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Renewable Energy Sources and Their Impact on Electricity Production in the EU

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ABSTRACT:
Increasingly often, certain changes in the energy sector appear as a necessity. The purpose of these changes is given by both the desire to improve energy security and to mitigate climate change. One of the solutions for reducing greenhouse gas emissions is the use of renewable energy sources. Both energy production and consumption are important. Thus, the article presents an analysis of gross electricity production, as well as gross final energy consumption. For this reason, energy productivity is analyzed by presenting its evolution. For a transition to clean energy, renewable energy sources can replace fossil fuels. Thus, the use of renewable energy sources can constitute an alternative to the use of fossil fuels. Energy systems that have low carbon emissions allow for the reduction of pollution and increase energy security. Considering the main renewable sources, a comparative situation of electricity production capacities is presented for the period 2013-2023.

Keywords: renewable sources, gross electricity production, European Union

1. Introduction

The functioning of natural systems is based on certain balances. Human intervention influences these natural systems (Rădulescu et al., 2023). Thus, the increase in resource consumption, rapid population growth, and the accelerated development of technologies cause global changes that can even affect human civilization (Bodislav et al., 2020). The energy transition can be based on both the digitalization of energy networks and the improvement of energy efficiency, as well as the use of electricity produced from renewable sources to the detriment of electricity produced using fossil sources (Angheluta et al., 2019). At the same time, with regard to fossil fuel-based power plants, the use of existing infrastructure and their integration into the circular economy can contribute to reducing pollution. At this time, renewable energy considers wind energy and solar energy as renewable sources in particular (Ahmed and Măgurean, 2024).
An important aspect in terms of reducing the impact on the environment and saving natural resources is the storage of renewable energy (Beaupere et al., 2024).
Regarding smart cities, in the context of sustainable urban development, climate change brings energy management to the forefront. For this, innovative technologies, energy storage methods, and the development of smart energy networks play a major role (Szpilko et al., 2024).

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Since the energy consumption in urban areas is based to a small extent on renewable energy sources, the aim is to promote the use of both solar energy and geothermal and wind energy. However, energy policies do not yet attach high importance to energy storage systems (Ulpiani et al., 2023).
The demand for renewable energy is increasing. For this reason, the importance of responses to energy security challenges, as well as how to implement the transition to green energy, has increased (Hofmann and Lindberg, 2024).
Residential electricity consumption is closely linked to human and capital investments (Diaconu et al., 2019). The use of fossil fuels has an impact on the transition to renewable energy. A high dependence on fuel use positively influences green economic growth. However, the adoption of clean energy technologies and the expansion of renewable energy use raise their initial costs (Hwang and Díez, 2024).

2. Literature review

Geological and meteorological characteristics influence renewable energy resources in terms of quality and quantity. It is found that, by integrating renewable energy, certain positive effects are manifested in terms of land use, employment, and investment (Onodera et al., 2024).
An effect of economic complexity is given by an increase in the consumption of renewable energy. This, by promoting clean energies, implies an improvement in the environment. At the same time, the decrease in energy intensity can be attributed to economic growth. And the decrease in energy intensity has a favorable impact in terms of energy efficiency. A greener economy can be achieved by promoting the production, as well as the consumption, of renewable energy (Taghvaee et al., 2024).
Renewable energy technologies can expand their portfolio to include ocean thermal energy or wave energy in addition to solar and wind energy. This can make the energy transition both cost-effective and rapid (Keiner et al., 2024).
However, environmental policies in one region can also have spillover effects on neighboring regions. This can lead to green economic growth. In this regard, the enforcement of environmental regulations should be a priority for policymakers. The energy efficiency of renewable energy technologies can be increased through fiscal incentives, and through investments in infrastructure and research (Chen et al., 2024).
Renewable energy can be intermittent. Various types of capacity mechanisms have been introduced to protect the reliability of their energy systems. Within capacity mechanisms, renewable energy sources can make an important contribution to improving resource adequacy (Kozlova et al., 2023).
A future solution may be represented by the decarbonization of fossil fuels, namely renewable hydrogen (Strömer et al., 2024). Thus, hydrogen has an essential role in terms of decarbonization (EC, 2020).
Moreover, carbon neutrality can be achieved by reducing greenhouse gas emissions to zero, including by eliminating greenhouse gas emissions from buildings. These challenges translate into making buildings more energy efficient. In this sense, modernizing buildings requires that they become more adaptable and flexible, respectively more resilient to climate change (Naik et al., 2024).

The profitability of renewable energy production has increased. Its competitiveness has led to increased efficiency, as a result of technological advances. However, there are situations in which energy infrastructure can be damaged due to climate change. This affects energy production, but also the price of renewable energy (Hu et al., 2024).
In order to reduce greenhouse gas emissions, it is important to address climate change. In order to decarbonize the energy sector, measures are needed to increase the share of renewable sources in total energy production (Martinez and Iglesias, 2024).
In order to maximize profits, as well as to guarantee the energy needs of end users, investors need to select options through which the configuration of an energy installation is optimal. This is considering that investments in the energy sector can be influenced by environmental factors, economic factors, but also social and technical factors (Pagnini et al., 2024).

3. Methodology of research

The development of energy generation technologies based on renewable sources is of increasing interest. An analysis of gross electricity production was also made. For the period 2013-2023, a comparative situation of electricity production capacities for the main renewable sources is presented, as well as energy productivity. However, there are situations in which the energy infrastructure can be damaged due to climate change. Thus, energy production is affected, but also the price of renewable energy (Hu et al., 2024). At the same time, in the article, renewable energy sources is customized for the electricity sector.

4. Results and discussions

An important indicator regarding the production of renewable energy is given by the share of renewable energy sources in gross final energy consumption. Thus, the following table presents the comparative situation for the share of renewable energy sources in gross final energy consumption, for the period 2013-2023 (%).

Table 1 - The comparative situation of share of renewable energy sources in gross final energy consumption 2013-2023 (%). Source: processing according to data published by EUROSTAT, 2025

Countries	2013	2015	2017	2019	2021	2023
European Union	16,66	17,82	18,41	19,89	21,89	24,54
Belgium	7,67	8,06	9,14	9,93	13,08	14,74
Bulgaria	18,90	18,26	18,70	21,55	19,45	22,55
Czechia	13,93	15,07	14,80	16,24	17,61	18,59
Denmark	27,17	30,47	34,39	37,02	41,81	44,40
Germany	13,76	14,90	15,47	17,27	19,28	21,55
Estonia	25,36	28,99	29,54	31,73	37,34	40,95
Ireland	7,52	9,08	10,52	11,98	13,00	15,25
Greece	15,33	15,69	17,30	19,63	22,00	25,27
Spain	15,08	16,22	17,12	17,85	20,55	24,85
France	13,88	14,80	15,85	17,17	19,32	22,28
Croatia	28,04	28,97	27,28	28,47	31,29	28,05

Countries	2013	2015	2017	2019	2021	2023
Italy	16,74	17,53	18,27	18,18	18,88	19,59
Cyprus	8,43	9,90	10,48	13,78	19,07	20,21
Latvia	37,04	37,54	39,01	40,93	42,10	43,22
Lithuania	22,69	25,75	26,04	25,47	28,17	31,93
Luxembourg	3,49	4,99	6,19	7,05	11,73	14,36
Hungary	16,21	14,50	13,56	12,63	14,13	17,12
Malta	3,76	5,12	7,22	8,23	12,63	15,08
Netherlands	4,69	5,71	6,51	8,89	12,96	17,15
Austria	32,67	33,50	33,14	33,76	34,79	40,84
Poland	11,45	11,88	11,06	15,38	15,62	16,56
Portugal	25,70	30,51	30,61	30,62	33,98	35,16
Romania	23,89	24,79	24,45	24,29	23,87	25,76
Slovenia	23,16	22,88	21,66	21,97	25,00	25,07
Slovakia	10,13	12,88	11,47	16,89	17,42	16,99
Finland	36,63	39,23	40,86	42,81	42,85	50,75
Sweden	50,15	52,22	53,39	55,79	62,53	66,39

Compared to 2013, in 2023, at the European Union level, the share of renewable energy in gross final energy consumption increased by 7.88%. The largest increases in this indicator were in: Denmark (+17.22%), Sweden (+16.24%), Estonia (+15.59%), Finland (+14.12%), Netherlands (+12.46%). In 2023, the share of renewable energy in gross final energy consumption, at the European Union level, was 24.54%. The highest values were recorded in: Sweden (66.39%), Finland (50.75%), Denmark (44.40%), Latvia (43.22%), Estonia (40.95%), Austria (40.84%). At the same time, the lowest values were in: Luxembourg (14.36%), Belgium (14.74%).

Also, another important indicator is renewable energy sources in electricity. Table 2 presents the comparative situation of the share of renewable energy sources in electricity, for the period 2013-2023.

Table 2 - The comparative situation of share of renewable energy sources in electricity 2013-2023 (%). Source: processing according to data published by EUROSTAT, 2025

Countries	2013	2015	2017	2019	2021	2023
European Union	26,77	29,66	31,10	34,09	37,76	45,29
Belgium	12,55	15,57	17,21	20,82	26,02	31,37
Bulgaria	18,68	18,98	19,02	23,51	21,41	29,43
Czechia	12,78	14,07	13,65	14,05	14,47	16,45
Denmark	43,08	51,29	59,94	65,35	72,92	79,39
Germany	25,28	30,88	34,61	40,60	43,88	52,24
Estonia	12,95	16,15	17,58	22,00	29,20	31,85
Ireland	20,96	25,73	30,32	36,46	37,67	40,43
Greece	21,24	22,09	24,46	31,30	35,88	48,23
Spain	36,03	36,97	36,47	37,13	46,00	56,93
France	16,98	18,82	19,93	22,39	24,73	29,98
Croatia	42,08	45,41	46,44	49,78	53,47	58,83
Italy	31,30	33,46	34,10	34,97	36,00	38,10
Cyprus	6,65	8,45	8,91	9,76	14,84	20,94

Countries	2013	2015	2017	2019	2021	2023
Latvia	48,69	52,21	54,35	53,42	51,40	54,32
Lithuania	13,15	15,54	18,26	18,79	21,28	36,47
Luxembourg	5,33	6,20	8,06	10,86	14,22	18,04
Hungary	6,60	7,34	7,51	9,97	13,66	19,54
Malta	1,57	4,31	6,85	7,49	9,65	10,74
Netherlands	9,91	11,04	13,81	18,23	33,25	46,40
Austria	68,91	71,49	71,63	75,07	73,88	87,76
Poland	10,68	13,40	13,08	14,36	17,17	25,79
Portugal	49,10	52,62	54,17	53,77	58,43	63,01
Romania	37,52	43,16	41,97	42,62	42,68	47,39
Slovenia	33,08	32,72	32,43	32,63	34,98	41,89
Slovakia	20,80	22,66	21,34	22,10	22,40	24,20
Finland	30,54	32,21	35,04	37,97	39,58	52,38
Sweden	61,74	65,73	65,91	71,23	75,76	87,55

At the European Union level, in 2023 compared to 2013, the growth was +18.52%. In 2023, the highest share of renewable energy sources in electricity was recorded in: Austria (87.76%), Sweden (87.55%), Denmark (79.39%), Portugal (63.01%). The lowest values were: Malta (10.74%), Czechia (16.45%), Luxembourg (18.04%), Hungary (19.54%).

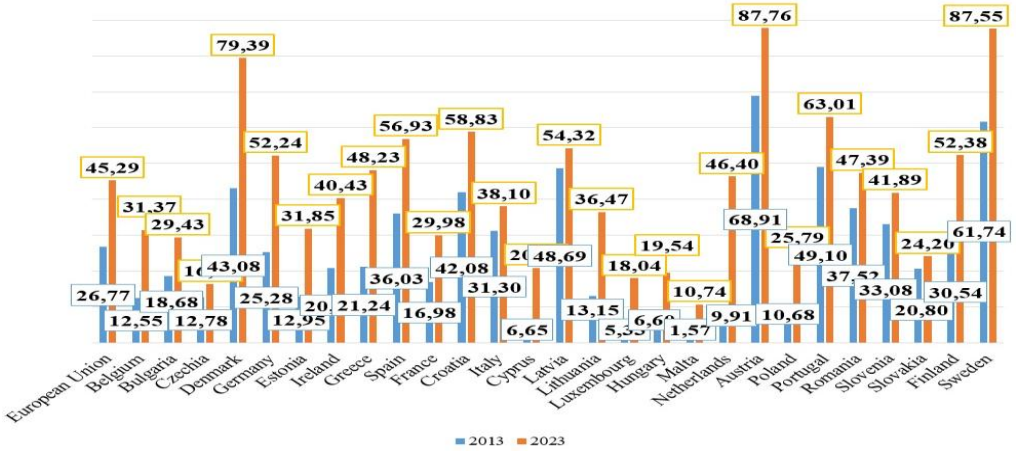

Figure 1 - Evolution of renewable energy sources in electricity at the level of the European Union, for the period 2013-2023 (%). Source: processing according to data published by EUROSTAT, 2025

For the member countries of the European Union, figure 1 shows the evolution of renewable energy sources in electricity for the period 2013-2023. It is observed that for many countries the values have at least doubled. Thus, the values have increased more than three times for: Malta, Netherlands, Luxembourg, Cyprus, Hungary. Also, if in 2013 only 2 countries had shares of over 50% (Austria and Sweden), in 2023 the number of countries with shares of over 50% has increased to 9 (Austria, Sweden, Denmark, Germany, Spain, Croatia, Latvia, Portugal, Finland).

The amount of economic production that is produced per unit of gross energy is represented by energy productivity. The table shows the comparative situation of this indicator for the period 2013-2023 (KGOE).

Table 3 - Comparative situation of energy productivity 2013-2023 (Euro per kilogram of oil equivalent) Source: processing according to data published by EUROSTAT, 2025

Countries	2013	2015	2017	2019	2021	2023
European Union	7,34	7,80	7,93	8,43	8,69	9,84
Belgium	5,94	6,46	6,17	6,41	6,47	7,84
Bulgaria	2,28	2,18	2,28	2,46	2,48	2,94
Czechia	3,71	4,11	4,29	4,62	4,58	5,23
Denmark	13,23	14,34	14,93	15,72	17,23	18,81
Germany	8,22	8,87	9,21	9,86	10,19	11,84
Estonia	2,66	3,43	3,08	4,04	4,37	4,64
Ireland	12,88	16,48	17,54	19,64	25,62	26,16
Greece	6,89	7,02	6,94	7,37	8,13	8,94
Spain	8,01	8,30	8,36	8,93	9,07	9,94
France	7,69	8,04	8,42	8,87	9,16	10,23
Croatia	5,24	5,36	5,49	5,87	6,13	6,68
Italy	9,65	9,92	9,94	10,30	10,32	11,80
Cyprus	7,22	7,04	7,14	7,82	9,19	9,48
Latvia	4,22	4,54	4,63	4,74	5,05	5,66
Lithuania	4,50	4,70	4,65	5,03	5,26	6,02
Luxembourg	10,35	11,29	11,58	11,50	13,14	15,08
Hungary	4,27	4,38	4,42	4,90	4,90	5,69
Malta	3,71	3,94	3,60	3,75	4,74	4,52
Netherlands	7,02	7,60	7,77	8,45	8,83	10,46
Austria	8,90	9,19	9,30	9,71	9,69	10,93
Poland	3,94	4,39	4,33	4,77	4,83	5,69
Portugal	7,29	7,09	7,13	7,71	8,36	8,98
Romania	4,29	4,61	4,88	5,43	5,35	6,35
Slovenia	5,11	5,60	5,63	6,21	6,74	7,72
Slovakia	4,13	4,62	4,57	5,11	5,03	5,48
Finland	5,57	5,70	5,75	5,91	6,02	6,10
Sweden	7,51	8,46	8,18	8,70	9,40	10,07

From the data presented in the table, it can be seen that in 2023, at the European Union level, energy productivity was 9.84 KGOE. In 2023, the lowest values were recorded in: Bulgaria (2.94 KGOE), Malta (4.52 KGOE), Estonia (4.64 KGOE). The highest values were recorded in: Ireland (26.16 KGOE), Denmark (18.81), Luxembourg (15.08 KGOE). Compared to 2013, in 2023, the highest increase in energy productivity was recorded in Ireland (+13.28%).

For the main renewable sources, the comparative situation of electricity production capacities is shown in the following table (megawatts).

Table 3 - Comparative situation of electricity production capacities for the main renewable sources for 2013 and 2023. Source: processing according to data published by EUROSTAT, 2025

Countries	2013						2023					
	1	2	3	4	5	6	1	2	3	4	5	6
European Union	146045	796	105631	79667	8601	9074	153180	882	218860	246073	11435	9340
Belgium	1426	0	1769	2864	151	323	1431	0	5454	8352	216	354
Bulgaria	3203	0	683	1039	4	0	3350	0	704	2908	37	0
Czechia	2252	0	262	2053	361	47	2288	0	343	3251	376	58
Denmark	9	0	4819	571	93	332	7	0	7277	3529	124	347
Germany	112319	26	33477	367100	5148	2813	109551	52	69486	74882	7074	3006
Estonia	8	0	248	0	6	210	10	0	340	813	11	210
Ireland	529	0	1923	1	38	16	529	0	4739	753	39	83
Greece	3238	0	1809	2579	46	43	3459	0	5232	6689	121	43
Spain	191855	0	22958	7000	243	284	201400	0	30868	31884	272	317
France	256445	15	8160	5277	312	1324	263225	16	23132	17026	571	1007
Croatia	2178	0	254	19	17	0	2190	10	1160	463	54	0
Italy	220029	729	8542	181855	1317	857	229122	772	12307	29351	1391	861
Cyprus	0	0	147	35	10	0	0	0	158	581	14	0
Latvia	1587	0	66	0	53	0	1588	0	128	319	44	0
Lithuania	876	0	279	68	16	12	877	0	1284	1153	37	55
Luxembourg	1134	0	58	95	10	19	1330	0	207	404	11	17
Hungary	57	0	329	35	63	45	60	3	324	5910	81	79
Malta	0	0	0	29	3	0	0	0	0	226	4	0
Netherlands	37	0	2713	650	230	649	38	0	10734	21275	184	788
Austria	13383	1	1675	626	194	1078	14953	0	3896	6395	178	872
Poland	2355	0	3429	2	153	0	2410	0	9343	16428	276	91
Portugal	5661	25	4610	296	55	91	8187	29	5538	3869	75	81
Romania	6610	0	2773	761	11	0	6687	0	3027	2988	21	1
Slovenia	1299	0	2	187	28	2	1351	0	3	1031	30	2
Slovakia	2523	0	5	533	35	8	2531	0	4	594	84	23
Finland	3108	0	447	9	0	31	3169	0	6946	1009	10	169
Sweden	16494	0	4194	43	5	889	16406	0	16224	3993	100	876

1 – Hydro
2 – Geothermal
3 – Wind
4 – Solar
5 – Biogases
6 – Waste

From the data available on the EUROSTAT website, the previous table presents comparative information on electricity production capacities for the main renewable sources and Waste (Hydro, Geothermal, Wind, Solar, Biogases and Waste), corresponding

to the years 2013 and 2023, respectively. It is observed that, for all renewable sources, the values have increased.
It is observed that, in 2013, 5 countries had electricity production capacities based on the renewable source Geothermal (Germany, France, Italy, Austria, Portugal). In 2023, 6 countries had such capacities (Germany, France, Italy, Portugal, Croatia, Hungary). Also, in some countries an expansion of electricity production capacities for different types of renewable sources is observed.
Even though interest in renewable sources is increasing, tracking gross electricity production is important. The following table presents the comparative situation of gross electricity production, for the period 2013-2023.

Table 4 - Comparative situation for gross electricity production, 2013-2023 (gigawatt-hour). Source: processing according to data published by EUROSTAT, 2025

Countries	2013	2015	2017	2019	2021	2023
European Union	2921071	2906688	2961035	2907185	2916126	2748558
Belgium	83494	69705	86619	93644	100482	83669
Bulgaria	43816	49224	45613	44277	47568	40256
Czechia	86913	83890	87056	87035	85016	77004
Denmark	34743	28941	31023	29517	33051	33733
Germany	638701	648308	653723	606917	592799	511881
Estonia	13275	10148	13160	7615	7204	5745
Ireland	25996	28498	30997	31122	32028	31853
Greece	57153	51874	55266	48626	54715	49917
Spain	285631	280911	275726	273257	274312	285881
France	582318	579476	561989	570720	555131	524651
Croatia	14053	11403	11984	12760	15210	17541
Italy	289802	282991	295830	293853	289070	264716
Cyprus	4290	4535	5004	5141	5119	5329
Latvia	6208	5534	7531	6438	5846	6388
Lithuania	4762	4933	4187	3972	5079	5979
Luxembourg	2889	2766	2235	1908	2211	2532
Hungary	30292	30361	32915	34291	36120	35546
Malta	2251	1305	1652	2060	2215	2345
Netherlands	101630	110213	117168	121408	122170	121331
Austria	68357	65299	71324	74234	70887	74459
Poland	164579	164945	170465	163989	179632	167362
Portugal	51672	52420	59432	53154	50980	49043
Romania	58886	66295	64296	59623	59470	57983
Slovenia	16103	15100	16326	16100	15877	15879
Slovakia	28832	26903	27738	28434	30016	29903
Finland	71258	68598	67525	68651	72120	81541
Sweden	153166	162113	164250	168439	171798	166093

It is observed that, for 12 countries, gross electricity production decreased in 2023 compared to 2013. For the remaining 15 countries, the values increased. The most

significant increases were: Netherlands (+19700 GWh), Sweden (+12927 GWh), Finland (+10282 GWh).
At the same time, in 2023, the countries where gross electricity production was high are: France (524651 GWh), Germany (511881 GWh), Spain (285881 GWh), Italy (264716 GWh), Poland (167362 GWh), Sweden (166093 GWh), Netherlands (121331 GWh). The countries with the lowest values of gross electricity production are: Malta (2345 GWh), Luxembourg (2532 GWh), Cyprus (5329 GWh), Estonia (5745G Wh), Lithuania (5979 GWh), Latvia (6388 GWh).
At the European Union level, figure 2 presents the evolution of gross electricity production for the period 2013-2023.

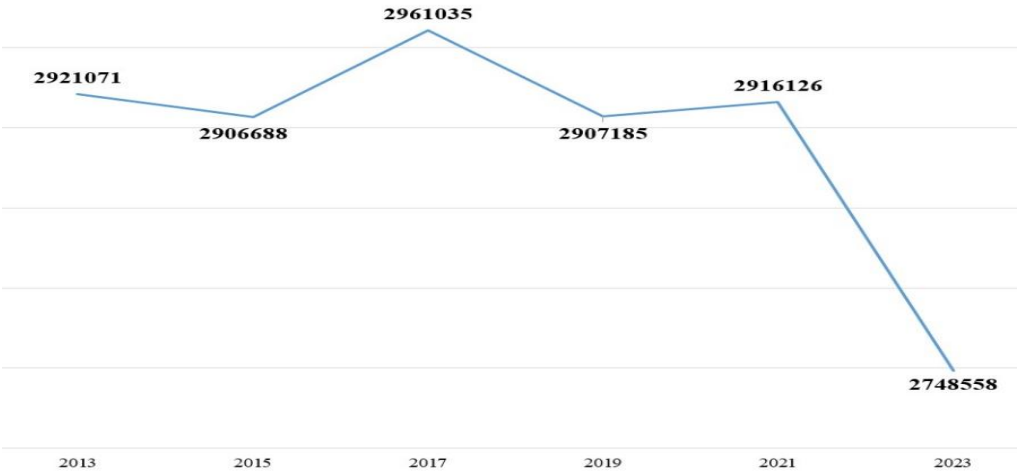

Figure 2 - Evolution of gross electricity production in the European Union, 2013-2023 (gigawatt-hour). Source: processing according to data published by EUROSTAT, 2025

It is observed that for the period 2013-2023 the evolution of gross electricity production is relatively decreasing. The values in 2023 are lower than those in 2013 by -172513 GWh.

5. Conclusions

Energy efficiency objectives can be achieved through investments in human capital and infrastructure. In this way, it can be appreciated that the transition from fossil fuels to renewable energy is converging towards a sustainable energy future (Taghvaee et al., 2024).
From the analysis carried out, it is observed that, compared to 2013, in 2023, the share of renewable energy in gross final energy consumption increased in all member countries of the European Union. Increases of over 10% were: Denmark, Sweden, Estonia, Finland, Netherlands, Cyprus, Malta, Luxembourg. In 2023, values of over 40% were: Sweden, Finland, Denmark, Latvia, Estonia, Austria. At the same time, values of over 50% for the share of renewable energy sources in electricity were: Austria, Sweden, Denmark, Portugal, Germany, Spain, Croatia, Latvia, Finland.

Regarding energy productivity, in 2023, values over 10 KGOE were: Ireland, Denmark, Luxembourg, Germany, France, Italy, Netherlands, Austria, Sweden.
Even though for the period 2013-2023 the evolution of gross electricity production is relatively decreasing, in 2023 values over 100,000 GWh were: France, Germany, Spain, Italy, Poland, Sweden, Netherlands.
For renewable energy sources in electricity, the data show an increasing trend for the period 2013-2023. Also, if in 2013 only 2 countries had shares over 50% (Austria and Sweden), in 2023 the number of countries with shares over 50% increased to 9 (Austria, Sweden, Denmark, Germany, Spain, Croatia, Latvia, Portugal, Finland).
At present, total energy needs are not fully met by renewable sources. For this reason, it is considered that future technologies will consider the implementation and development of new ways of extracting energy produced based on renewable sources (Vieira et al., 2024)v.

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