets) shows high levels of p-value, denying the statistical significance of this variable in all the three models. The same holds for the variable X_3 (Outlier dummy), that shows poor significance. We have decided to include it in the model in any case for the sake of completeness.

In conclusion, Italy's aggregated Sales and Total Assets regressions shows a good degree of significance at the level of the model, but not at the level of the single variable. Neither Sales neither Total Assets seems to predict significantly the Italian CO_2 emissions. This is in contrast with what we have found analyzing French and German data.

5.5 | Correlation analysis for Spain

5.5.1 | Spain's CO2 emissions from 2012 to 2022

Table 5.14 reports the data of total CO_2 emissions, CO_2 emission per GDP and CO_2 emission per capita for Spain, collected from EDGAR over the period 2012-2022.

Figure 5.16, Figure 5.17, and Figure 5.18 report those data graphically, in order to understand better the evolution and the trends of Spanish CO_2 emissions over the analyzed time horizon.

TABLE 5.14: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for Spain over the period 2012 -2022

Year	Total CO2 (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	286,6	0,171	6,1
2013	259,9	0,158	5,5
2014	257,3	0,154	5,5
2015	273,2	0,157	5,8
2016	264,5	0,148	5,7
2017	281,1	0,153	6,1
2018	274,3	0,146	5,9
2019	257,1	0,134	5,5
2020	216,9	0,127	4,6
2021	231,4	0,129	4,9
2022	254,4	0,134	5,5
Variations	**-11,3%**	**-21,7%**	**-10,4%**

FIGURE 5.16: Spain's Total Emissions (MtCO2) over the period 2012-2022

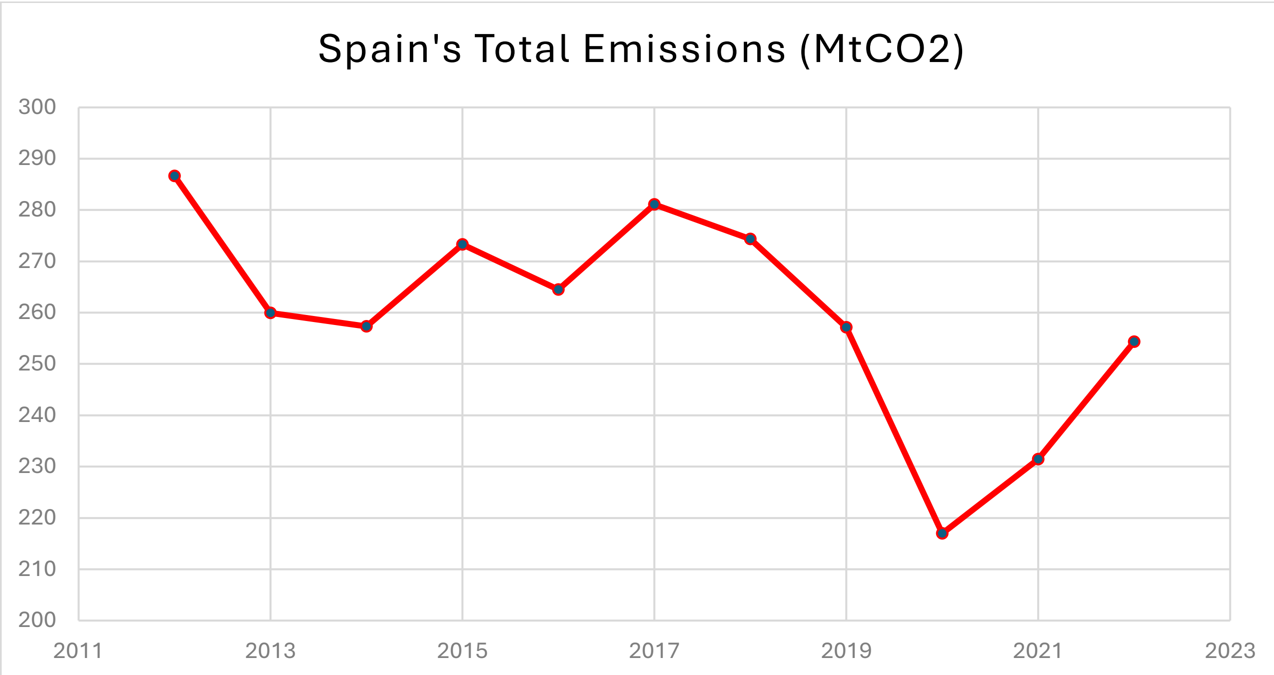


FIGURE 5.17: Spain's Emissions per GDP (tCO2/kUSD) over the period 2012-2022

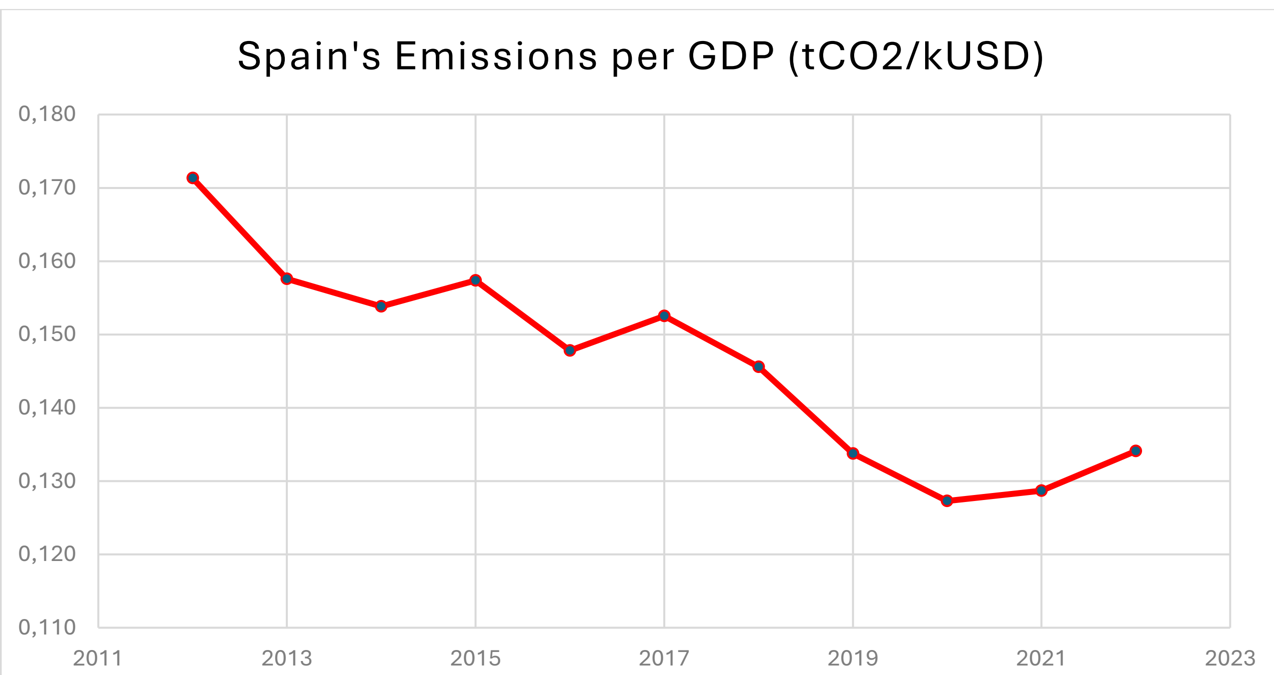
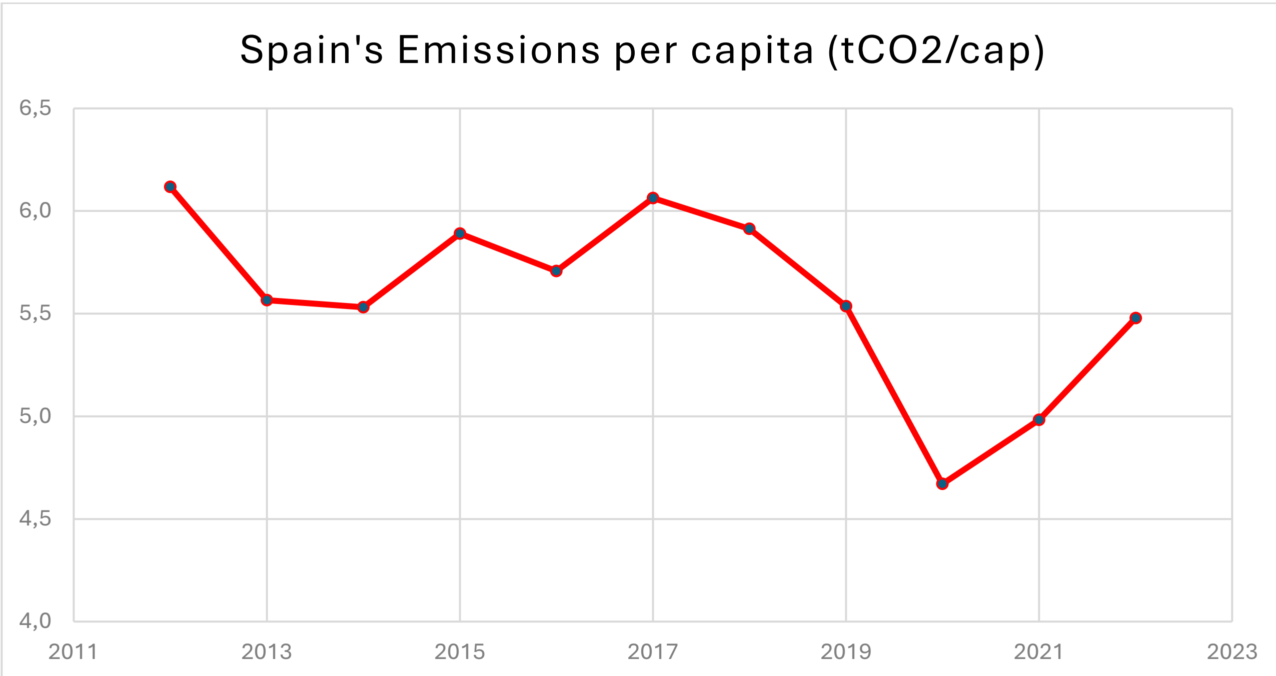


FIGURE 5.18: Spain's Emissions per capita (tCO2/cap) over the period 2012-2022



Over the past two decades, Spain's energy mix has shifted significantly towards renewable sources, driven by ambitious government policies and substantial investments.

Spanish Total CO2 Emissions have decreased by 11,3% over the period analyzed, slighter behind the EU average of 13,5%. The overall Spanish economy has reached better results in terms of decarbonization, given that CO2 Emissions per GDP have decreased by 21,7%.

A report of Statista on the evolution of Spanish energy mix highlights that over the period between 2012 and 2022, the renewable energy consumption of the Iberic country has increased by 38,6%. In 2022, the national electric energy supply was made up by renewable energy for the 42,2%. Almost two thirds of the Spanish green energy come from wind and solar photovoltaic installations.

The Spanish government has set a target of 74% renewable electricity by 2030, supported by initiatives such as the National Integrated Energy and Climate Plan, which allocates €240 billion to energy transition efforts through 2030. Spain hosts the biggest solar plant in Europe, called "Núñez de Balboa" and located in Extremadura, that covers an area of nearly 1,000 hectares and produces around 832 GWh per year, thanks to its 1.430.000 photovoltaic panels.

Due to the Covid pandemic, the contraction in the consumptions and in the industrial activity has caused a fall in 2020 Total CO2 Emissions, that were the 15,6% lower than the previous year.

5.5.2 | Spain’s Green Energy aggregated financial metrics from 2012 to 2021

We have computed the aggregate sales of Spain Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category “3.1 Sustainable energy production”, “3.2 Sustainable fuels”, and “3.3 Energy-efficient industrial technologies”.

Table 5.15 shows the aggregated sales and total assets for Spanish Green Energy companies. Figures 5.19 and 5.20 plot their time series. Spanish Green Energy aggregate sales have decreased by 24,3% over the period analyzed, while total assets rose by 30,2%.

TABLE 5.15: Spain’s Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	1030	22,9	124,2
2013	1035	24,25	123,8
2014	1047	23,5	125,2
2015	1054	23,42	130,5
2016	1057	22,96	132,3
2017	1060	22,8	135,2
2018	1064	20,71	138,1
2019	1064	20,7	145,5
2020	1064	20,3	145
2021	1064	17,33	161,7

FIGURE 5.19: Spain's Green Energy aggregated Sales, from 2012 to 2021

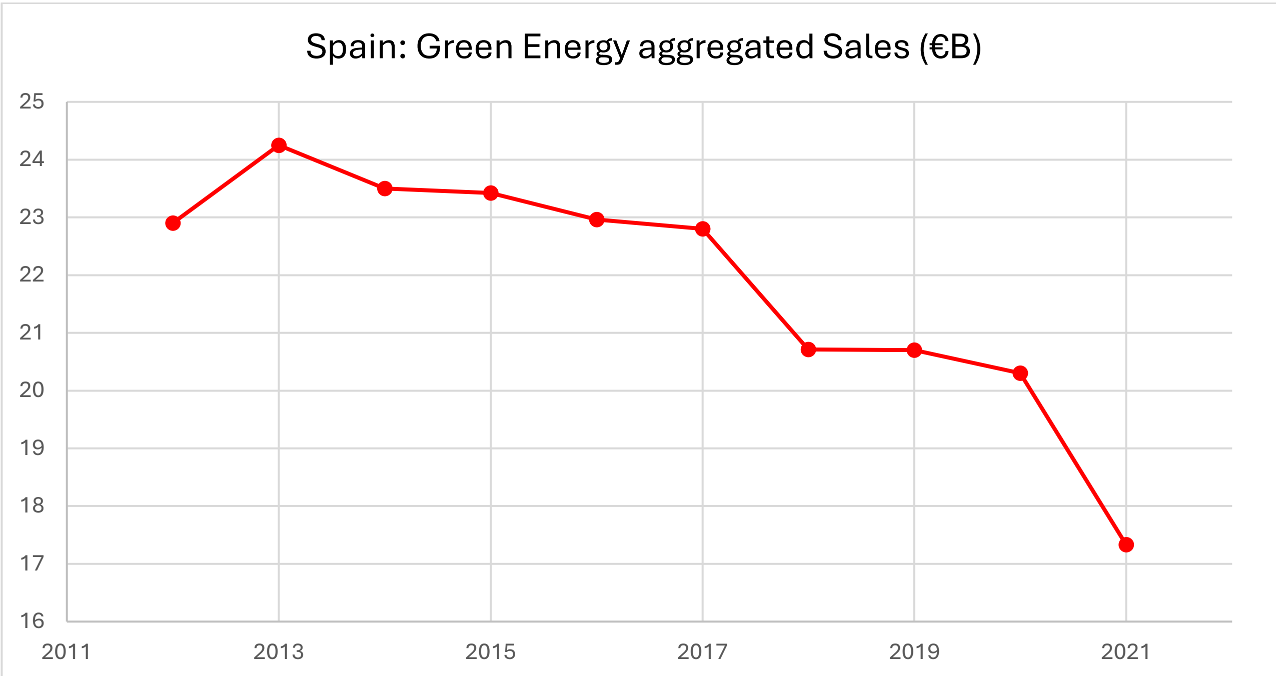
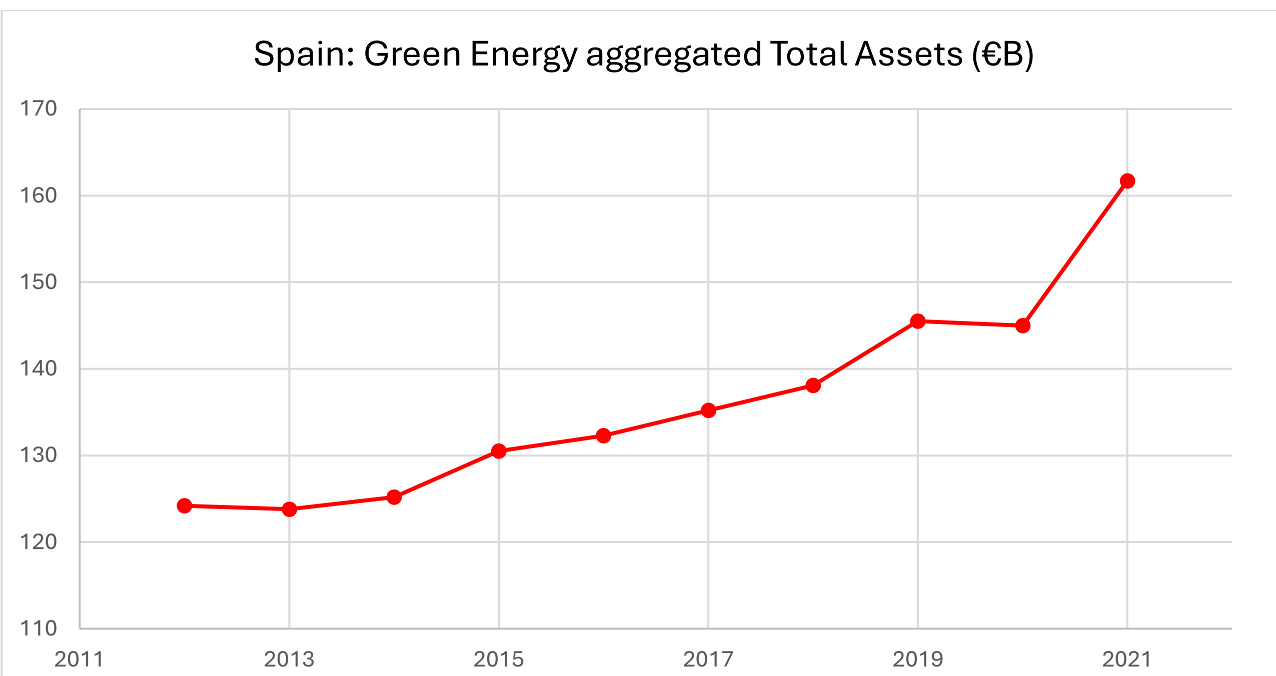


FIGURE 5.20: Spain's Green Energy aggregated Total Assets, from 2012 to 2021



5.5.3 | Multiple linear regression analysis for Spain's aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years.

The following Table 5.16 shows the output of the regressions.

TABLE 5.16: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	3,4244	0,004***	0,0732
Covid Dummy	-39,9971**	-0,013	-0,8630**
Constant	186,088***	0,0563*	4,0163***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) well predict the dependent variables (CO2 emissions). Unexpectedly, the coefficient of X1 (Sales) is higher than zero, showing a positive correlation with emissions: a result that is caused by the declining Spanish Green Energy aggregated Sales, at least according to the data recorded in the dataset (that doesn't contain the totality of the population).

Looking at the significancy, the p-value of the overall models are lower than 0,05 meaning that they are statistically reliable. Nonetheless, the variable X1 (Sales) shows statistical significance only in predicting CO2 emissions per GDP. In the other two cases it is not significant, either at 0,10 level. Thus, aggregated sales seem to not play a significant role in explaining the Spanish emissions.

5.5.4 | Multiple linear regression analysis for Spain's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have also added a dummy variable (independent variable X3) to account for the outlier in the value of 2021 Total Assets that is unreasonable higher than the previous years, due to the impact of governmental grants and subsidies offered to companies to cope with industrial disruption caused by Covid pandemic.

The following Table 5.17 shows the output of the regressions.

TABLE 5.17: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Total Assets	-1,0362	-0,0013***	-0,0216
Covid Dummy	-31,24	-0,0019	-0,7161
2021 Dummy	23,0475	0,0267**	0,534
Constant	398,91***	0,3241***	8,4609**

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Total Assets, Covid dummy and Outlier dummy) well explain the dependent variables (CO2 emissions). The coefficient of X1 (Total Assets) is negative, confirming the reasonable intuition that higher Green Energy Total Assets lead to lower CO2 emissions.

The p-value of the models for the Total CO2 Emissions and Emissions per GDP are significant at a 0,10 level, while the model for Emissions per capita is not. The variable X1 (Total Assets) shows statistical significance only in predicting CO2 emissions per GDP. In the other two cases it is not significant, either at 0,10 level. Thus, aggregated sales seem to be a weak predictor for Spanish Emissions.

In conclusion, even though the overall models for Sales and Total Assets are quite significant, the single variables are not. Sales is positively correlated to Emissions, in contrast with the result of the other Countries and with our intuition, while Total Assets is negatively correlated to Emissions but lacks statistical significance.

5.6 | Correlation analysis for Poland

5.6.1 | Poland' CO2 emissions from 2012 to 2022

Table 5.18 reports the data of total CO2 emissions, CO2 emission per GDP and CO2 emission per capita for Poland, collected from EDGAR over the period 2012-2022.

Figure 5.21, Figure 5.22, and Figure 5.23 report those data graphically, in order to understand better the evolution and the trends of Polish CO2 emissions over the analyzed time horizon.

TABLE 5.18: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for Poland over the period 2012 -2022

Year	Total CO2 (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	319,8	0,333	8,3
2013	315,5	0,325	8,2
2014	303,0	0,301	7,9
2015	306,1	0,291	8,0
2016	317,2	0,293	8,3
2017	330,7	0,291	8,7
2018	330,1	0,274	8,7
2019	312,3	0,248	8,2
2020	296,3	0,240	7,8
2021	327,2	0,248	8,6
2022	322,0	0,233	8,5
Variations	**0,7%**	**-30,0%**	**2,2%**

FIGURE 5.21: Poland's Total Emissions (MtCO2) over the period 2012-2022

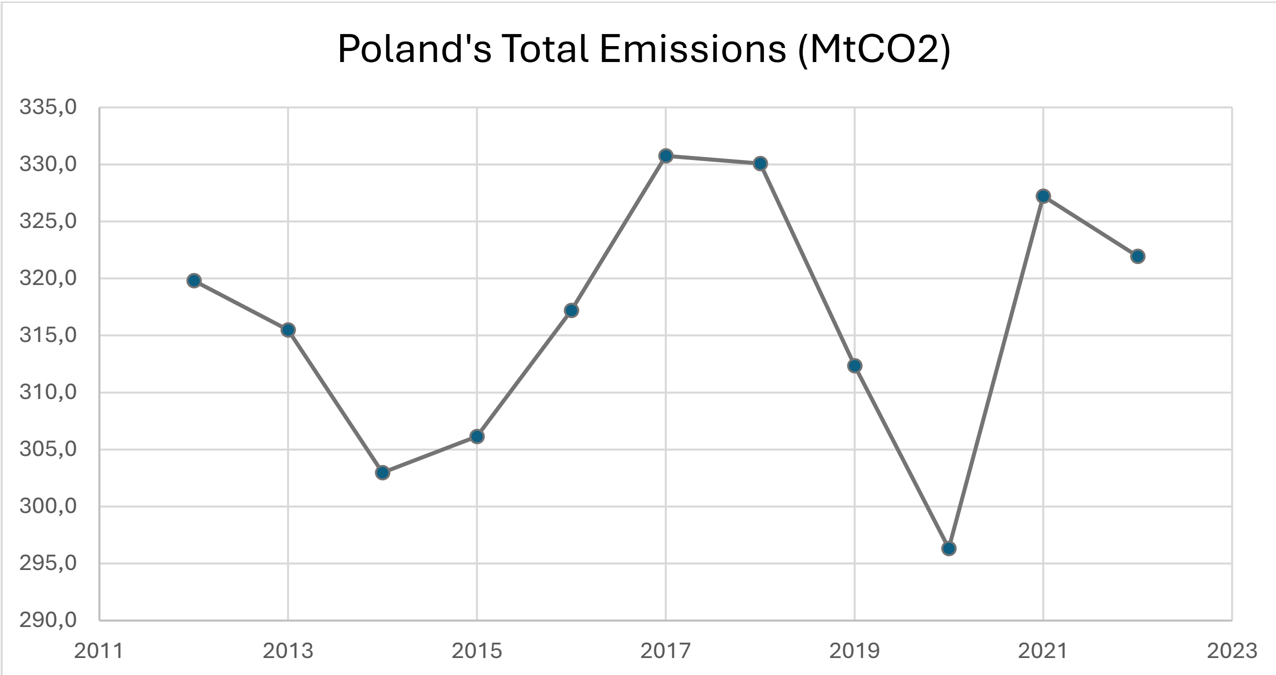


FIGURE 5.22: Poland's Emissions per GDP (tCO2/kUSD) over the period 2012-2022

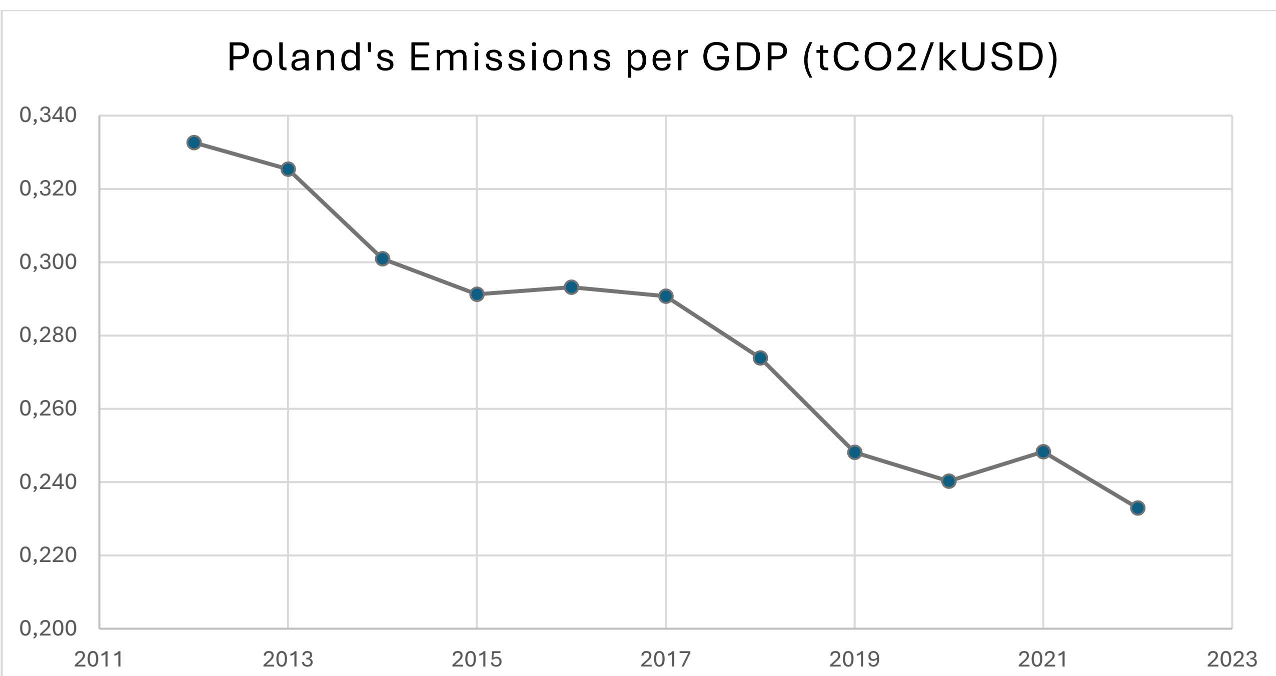
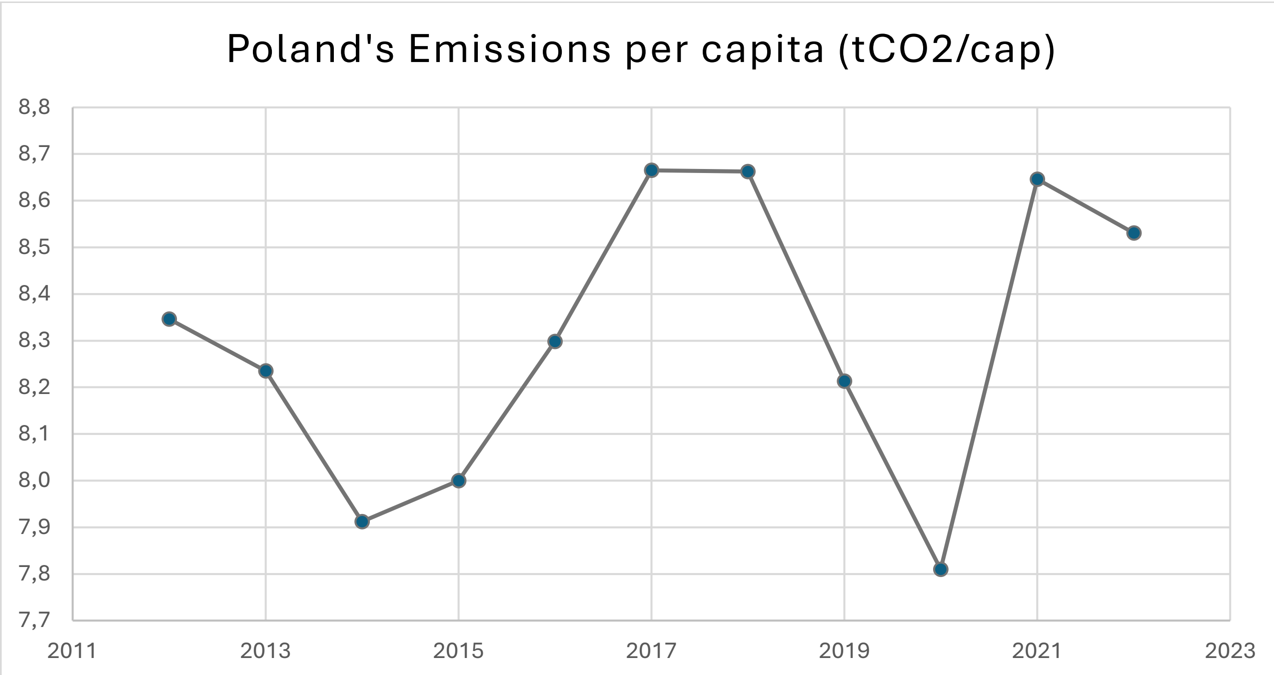


FIGURE 5.23: Poland’s Emissions per capita (tCO2/cap) over the period 2012-2022



Polish Total CO2 Emissions have slightly increased (+0,7%) over the observed period. Poland is one of the 5 European Countries (with Bulgaria, Cyprus, Hungary and Ireland) that show this against-the-tide behavior. It could seem astonishing how, despite the Communitarian carbon neutrality goal, some countries still struggle in lowering emissions. Poland’s energy mix has been undergoing a gradual transition, driven by the need to diversify away from coal, which historically dominated its energy production. Although the nation has boosted its investment in natural gas and renewable energy, coal still generated about 69% of electricity in 2022, down from over 90% in the early 2000s. the Polish government intends to reduce its dependency on coal to 11%-28% by 2040, according to its Energy Policy for 2040 (PEP2040).

A report from Statista shows that renewable energy sources are becoming more and more important, but still play a secondary role in the Polish energy strategy. Solar energy was in practice totally absent in Poland till 2018 (just 1 GW was installed), but now it is growing rapidly, with photovoltaic capacity exceeding 10 GW in 2023 (6,3% of national electricity consumption) thanks to government subsidies like the “My Electricity” program. Wind energy is now roughly the 14% of the Polish energy mix and the government is massively investing in offshore Baltic wind farms.

The slow green evolution of Poland's energy sources shows up clearly if we look at the CO2 Emissions per GDP metric, that normalizes the emissions for the economic activity of the country. That metric has fallen by 30% over the decade 2012-2022. Even Poland was impacted by the Covid pandemic, indeed the metrics of CO2 emissions report an outlier value in 2020, that fell by 5% if compared to 2019.

5.6.2 | Poland's Green Energy aggregated financial metrics from 2012 to 2021

We have computed the aggregated sales and aggregated total asset of Polish Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category "3.1 Sustainable energy production", "3.2 Sustainable fuels", and "3.3 Energy-efficient industrial technologies".

Table 5.19 shows these financial metrics, while Figure 5.24 and Figure 5.25 plot their time series. Polish Green Energy aggregated sales have increased by 5,4% over the period analyzed, while aggregated total assets have increased by 4,6%.

TABLE 5.19: Poland's Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	408	13,43	14,26
2013	451	15,3	15,41
2014	454	15,81	15,8
2015	463	15,83	16,12
2016	484	16,37	17,2
2017	504	16,55	17,43
2018	501	15,8	17,28
2019	487	15,86	17,2
2020	468	15,1	16,08
2021	458	14,16	14,92

FIGURE 5.24: Poland's Green Energy aggregated Sales, from 2012 to 2021

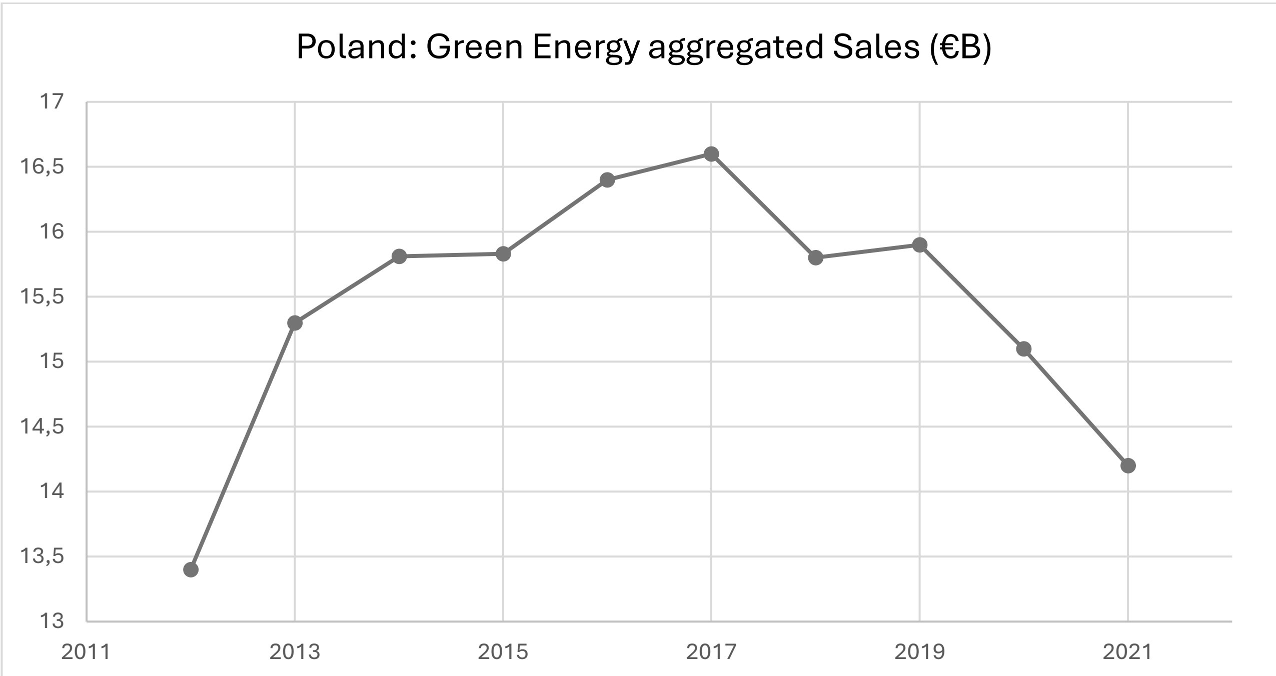
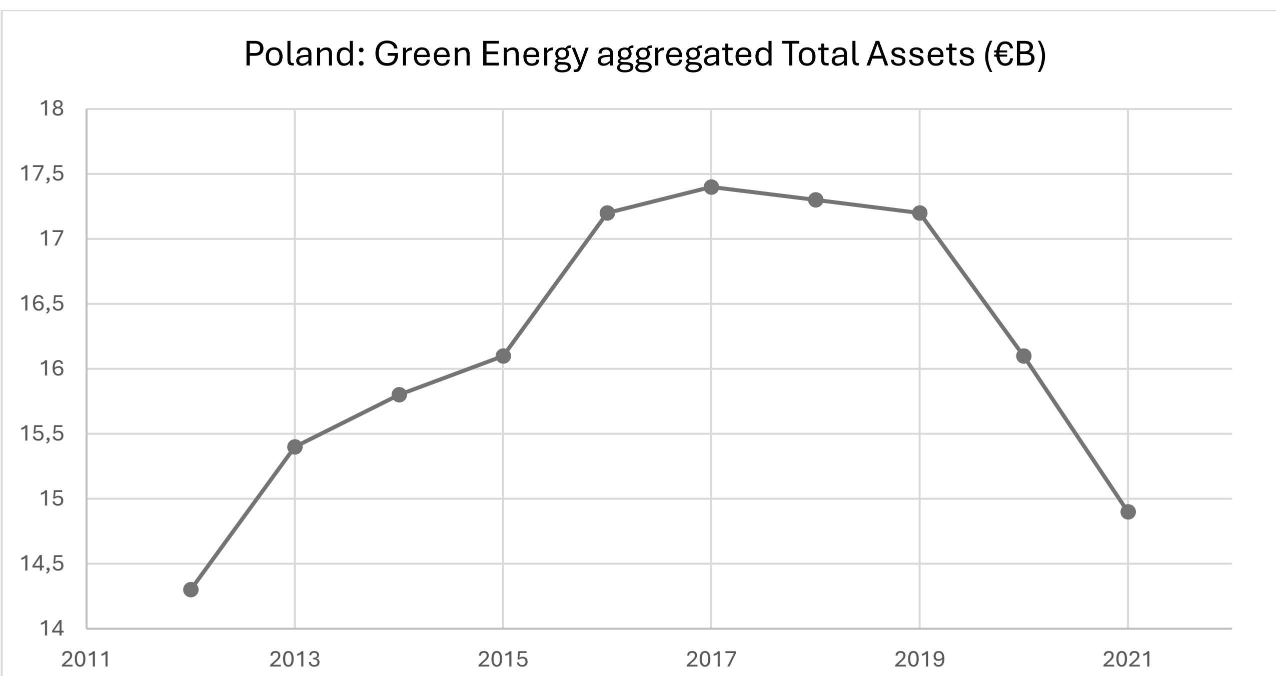


FIGURE 5.25: Poland's Green Energy aggregated Total Assets, from 2012 to 2021



5.6.3 | Multiple linear regression analysis for Poland's aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years.

The following Table 5.20 shows the output of the regressions.

TABLE 5.20: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	2,2018	-0,0029	0,0746
Covid Dummy	-23,073*	-0,0366	-0,5831
Constant	284,36***	0,324*	7,1955***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

All the three models show poor value for both R squared and adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) fail to explain the dependent variables (CO2 emissions). The p-value of the models is never significant, either at a 0,10 level. Same results come up when we analyze the single independent variables: the aggregated Sales have no significant predictable power on the Polish emissions.

These results are in contrast with all the previous countries (where at least the models showed a good level of statistical significance) and are partially justified by the small share of green energy sources in the national mix, that limits heavily the impact of the Green Energy companies on the country's decarbonization.

5.6.4 | Multiple linear regression analysis for Poland's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have excluded this time the dummy variable that accounts for the value of 2021 Total Assets because there isn't any outlier.

The following Table 2.21 shows the output of the regressions.

TABLE 5.21: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Total Assets	3,8324	-0,0080	0,1218
Covid Dummy	-26,3193**	-0,0289	-0,6839*
Constant	256,70**	0,4079**	6,3877***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Even when considering Total Asset, the three models show poor values for both R squared and adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) fail to explain the dependent variables (CO2 emissions). The p-value of the models is never significant, either at a 0,10 level. Same results come up when we analyze the single independent variables: the aggregated Total Assets have no statistical significance in predicting the trend of Polish emissions.

These results are quite in line with that of previous countries, because even in those cases Total Assets rarely show significance. Clearly the Polish emissions regressions are impacted by the small share of green energy sources in the national mix, that limits heavily the impact of the Green Energy companies on the country's decarbonization.

In conclusion, neither Sales neither Total Assets are valid predictors of the Polish Emissions.

5.7 | Correlation analysis for Sweden

5.7.1 | Sweden's CO2 emissions from 2012 to 2022

Table 5.22 reports the data of total CO2 emissions, CO2 emission per GDP and CO2 emission per capita for France, collected from EDGAR over the period 2012-2022.

Figure 5.26, Figure 5.27, and Figure 5.28 report those data graphically, in order to understand better the evolution and the trends of French CO2 emissions over the analyzed time horizon.

TABLE 5.22: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for Sweden over the period 2012 -2022

Year	Total CO2 (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	46,9	0,102	4,9
2013	45,1	0,097	4,7
2014	43,8	0,092	4,5
2015	44,2	0,088	4,5
2016	43,7	0,086	4,4
2017	43,3	0,083	4,4
2018	40,9	0,077	4,1
2019	40,2	0,074	4,0
2020	39,1	0,074	3,9
2021	38,0	0,068	3,7
2022	37,9	0,066	3,7
Variations	**-19,3%**	**-35,4%**	**-24,9%**

FIGURE 5.26: Sweden’s Total Emissions ($MtCO_2$) over the period 2012-2022

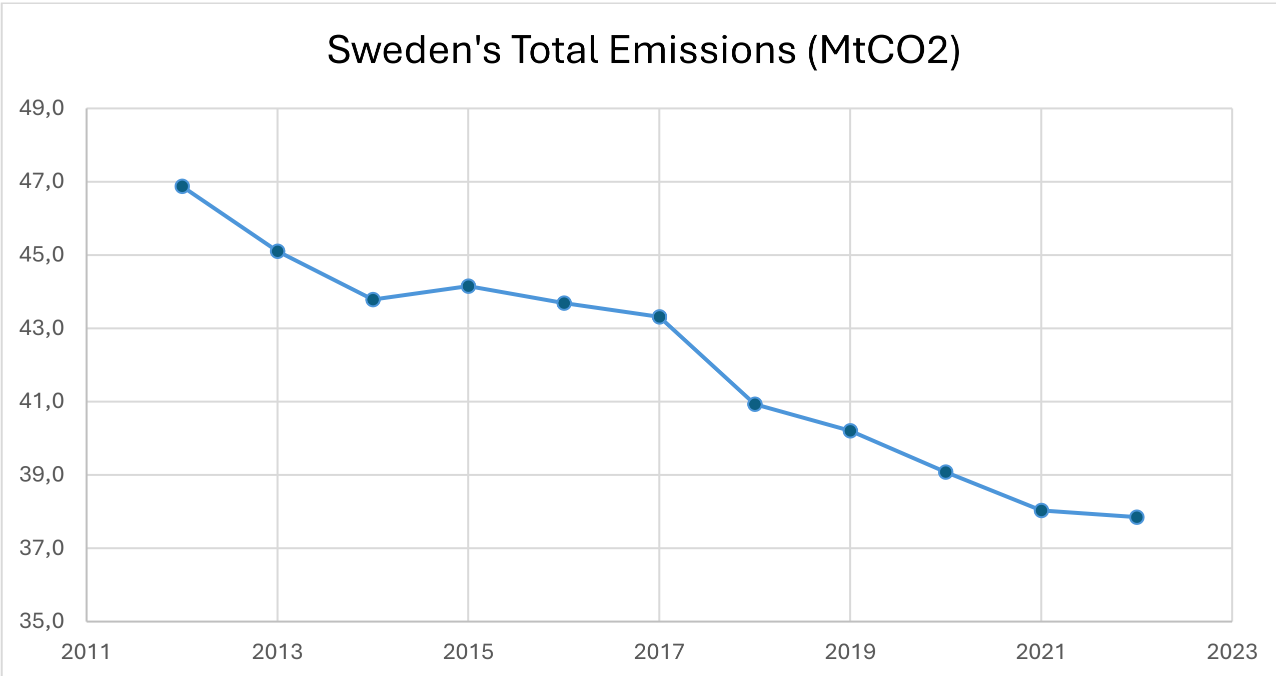


FIGURE 5.27: Sweden’s Emissions per GDP (tCO_2/kUSD) over the period 2012-2022

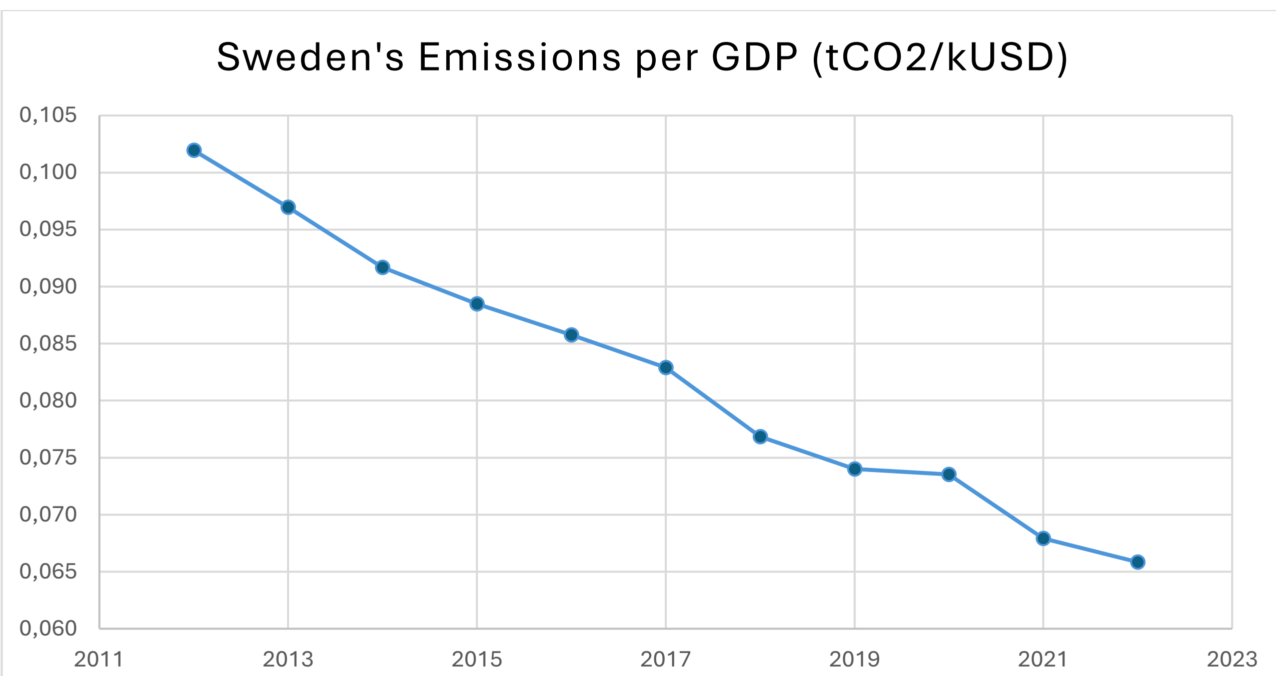
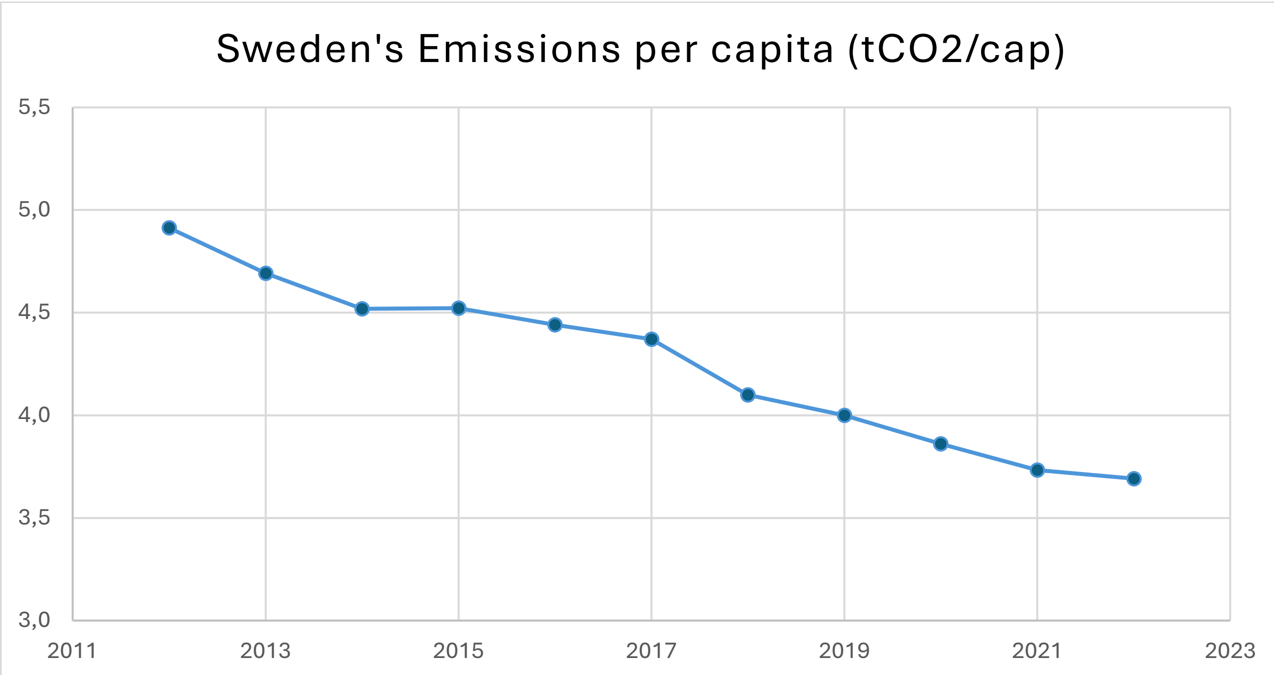


FIGURE 5.28: Sweden's Emissions per capita (tCO2/cap) over the period 2012-2022



Over the period analyzed, Sweden's total emissions have decreased by 19,7%, by far better than EU average of 13,5% and first among the seven countries we have analyzed. In recent decades, Sweden's energy mix has seen a dramatic increase in renewable energy share, due to legislative actions and significant investments meant to achieve carbon neutrality by 2045. Data from Statista show that more than 60% of Sweden's energy came from renewable sources as of 2022. This makes Sweden one of the European countries with the highest share of renewables in final energy consumption.

Hydropower alone generated 43% of the country's electricity. Despite its relatively small population, Sweden ranks as one of the 10 countries with the largest hydroelectricity generation worldwide.

Supported by government incentives and expedited approval procedures, wind energy has shown extraordinary growth with installed capacity reaching 14 GW in 2022, a substantial increase from just 2 GW in 2010.

Due to the huge share of clean energy consumed by the Scandinavian country, the Covid pandemic has little affected the national CO2 emissions, indeed the metrics for 2020 show value in line with the other observations. Nonetheless, we have kept the Covid dummy in the models, for the sake of comparability.

5.7.2 | Sweden's Green Energy aggregated financial metrics from 2012 to 2021

We have computed the aggregated sales and aggregated total asset of Sweden Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category "3.1 Sustainable energy production", "3.2 Sustainable fuels", and "3.3 Energy-efficient industrial technologies".

Table 5.23 shows these financial metrics, while Figure 5.29 and Figure 5.30 plot their time series. Swedish Green Energy aggregated sales have increased by 11,6% over the period analyzed, while aggregated total assets have increased by 22,4%.

TABLE 5.23: Sweden's Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	303	9,17	9,63
2013	334	10,7	10,76
2014	347	11,83	11,03
2015	350	11,85	11,56
2016	372	11,84	11,37
2017	375	11,14	12,06
2018	373	11,25	11,93
2019	377	11,37	11,75
2020	367	10,9	11,91
2021	365	10,24	11,79

FIGURE 5.29: Sweden's Green Energy aggregated Sales, from 2012 to 2021

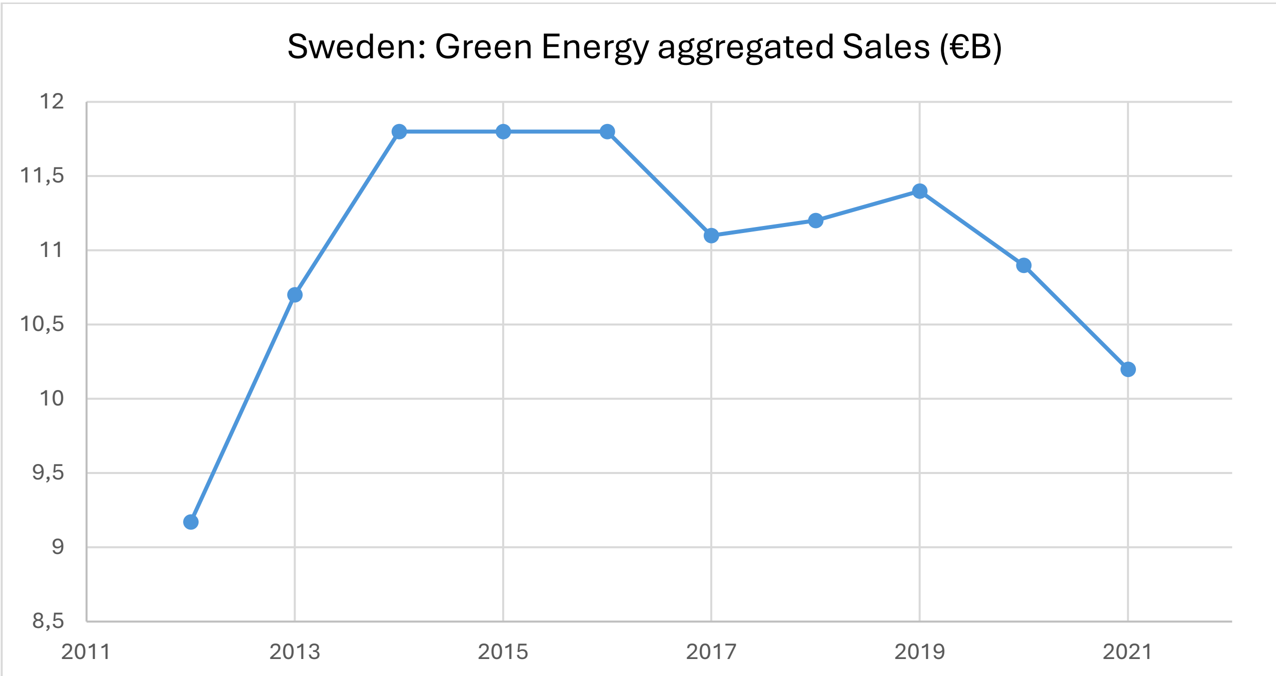
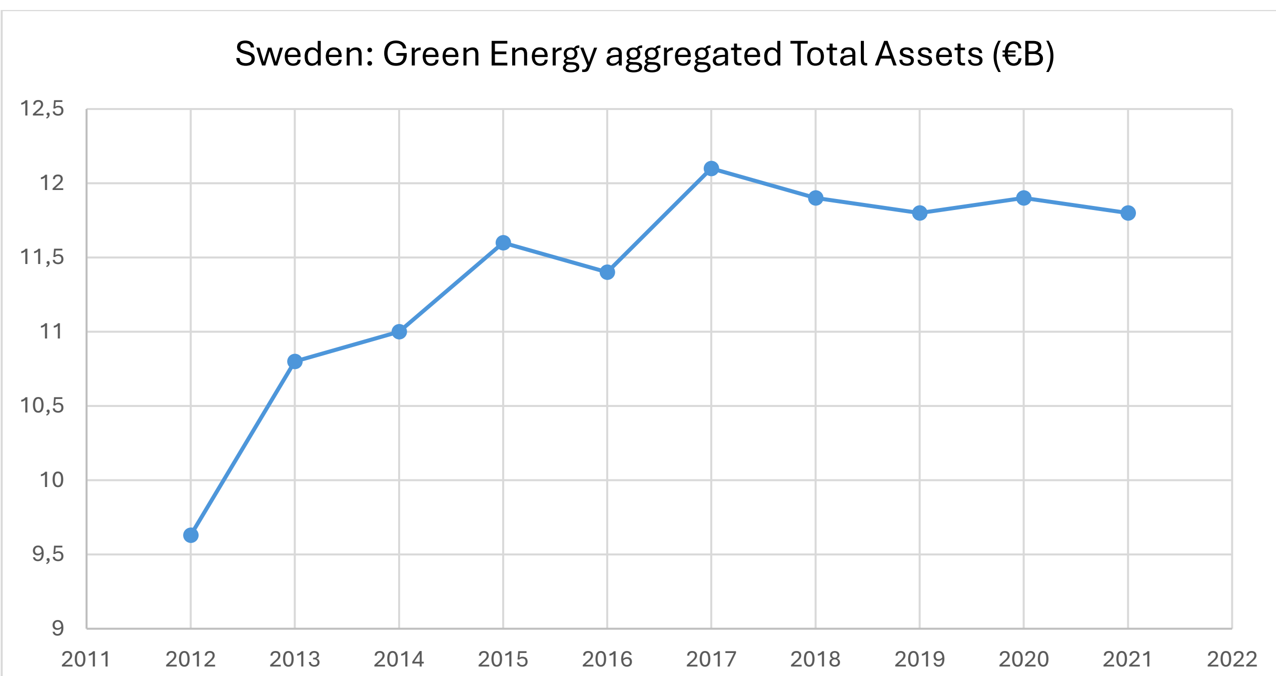


FIGURE 5.30: Sweden's Green Energy aggregated Total Assets, from 2012 to 2021



5.7.3 | Multiple linear regression analysis for Sweden’s aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included for the sake of comparability the dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years.

The following Table 5.24 shows the output of the regressions.

TABLE 5.24: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	0,1858	-0,0016	-0,0062
Covid Dummy	-2,8811	-0,0065	-0,3195
Constant	39,862**	0,099*	4,2905**

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

All the three models show very poor values for R squared and, mostly, for adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) fail to explain the dependent variables (CO2 emissions). The p-value of the models is never significant, either at a 0,10 level, as it shows very high values. Same results come up when we analyze the single independent variables: the aggregated Sales have not at all statistical significance in predicting the Swedish emissions.

These results are in contrast with all the previous countries apart from Poland, where at least the models showed a good level of statistical significance and are partially justified by the great share of green energy sources in the national mix, that leaves little room to the impact of the Green Energy companies on the country’s decarbonization given that the Scandinavian country is still enough green.

5.7.4 | Multiple linear regression analysis for Sweden's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included for the sake of comparability a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have excluded this time the dummy variable that accounts for the value of 2021 Total Assets because there isn't any outlier.

The following Table 5.25 shows the output of the regressions.

TABLE 5.25: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Total Assets	-2,5867**	-0,0115***	-0,3641**
Covid Dummy	-1,6302	-0,002	-0,1575
Constant	71,254***	0,2117***	8,3544***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Total Assets and Covid dummy) well predict the dependent variables (CO2 emissions). The coefficient of X1 (Total Assets) is negative, confirming that higher Green Energy Total Assets lead to lower CO2 emissions.

Furthermore, the p-value of the overall models and the p-value of the independent variable X1 are lower than 0,05 for all the emissions metrics, meaning the models and the Total Assets are statistically significant in predicting Swedish CO2 Emissions.

On the contrary, as expected in this case, the independent variable X2 (Covid dummy) is never significant, indeed Sweden emissions were not disrupted by Covid. We have kept this variable just for comparability purposes.

In conclusion, the Sales are not statistically significant while Total Assets and their models are very significant predictors for the Swedish emissions.

5.8 | Correlation analysis for Austria

5.8.1 | Austria's CO2 emissions from 2012 to 2022

Table 5.26 reports the data of total CO2 emissions, CO2 emission per GDP and CO2 emission per capita for Austria, collected from EDGAR over the period 2012-2022.

Figure 5.31, Figure 5.32, and Figure 5.33 report those data graphically, in order to understand better the evolution and the trends of Austrian CO2 emissions over the analyzed time horizon.

TABLE 5.26: Total CO2 emissions, CO2 per GDP and CO2 per capita emissions for Austria over the period 2012 -2022

Year	Total CO (MtCO2)	CO2 per GDP (tCO2/kUSD)	CO2 per capita (tCO2/cap)
2012	68,9	0,153	8,1
2013	69,5	0,155	8,1
2014	65,9	0,146	7,6
2015	67,3	0,147	7,7
2016	67,7	0,145	7,8
2017	70,0	0,147	8,0
2018	67,0	0,137	7,7
2019	68,6	0,138	7,8
2020	62,6	0,135	7,1
2021	65,6	0,135	7,4
2022	61,2	0,120	6,9
Variations	**-11,2%**	**-21,6%**	**-14,3%**

FIGURE 5.31: Austria's Total Emissions (MtCO2) over the period 2012-2022

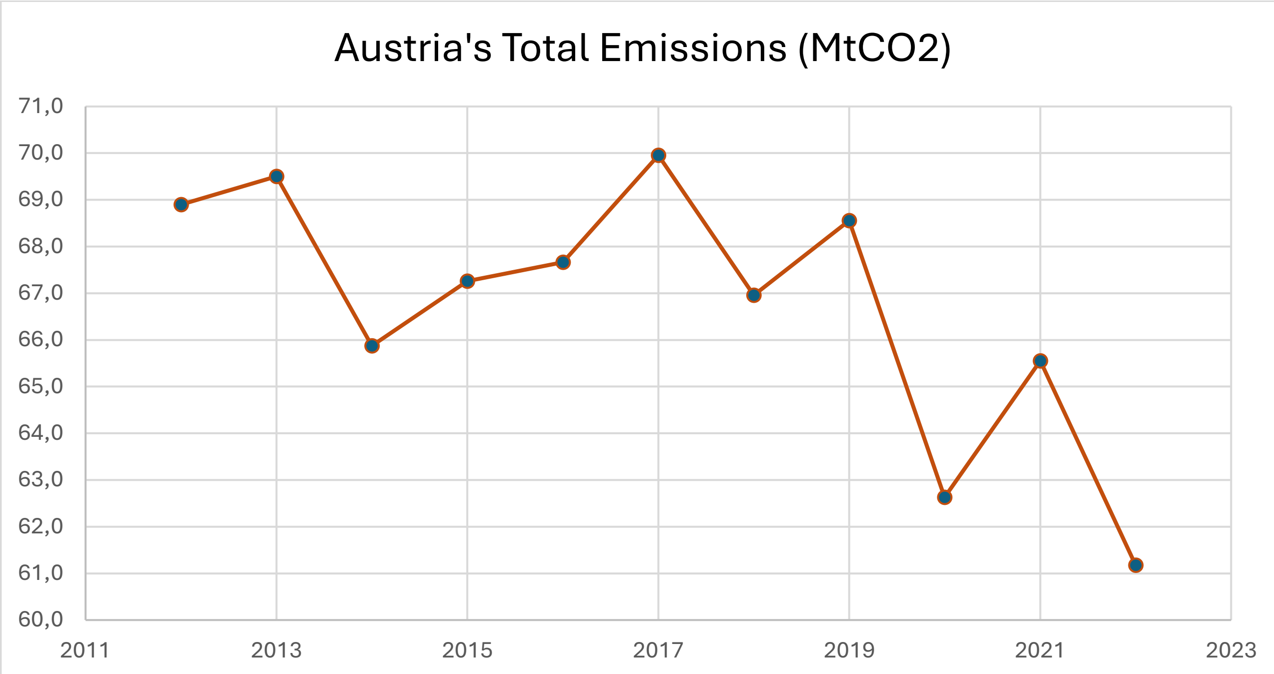


FIGURE 5.32: Austria's Emissions per GDP (tCO2/kUSD) over the period 2012-2022

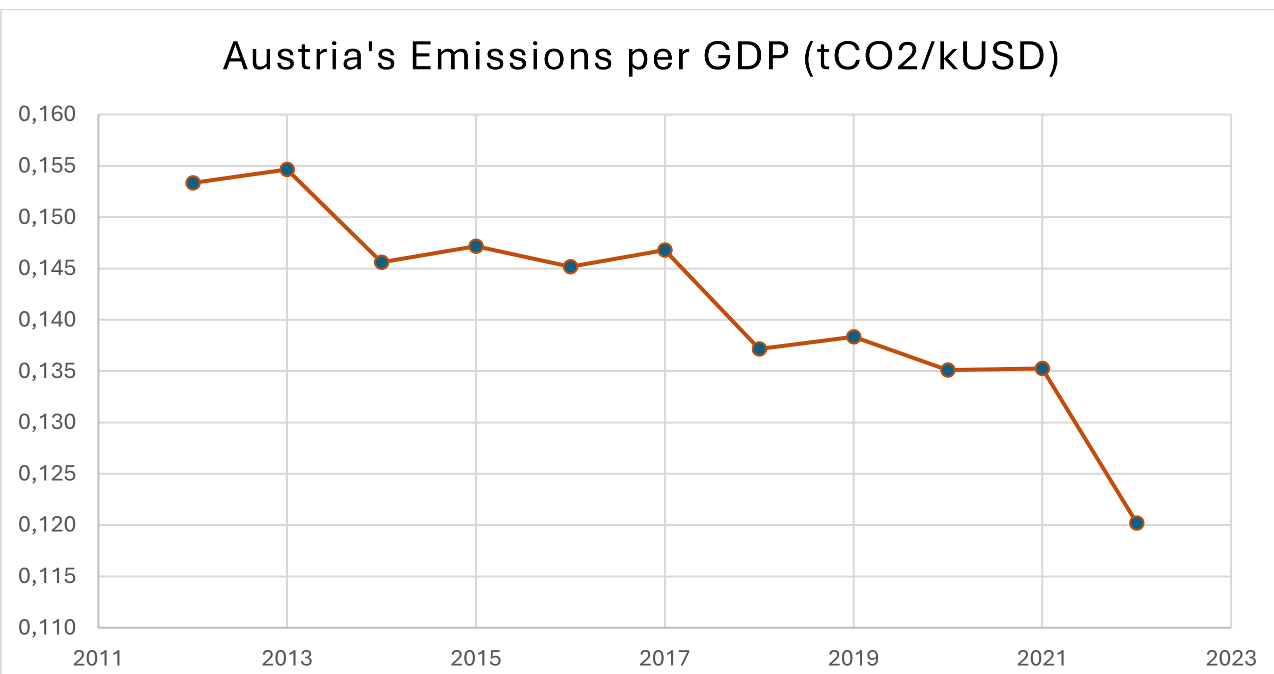
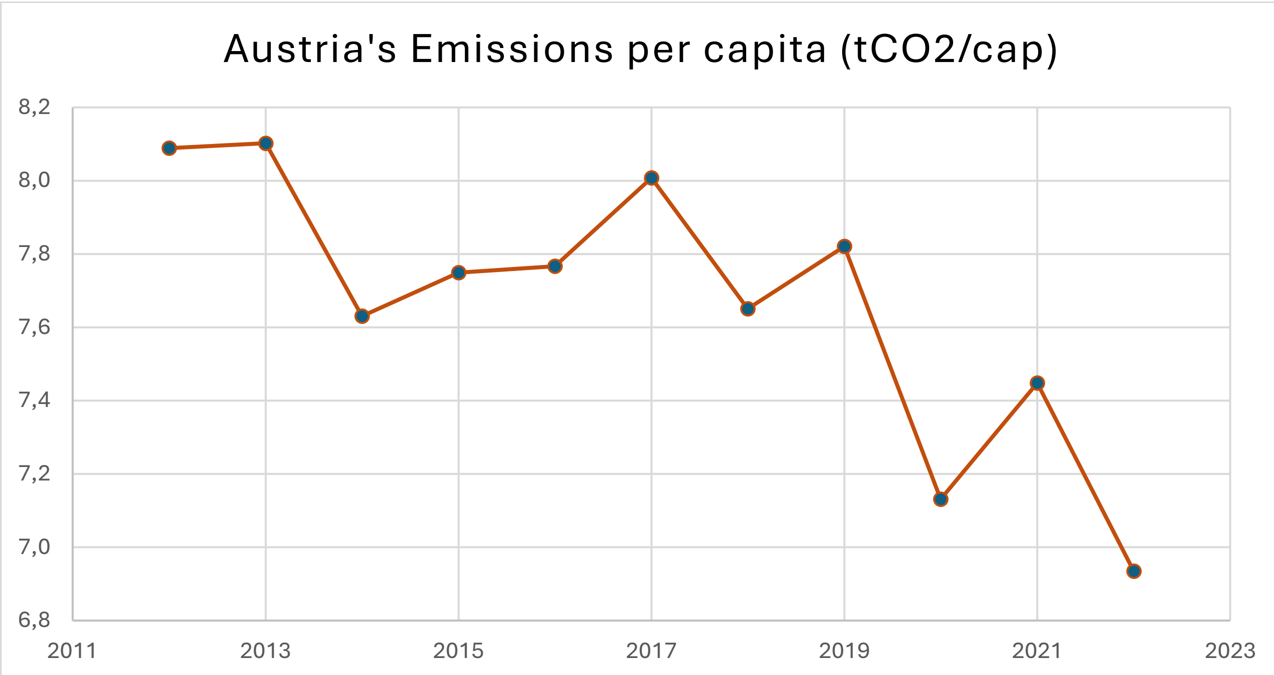


FIGURE 5.33: Austria's Emissions per capita (tCO2/cap) over the period 2012-2022



Over the period analyzed, Austria's total emissions have decreased by 11,2%, slightly lower than EU average of 13,5%. This result is partially justified by the fact that Austrian energy mix is already largely backed by renewable sources.

Austria has made significant progress in shifting its energy mix towards renewable energy in the last decades, reflecting a strong commitment to sustainability and climate goals.

According to a report by Statista, in 2022 around 80% of Austria's electricity was generated from renewable energy sources, with hydropower accounting for the majority at almost 60%, a result very close to the Swedish one. Through the Renewable Expansion Act (EAG) and the Austrian government's #mission2030 program, the country is set to produce 100% renewable electricity by 2030. This goal is backed by yearly investments of about €1 billion that are supporting new wind and solar plants. Austria is also very active on grid modernization and energy storage solutions, so to enhance renewable energy integration in its current network.

The impact of Covid on Austrian economy pushed down the 2020 Total CO2 Emissions by almost 9% if compared to 2019.

5.8.2 | Austria's Green Energy aggregated financial metrics from 2012 to 2021

We have computed the aggregated sales and aggregated total asset of Austrian Green Energy companies over the period 2012-2021 from the recordings in the database. We have included all the companies classified in the technology category "3.1 Sustainable energy production", "3.2 Sustainable fuels", and "3.3 Energy-efficient industrial technologies".

Table 5.27 shows these financial metrics, while Figure 5.34 and Figure 5.35 plot their time series. Austrian Green Energy aggregated sales have decreased by 32% over the period analyzed, while aggregated total assets have increased by 5%.

TABLE 5.27: Austria's Green Energy aggregated Total Sales and Total Assets from 2012 to 2021

Year	#Companies	Total Sales (B€)	Total Assets (B€)
2012	244	4,94	7,73
2013	257	5,56	8,6
2014	261	5,1	8,35
2015	268	4,87	8,54
2016	275	3,86	9,33
2017	270	4,07	8,81
2018	270	3,14	8,84
2019	265	3,81	9,03
2020	254	3,59	8,52
2021	255	3,36	8,12

FIGURE 5.34: Austria's Green Energy aggregated Sales, from 2012 to 2021

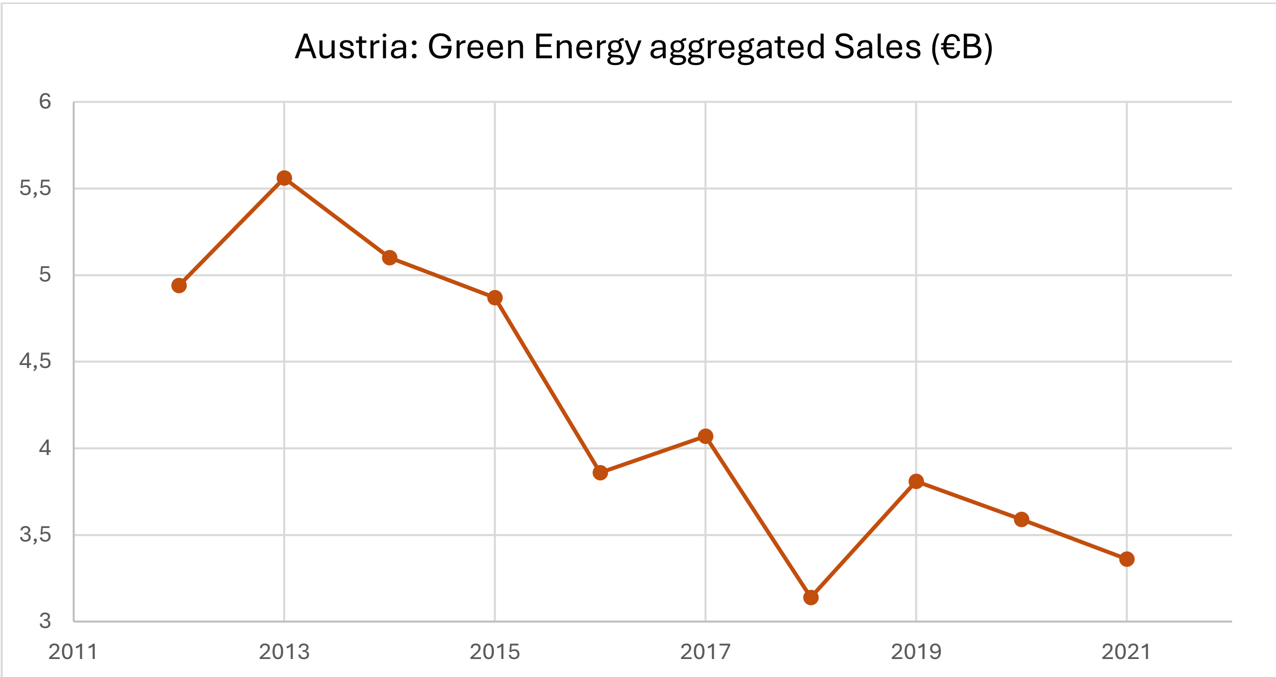
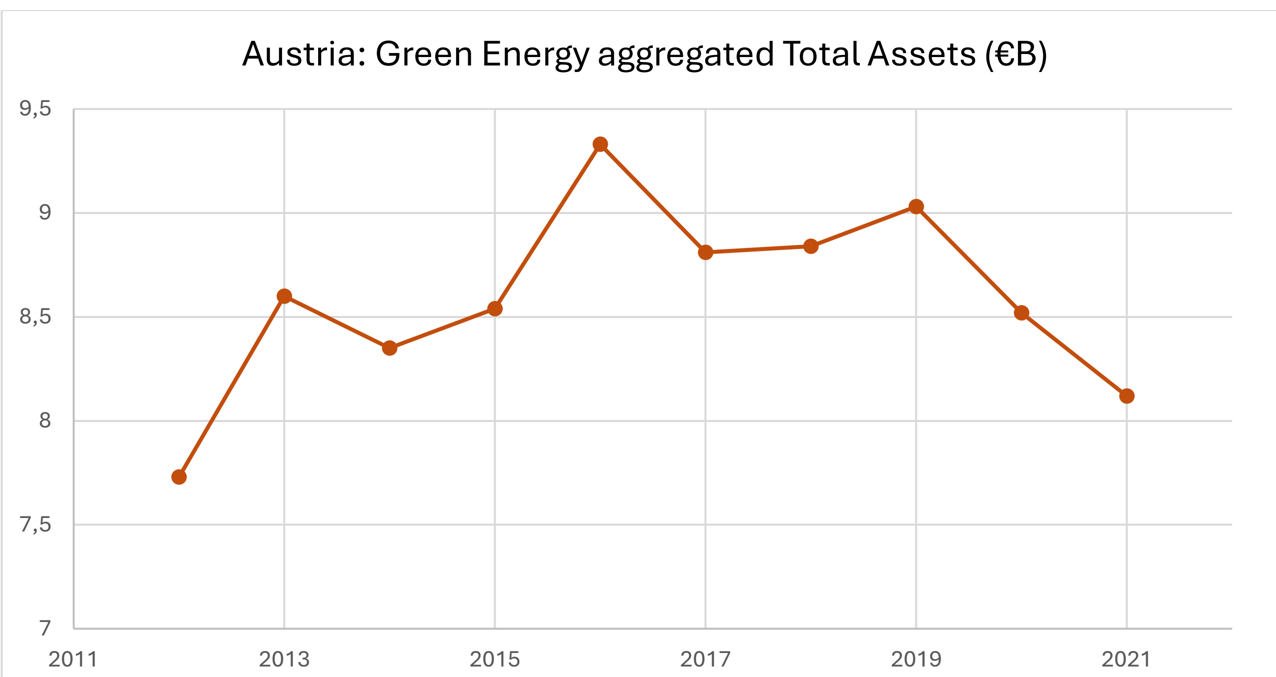


FIGURE 5.35: Austria's Green Energy aggregated Total Assets, from 2012 to 2021



5.8.3 | Multiple linear regression analysis for Austria's aggregated Sales

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Sales (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years.

The following Table 5.28 shows the output of the regressions.

TABLE 5.28: Multiple linear regression output, Sales as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Sales	0,6936	0,0081**	0,151
Covid Dummy	-4,054	-0,0023	-0,4961
Constant	64,011***	0,1064***	7,02***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Two out of three models, those for Total CO2 emissions and for Emissions per capita, show very poor values for R squared and, mostly, for adjusted R squared, meaning that the independent variables together (Sales and Covid dummy) fail to explain the dependent variables (CO2 emissions). The p-value of the models is never significant, either at a 0,10 level, as it shows very high values. On the contrary, the model for Emissions per GDP is significant at a 0,10 level and the independent variable X1 is significant at a 0,05 level.

We can conclude that the aggregated Sales have not a good statistical significance in predicting the Austrian emissions.

These results are in contrast with all the previous countries apart from Poland and Sweden, where at least the models showed a good level of statistical significance. The reasons of this result are to be found in the great share of green energy sources in the national mix, and in the little dimensions of the national Green Energy sector (as the size of its aggregated financial metrics can show). Indeed, Austria hosts only the 2,7% of the European Green Energy companies recorded in the database (Table 3.5).

5.8.4 | Multiple linear regression analysis for Austria's aggregated Total Assets

We have performed three multiple linear regression analysis on Excel to study the correlation between aggregated Total Assets (independent variable X1) and each of the three CO2 emissions metrics gathered (Total CO2 emissions, CO2 per GDP and CO2 per capita emissions), that are our dependent variables. We have included a dummy independent variable X2 to manage the 2020 emission data outliers due to Covid pandemic. Given that the emissions data are lagging 1 year over the financial data, this dummy variable is equal to 1 in 2019 and equal to 0 in all the other years. We have also added a dummy variable (independent variable X3) to account for the outlier in the value of 2021 Total Assets that is unreasonable higher than the previous years, due to the impact of governmental grants and subsidies offered to companies to cope with industrial disruption caused by Covid pandemic.

The following Table 5.29 shows the output of the regressions.

TABLE 5.29: Multiple linear regression output, Total Assets as independent variable

	Total CO2 Emissions	CO2 Emissions per GDP	CO2 Emissions per capita
Total Assets	0,3075	-0,0071	-0,056
Covid Dummy	-5,2353**	-0,0056	-0,6378*
2021 Dummy	-6,355**	-0,027***	-0,8888**
Constant	65,058***	0,2048***	8,2438***

Significance at 1%, 5% and 10% is denoted by ***, ** and *, respectively.

Each of the three multiple linear regressions report a high level for both R squared and adjusted R squared, meaning that the independent variables together (Total Assets, Covid dummy and Outlier dummy) well predict dependent variables (CO2 emissions). The coefficient of X1 (Total Assets) is negative for Emissions per GDP and per capita but positive for Total CO2 Emissions.

The p-value of the overall models is lower than 0,05 for all the emissions metrics, meaning that these models are overall statistically significant in predicting the CO2 Emissions. On the contrary, the independent variable Total Assets is never statistically significant, either at a 0,10 level. Thus, it is not a significant predictor for Austrian Emissions.

In conclusion, Sales, the models based on Sales and Total Assets have no statistical significance in explaining Austria's Emissions. The contrary is true for the models based on Total Assets.

5.9 | Comparison and conclusions

In Table 5.30 we summarize the results of our analysis to determine whether it is possible or not to find a unique pattern in the outputs obtained.

The multiple linear regressions we have run for the different countries and different metrics have resulted in complex and various outputs. From these results, it is not possible to derive a unique correlation principle valid for all the countries and all the emissions metrics. On the contrary, each output must be contextualized and justified according to the specific economic, energetic and political conditions by which the specific country is characterized.

For the bigger countries in terms of local Green Energy sector size, GDP and population (like France, Germany, Italy and Spain), it seems that aggregated Sales, at least at the level of the overall model, are good predictors of the CO2 Emissions. While aggregated Total Assets are usually weaker predictors and their statistical significance is usually lower.

For the smaller countries, like Poland, Sweden and Austria, Total Sales are never statistically significant. On the contrary, in some cases Total Assets are good predictors of the national Emissions, as in the Swedish case. But we can’t generalize these results, because each country is highly specific and unique in its energy mix, climate policies and industrial composition.

Our analysis, thus, has not found a unique pattern among all the countries analyzed.

TABLE 5.30: Comparison of the results for the different countries

Country	Aggregated Sales	Aggregated Total Assets
France	Statistically strongly significant in predicting all the Emissions metrics; negatively correlated to them	Statistically strongly significant in predicting all the Emissions metrics; negatively correlated to them
Germany	Statistically strongly significant in predicting all the Emissions metrics; negatively correlated to them	Statistically weakly significant in predicting all the Emissions metrics; positively correlated to them
Italy	The models are statistically significant in predicting Emissions, the single variable is not significant; negatively correlated to Emissions	The models are weakly statistically significant in predicting Emissions, the single variable is not significant; positively correlated to Emissions
Spain	The models are statistically significant in predicting Emissions, the single variable is not significant; positively correlated to Emissions	The models are weakly statistically significant in predicting Emissions, the single variable is not significant; negatively correlated to Emissions
Poland	Both the models, both the single variable are not significantly correlated to Emissions.	Both the models, both the single variable are not significantly correlated to Emissions.
Sweden	Both the models, both the single variable are not significantly correlated to Emissions.	Both the models, both the single variable are statistically strongly significant in predicting all the Emissions metrics; negatively correlated to them
Austria	Both the models, both the single variable are not significantly correlated to Emissions.	The models are statistically significant in predicting Emissions, the single variable is not significant; negatively correlated to Emissions

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"Nihil sub sole novum,

nec valet quisquam dicere

"Ecce hoc recens est",
jam enim præcessit in sæculis

quæ fuerunt ante nos."

A mia mamma, senza la quale nulla di tutto questo sarebbe stata possibile. Roccia incrollabile di fede, di amore e di lavoro.

A mio nonno Peppe Testanterra, il mio liuni, che mi ha insegnato le lezioni più importanti della Vita. Averlo come esempio è stato il fondamento dei miei traguardi e di ciò che sono.

A mia nonna Rosina, che nell'aurea mediocritas di una vita semplice, diretta e sincera mi ha saputo trasmettere un'inesauribile sapienza di un mondo di altri tempi.

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To the marble saint that doesn't sweat, I will be always there when you need someone.

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