Offsetting Carbon Emissions from Household Electricity Consumption in Europe

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Abstract

The residential sector has been targeted as the one with a huge potential for reducing carbon emissions. In order to determine the present carbon footprint and the potential for achieving carbon neutrality, the study examines electricity consumption in average households, whose electricity is supplied by their national power grids. 31 European countries (27 EU and 4 non-EU countries) were included in this analysis. Our results indicate that the annual carbon emissions of these average households range from 0.09 to 6.44 tCO_2e (1.36 tCO_2e on average), depending on a country. In addition, the calculated electricity costs per tCO_2e emission for an average household vary significantly (from 94 to 10,135 EUR/tCO_2e).

Carbon offsetting is a mechanism which enables households to achieve carbon neutrality, i.e. households can compensate for the emissions caused by their electricity consumption by purchasing voluntary carbon offsets. This study also analyses the financial implications of purchasing voluntary carbon offsets. The results indicate that voluntary carbon offsets do not burden household budgets significantly because their share in total electricity costs is small. European households, particularly those in countries where electricity is more expensive, can comfortably achieve carbon neutrality with voluntary carbon offsets. In this way, they can contribute to global sustainable development.

Highlights:

- Average carbon footprint of grid-connected household in Europe is less than 2 tCO_2e
- The cost of electricity per CO_2 emissions varies from 94 to 10,135 EUR/tCO_2
- Voluntary carbon offset costs in electricity costs vary widely across Europe
- Carbon offsetting is a practical solution for achieving a carbon-neutral household

Keywords:

Household electricity consumption, CO_2 emissions, Voluntary carbon offsets, Climate change mitigation, Europe

Word Count: 4942

Nomenclature

Abbreviations

EU - European Union

VCO - voluntary carbon offsets

RES - renewable energy sources

VAT - value added tax

Notation/Symbols

CO_{2em} - annual carbon emissions, [tCO_{2e}/year]

$COST_E$ - annual electricity cost, [EUR/year]

$COST_{VCO}$ - carbon offsetting costs, [EUR/year]

$COST_{E/CO2em}$ - electricity cost per unit of carbon emissions, [EUR/tCO_2e]

E_c - average annual electricity consumption, [kWh/year]

gef - grid electricity emission factor, [$kgCO_2e$/kWh]

$PRICE_E$ - electricity price (taxes and VAT included), [EUR/kWh]

$PRICE_{VCO}$ - the price of voluntary carbon offsets, [EUR/tCO_2e]

RATIO - additional carbon offsetting costs in electricity costs, [%]

1.0 Introduction

Climate change is one of the biggest challenges that humanity faces today. There is almost a consensus in the scientific community that anthropogenic CO_2 emissions are most responsible for climate change. Since fossil fuels are the principal cause of the emissions, the majority of countries have already pledged to reduce or neutralise their carbon emissions in the coming years in response to the Paris Agreement[1]. The European Union (EU) has also supported this trend with an extensive EU Energy roadmap, which calls for an overall 80% reduction in greenhouse gas emissions by 2050 compared to the 1990 levels. The plan also assumes the reductions of 40% by 2030 and 60% by 2040 [1].

Out of about 35 billion tonnes of greenhouse gases (measured in tonnes of carbon dioxide equivalents – tCO_2e) that the world emits each year, the emissions resulting from the use of energy in residential buildings account for over 10% [2]. In the EU, the residential energy use in 2020 accounted for 27.4% of the total energy consumption, 24.8% of which was electricity [3]. The household power usage decreased by 2.3% from 2010 to 2020. Over the ten-year period, the household electricity consumption increased dramatically in Malta (49.1%), Slovakia (34.4%), and Romania (20.2%). In contrast, the countries with the largest reductions in household electricity consumption were Germany (-10.4 %), Latvia (-9.6 %) and Croatia (-8.8 %) [4]. The household energy consumption varies largely depending on both macro factors (such as average income, increase in per capita income, population, electricity price, and cultural differences) and micro ones (household income, educational level, age, and household type and size) [5] [6]. Study [7] highlighted that the relationship between energy consumption and economic development is the most important issue in the economy of environmental protection since life quality and socio-economic characteristics affect energy needs significantly.

The carbon footprint of a society is an important indicator for evaluating how countries and individuals affect the climate. Modifications in energy use patterns are required across various sectors in order to decrease the carbon footprint. Although it may seem insignificant, carbon footprint of households has demonstrated notable potential when it comes to prioritizing climate change actions both nationally and internationally [8]. The reduction of carbon emissions in households is the major issue for the process of creating climate-neutral cities. It represents an important socio-economic challenge [9] and plays a significant role in achieving national goals in combating climate change [10]. Reducing carbon emissions is also necessary since the intensification of global warming can lead to increased energy poverty. The intensification of global warming will substantially increase household cooling needs in households, which is expected to have the greatest impact on residents with the lowest income [11].

Governmental strategies vary in line with varied carbon footprints. Some EU countries have instituted the payment of carbon taxes as a way to reduce their carbon impact [12]. 19 EU countries have implemented carbon taxation [13], and the effectiveness of the policy has been

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[1] The Paris Agreement is a legally binding international treaty on climate change adopted by 196 Parties entered into force in 2016. Its goal is to limit global warming below 2°C compared to pre-industrial levels.

examined in several studies [14–16]. The estimated effectiveness is very limited in each of the analysed cases. This is particularly important in terms of carbon taxes in households because it has been demonstrated that the introduction of mandatory payments affects lower-income and middle-income households by further degrading their quality of life [17]. A group of authors who analysed the possibility of a fair energy transition has come to the same conclusion. They highlight that energy use for transportation and households decreases as affluence rises in developed countries. They also argue that the introduction of mandatory carbon penalties increases the ratio of energy-related expenditures in total income in lower-income households [18]. The introduction of mandatory payment could increase the poverty rate by 1% [19]. Additionally, although it has been shown that this measure can have a positive effect on the transportation sector, increasing energy bills will not reduce household electricity consumption [19]. In conclusion, carbon taxes are not the best solution for achieving carbon neutrality in households.

Additionally, companies and individuals all over the world invest voluntarily in carbon offsetting in order to neutralise their carbon footprint. By purchasing voluntary carbon offsets (VCO) they invest in environmental projects. The project implementation cuts emissions in other parts of the world by an equivalent amount since the reduction of greenhouse gas emissions is a global goal. The amount of VCO is determined based on the reduction in carbon emissions resulting from the activities.

Voluntary carbon offsetting market represents a minor fraction of the total carbon market. The purchase of VCO increased by almost ten times between 2016 and 2021 and further growth is expected. According to estimates [20], voluntary carbon markets will need to expand by more than 15 times by 2030 in order to support the investment necessary to implement the 1.5 ^{o}C pathway. In 2021, the VCO market exceeded $1 billion [21], while the total CO2 emission at the global level was 34.9 GtCO2 [22]. At the time, a total of 353 MtCO2 VCOs were issued, and 159 MtCO2 retired [23]. These data show that the application of VCO resulted in a 0.5% reduction in the total global CO2 emission for 2021. It is clear that the VCO market has a sizable potential to reduce overall global emissions in the future when taking its predicted growth into account.

When it comes to environmental awareness, a recent study has confirmed a positive correlation between willingness to invest in climate protection and one's awareness of individual impact on climate change [24]. Individuals who believe that voluntary carbon offsetting can significantly contribute to climate protection would be eager to engage [25]. This concept became popular during the previous decade, primarily in the transport sector. In survey which included 1,228 travellers in Italy [26], it has been shown that the willingness to pay for VCO and the price level depend on several factors: the length and purpose of the trip, the type of project supported by VCO, and the socio-demographic characteristics of the passengers. A price range of 12–38 EUR/tCO_2 has been established. Passengers are ready to spend 5‒55 EUR per flight, while those from Europe are ready to finance the most. Tourists, especially nature-oriented ones, were interested in VCO, as opposed to students and business travellers. [27]. Among all travellers, VCO was most represented among young people aged 20-34 and travellers from the UK/Europe.

The research conducted at the European airline level shows that 4.46% of 63,520 booked flights supported the purchase of VCO [28]. Travellers are the most willing to support projects that affect the preservation of biodiversity [29]. The price of VCO they are willing to pay is determined by a variety of factors and can range up to 29.23 EUR/tCO_2. Since the VCO concept in air transport has not yet been introduced in China, study examined the possibilities for the future market [30]. It was found that passengers are willing to pay up to 36.33 yuan (4.88 EUR) for domestic routes and up to 45.35 yuan (6.09 EUR) for international flights. According to survey on willingness to pay for VCO in road traffic, people would be more interested in VCO if it is a short distance, they are up to 40 years old and come from well-off parts of the city [31].

VCO was also analysed in hospitality industry. Of the 505 interviewed tourists, 45-70% expressed the attitude of wanting to buy VCO, but only 4-10% of them participated in their purchase [32]. A similar analysis was conducted by surveying 470 travellers who had travelled to Asia, Africa, or Latin America [33]. An analysis of behaviour in 12 different tourist activities found that 7% of travellers stayed in accommodation with a sustainability label while 8% of travellers have bought VCO at least once.

Interest in VCO also grows in households. Nakamura and Kato [34] analysed the attitudes of citizens of different regions in Japan regarding investment in international voluntary carbon offsetting projects. 45% of the respondents expressed a negative attitude towards VCO, believing that the emission should be reduced by changing consumer behaviour. Half of the respondents, interested in voluntary carbon offsetting would invest in VCO only in their own country. The other half expressed a willingness to invest globally because CO2 emissions are a global problem. The importance of voluntary carbon offsetting in controlling the rapidly growing emissions from households in China was analysed by Tao et al. [35]. More than 50% of respondents are willing to participate, with an acceptable price of $8.74/tCO2, or $61.2/year, which is 0.47% of total annual income. A strong desire to purchase VCO was influenced more by social pressure and social standing than by personal moral responsibility. A case study in which the climate neutrality of one energy-efficient household was achieved by investing in VCO confirms that owners are willing to pay [36]. The willingness of households to participate in carbon offsetting has been confirmed by Jia [37]. It has been demonstrated that 18% of the total climate financing comes from households and individuals in the United States. A survey of 1,022 Danish respondents found strong support for purchasing VCO to offset emissions from electricity use [38]. The current status of the VCO market shows considerable potential for improvement due to the growing concern for the environment and sustainable development. About 38% of respondents are willing to spend 0.67-1.34 EUR/kWh, and 7% to spend more than 2.2 EUR/kWh. It's worth noting that 59.9% of respondents said VCO makes them feel better because they're investing in environmental benefits. VCO was analysed on over 1,000 citizen in Switzerland [39]. About 22% of consumers have already invested in VCO projects, while 63% have shown interest. Willingness to pay for VCO is usually among young, educated people with good incomes who feel a personal responsibility for the consequences of climate change. A comprehensive analysis of the motives behind the purchase of VCOs in USA and Germany showed the potential of VCOs in the rapid reduction of CO2 emissions [40]. German citizens were motivated to be active participants in environmental protection, whereas Americans were motivated to meet social expectations. However, there is a correlation between participation in environmental organizations and VCO in USA. In contrast, German citizens still do not perceive this purchase as a leading possibility for reducing anthropogenic emissions.

Furthermore, in order to improve the state of the environment and to encourage voluntary carbon offsetting in the United States, movies on the consequences of CO_2 emissions and the possibilities for offsetting were broadcast [41]. According to the study, the impact of a single film on the willingness to pay for VCO resulted in a reduction of nearly 2,900 tCO_2 in households where the film was screened. This demonstrated how crucial it is to raise understanding of the options since willingness to pay for VCO strengthens the reputation of an environmentally conscious individual.

According to the authors' knowledge, the majority of European countries do not currently have comprehensive data on the emissions of the typical household connected to the national power grid. These data are particularly important since electricity is a fundamental and everyday need, and households account for 27% of the total electricity consumption [42]. The significance of voluntary carbon offsetting analysis is further underscored by the fact that over 5% of the 70 $MtCO_2$ retired VCO were purchased in the buildings in 2019 [43].

Therefore, it is crucial to systematize data on the:

- Carbon footprint of the typical grid-connected households in European countries;
- Financial aspects of investing in various global projects to offset these carbon emissions.

Besides, the electricity cost per unit of carbon emissions is introduced for the first time.

Finally, the results will show the conditions under which volunteer carbon offsetting can assist in achieving carbon-neutral households. Since no publication has ever included all of the information, it will represent a contribution to this scientific field.

2.0 Methodology

Figure 1 depicts the methodology used in the analysis. First, the data on the household electricity consumption were collected for the European countries studied in the Odysee-Mure Project[2] [44]. The data refer to 27 EU[3] and 4 non-EU countries (UK, Switzerland, Norway, and Serbia) presented in Figure 2. The countries were classified into consumption bands based on the annual electricity consumption of the average household - E_c [kWh/year]:

- Band-DA (Very small): < 1,000 kWh

[2] The Odyssee-Mure project provides comprehensive monitoring of data related to energy consumption and efficiency trends in all sectors and end-uses. The project is supported by a network of 36 partners, located in 31 different countries. Typically, these partners are national energy efficiency agencies or their representatives within the European network of energy efficiency agencies.

[3] The EU 27 countries are: Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.

– Band-DB (Small): 1,000 – 2,500 kWh
– Band-DC (Medium): 2,500 – 5,000 kWh
– Band-DD (Large): 5,000 – 15,000 kWh
– Band-DE (Very large): 15,000 kWh [45]

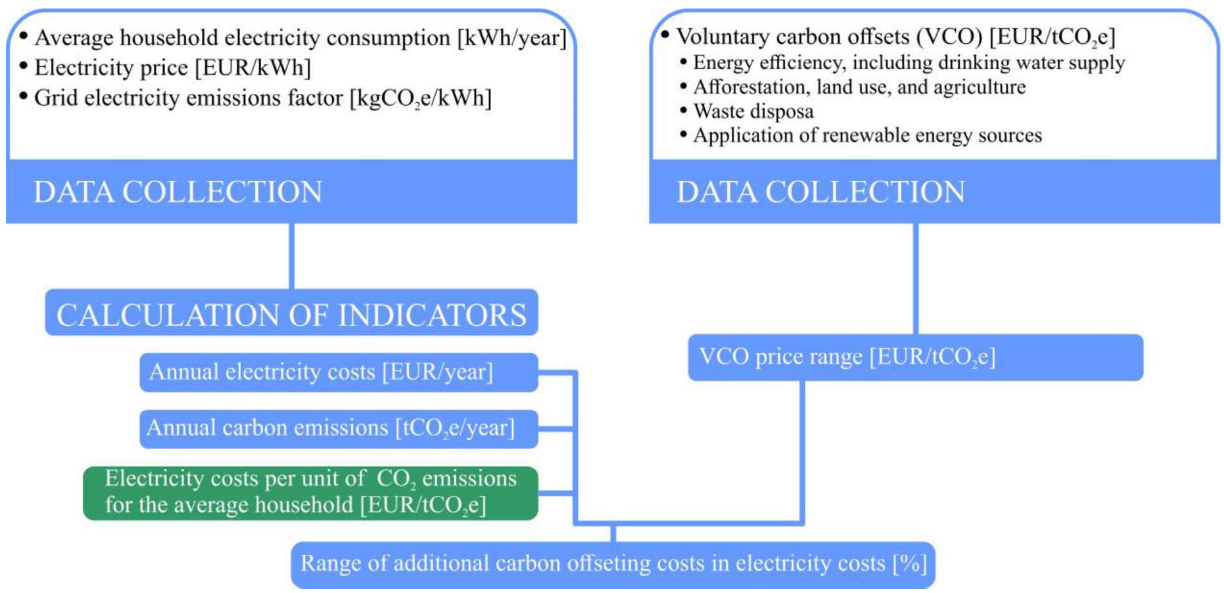

Fig. 1 The scheme of the implemented methodology

This classification was required because it affects the average price of electricity paid by a household. The Eurostat website was used to obtain the electricity price [EUR/kWh] for 30 countries. The electricity prices without taxes and VAT were taken from [46], and the electricity prices with taxes and VAT (denoted as $PRICE_E$ [EUR/kWh]) were obtained from [47]. The data on Swiss electricity costs were retrieved from [48,49].

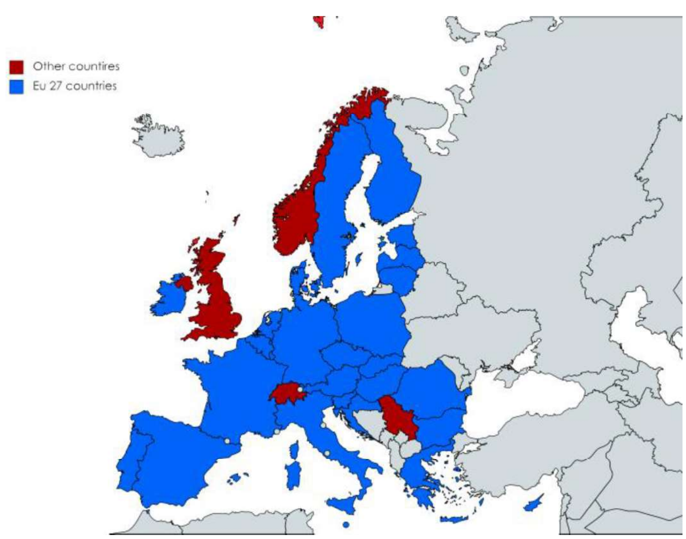

Fig. 2 Analysed European Countries

The carbon footprint of the household electricity use was calculated based on the residual mix factor - *gef* [kgCO_2e/kWh]. It is country-specific [50] and depends on the electricity production. This choice is justifiable by the fact that the residual mix factor is used when end consumers do not know the origin of their energy [51]. More importantly, its definition implies cooperation between countries and a detailed analysis of energy flows, in order to avoid multiple counting of renewable energy sources in the energy balance [52]. Austria is the only country for which the production fuel mix factor was used because all data have been fully transparent since 2017 [53].

The following indicators were calculated using the collected data for the average household in each country:

- Annual emissions CO_{2em} [tCO_2e/year]
- Annual electricity cost $COST_E$ [EUR/year]
- Electricity cost per unit of carbon emissions $COST_{E/CO2em}$ [EUR/tCO_2e].

The following set of equations is used for the calculation of the indicators:

$$\mathrm{CO}_{2em} = E_c \cdot gef \cdot 10^{-3} \tag{1}$$

$$COST_E = E_c \cdot PRICE_E \tag{2}$$

$$COST_{E/\mathrm{CO2e}} = \frac{PRICE_E}{gef} \cdot 10^3 \tag{3}$$

The Ecosystem Marketplace web platform was used to identify a list of carbon offsetting projects with VCO that can be purchased to make households carbon neutral [54]. Ecosystem Marketplace was established in 2005 with the aim to be an independent international voluntary and compliance carbon credits trade reporting and knowledge-sharing mechanism.

Four groups of projects can be distinguished:

1. Energy efficiency, including drinking water supply
2. Afforestation, land use, and agriculture
3. Waste disposal
4. Renewable energy sources

The lowest and highest $PRICE_{VCO}$ [EUR/tCO_2e] on the carbon market were determined for each category. The share of additional decarbonisation costs in the current electricity price is calculated based on the extreme VCO values as:

$$RATIO = \frac{COST_{VCO}}{COST_E} \cdot 100\% \tag{4}$$

where $COST_{VCO}$ [EUR/year] designates additional carbon offsetting costs which are calculated from:

$$COST_{VCO} = \mathrm{CO}_{2em} \cdot PRICE_{VCO} \tag{5}$$

3.0 Results and Discussion

The data for 2019 were used for the analysis of electricity consumption in households. This year was chosen as a reference for two reasons. It should be noted that this is the last year for which all data are available. Second, the authors intended to eliminate the effects of COVID-19 pandemics since it had a major impact on household energy use [55].

The results show that there is a wide disparity in household electricity consumption, ranging from 1.7 MWh in Romania to 16.2 MWh in Norway (3.7 MWh is the EU average and 4.3 MWh is the total average for both EU and non-EU countries) (Table 1). In 22 countries, the average electricity consumption in households ranges from 2.5 to 5 MWh (DC band). Lower consumptions were recorded in three countries (DB band), while in four countries the average consumption exceeds 5 MWh (DD band). The average consumption of more than 15 MWh is recorded only in one country. Electricity consumption has declined by 2% (i.e. 1% in EU) since 2000 in average. However, the use of electricity in Romania, Lithuania, Latvia, and Estonia increased significantly (by more than 20%). Despite the notable rise in electricity consumption, these countries still have some of the lowest annual electricity consumption rates. More developed countries like Luxembourg, Denmark, Germany, Belgium, the United Kingdom, and Ireland demonstrated a large decline (more than 10%) in their electricity consumption. The Republic of Serbia also experienced a decline in household electricity consumption. Even if its energy consumption has decreased, this country still ranks among the top five in Europe in terms of average electricity consumption.

Tab. 1 Average electricity consumption in European households

Country	[kWh/household]		Band	Difference 2019–2000 [%]
	2000	2019		
UK	4,553	3,582	DC	-21%
Switzerland	5,077	4,658	DD-DC	-8%
Sweden	9,772	9,032	DD	-8%
Spain	3,345	3,918	DC	17%
Slovenia	3,750	4,396	DC	17%
Slovakia	3,262	3,092	DC	-5%
Serbia	6,686	5,677	DD	-15%
Romania	1,076	1,694	DB	57%
Portugal	3,016	3,246	DC	8%
Poland	1,898	2,139	DB	13%
Norway	17,666	16,241	DE	-8%
Netherlands	3,151	3,127	DC	-1%
Malta	4,286	4,224	DC	-1%
Luxembourg	5,110	4,099	DC	-20%
Lithuania	1,303	1,940	DB	49%
Latvia	1,379	2,063	DB	50%
Italy	2,840	2,633	DC	-7%
Ireland	5,205	4,544	DD-DC	-13%
Hungary	2,623	2,988	DC	14%
Greece	3,712	4,152	DC	12%
Germany	3,695	3,213	DC	-13%
France	5,342	5,478	DD	3%
Finland	7,216	7,664	DD	6%
Estonia	2,430	3,026	DC	25%
Denmark	4,103	3,614	DC	-12%
Czechia	3,645	3,442	DC	-6%
Cyprus	4,841	4,847	DC	0%
Croatia	4,042	4,091	DC	1%
Bulgaria	3,399	3,652	DC	7%
Belgium	4,199	3,758	DC	-11%
Austria	4,403	4,653	DC	6%
Average	4,421	4,341		-2%
EU 27 average	3,763	3,728		-1%

According to data on net electricity prices for households from 2016 to 2019 (Table 2), the average household pays the least for electricity in Serbia and the most in Ireland. The countries with the highest electricity price increases throughout the observed period were Cyprus, Lithuania, Finland and Romania, whereas the countries with the highest price decreases were Norway and Spain. In Norway, the price of electricity in 2019 and 2020 was the lowest in the last decade, due to high water levels and a large share of hydropower in the electricity mix [56]. Although with a 28% reduction in electricity prices, Spain is one of the countries with the most expensive electricity in Europe and more than 40% of Spain's total electricity is produced from fossil fuels [57].

Tab. 2 Net price of electricity for households, without taxes and VAT (only for energy, supply and network)

Country	[EUR/kWh]				change 2019/2016
	2016[4]	2017	2018	2019	
UK	0.148	0.134	0.140	0.151	2%
Switzerland[5]	0.163	0.146	0.154	0.160	-2%
Sweden	0.128	0.131	0.129	0.132	3%
Spain	0.180	0.171	0.195	0.129	-28%
Slovenia	0.117	0.111	0.113	0.115	-2%
Slovakia	0.125	0.084	0.085	0.097	-22%
Serbia	0.050	0.053	0.054	0.055	10%
Romania	0.089	0.096	0.098	0.103	15%
Portugal	0.121	0.108	0.103	0.120	-1%
Poland	0.105	0.103	0.097	0.093	-11%
Norway	0.113	0.114	0.138	0.076	-33%
Netherlands	0.119	0.115	0.121	0.136	14%
Malta	0.121	0.122	0.123	0.123	1%
Luxemburg	0.133	0.117	0.130	0.133	0%
Lithuania	0.082	0.079	0.079	0.096	18%
Latvia	0.107	0.108	0.108	0.120	12%
Italy	0.134	0.133	0.142	0.143	6%
Ireland	0.188	0.187	0.201	0.213	13%
Hungary	0.089	0.089	0.088	0.086	-2%
Greece	0.119	0.109	0.113	0.119	0%
Germany	0.138	0.138	0.138	0.132	-4%
France	0.111	0.113	0.117	0.126	14%
Finland	0.102	0.106	0.114	0.120	18%
Estonia	0.096	0.095	0.105	0.103	7%
Denmark	0.095	0.092	0.112	0.104	10%
Czechia	0.116	0.122	0.130	0.126	8%
Cyprus	0.129	0.142	0.175	0.158	23%
Croatia	0.102	0.101	0.103	0.103	1%

[4] Data for the second semester of each year

[5] Data for the calculation of the CHF/EUR exchange ratio taken from https://www.exchangerates.org.uk/CHF-EUR-exchange-rate-history.html

Bulgaria	0.078	0.082	0.084	0.080	2%
Belgium	0.182	0.179	0.198	0.195	8%
Austria	0.122	0.122	0.127	0.135	10%

Figure 3 shows that the total cost is considerably impacted by additional taxes and VAT. Denmark recorded the highest percentage of taxes in the gross electricity bills (67%). The share is greater than 50% in Germany and Norway, while it is less than 20% in Bulgaria, Ireland, and Switzerland, and the lowest in Malta (6%). In most countries, taxes include either carbon taxes or incentive measures for RES electricity.

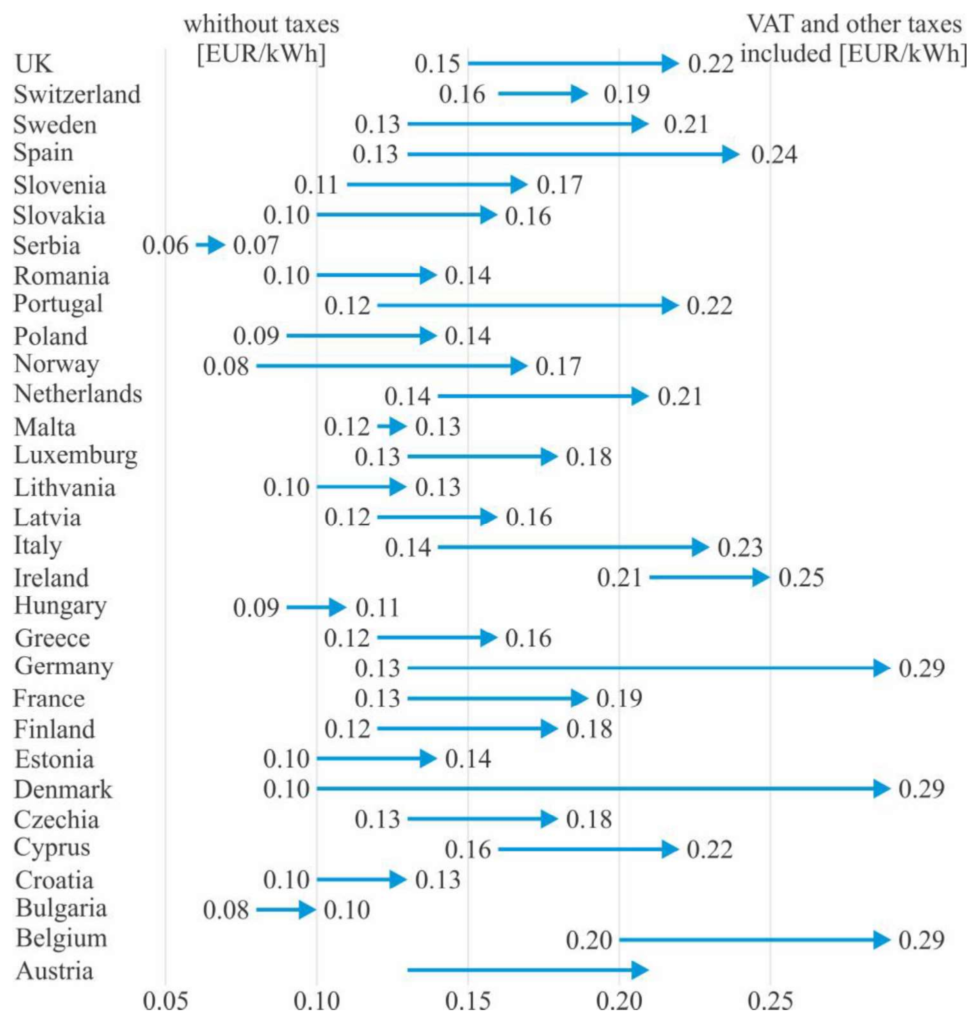

Fig. 3 Gross price of electricity in European countries

Table 3 shows the variation of grid electricity emissions factors from 2016 to 2019. The fluctuation was driven by several factors in the power market, including the electricity production mix and domestic and imported electricity output. The variation was influenced by different parameters in the electricity market, such as the production mix and the carbon footprint of imported electricity. As the data demonstrate, practically all countries experience a reduction in the factor, which is consistent with their efforts to shift to RES electricity and achieve energy independence. Serbia and Sweden are the only two countries with minor increases in this factor during the observed period. It is significant to emphasize that Sweden is a country where this factor is considerably low since fossil fuels are used to generate only 1% of the electricity [58]. The coal is still dominant fuel for electricity production in Serbia (approximately 2/3 of electricity is produced by coal) which makes it the second country in Europe in terms of $kgCO_2e$ emissions per kWh of produced electricity [59]. Despite the fact that less than 2% of Norway's electricity is produced using fossil fuels [60] the grid electricity emissions factors is considerable since a significant part of the energy mix remains unknown in the public reporting [61].

Tab. 3 Five-year variation of grid electricity emissions factors [$kgCO_2e/kWh$]

Country	2016	2017	2018	2019	2020
UK	0.458	0.406	0.379	0.348	0.323
Switzerland	0.021	0.021	0.019	0.019	0.019
Sweden	0.058	0.056	0.058	0.050	0.061
Spain	0.424	0.499	0.436	0.343	0.265
Slovenia	0.387	0.391	0.380	0.364	0.338
Slovakia	0.225	0.230	0.225	0.199	0.180
Serbia	0.758	0.802	0.759	0.766	0.762
Romania	0.303	0.311	0.304	0.311	0.261
Portugal	0.307	0.379	0.316	0.256	0.205
Poland	0.890	0.879	0.876	0.831	0.804
Norway	0.371	0.389	0.391	0.396	0.290
Netherlands	0.682	0.644	0.623	0.555	0.475
Malta	0.683	0.451	0.377	0.378	0.384
Luxemburg	0.757	0.651	0.543	0.449	0.330
Lithuania	0.558	0.411	0.413	0.352	0.469
Latvia	0.319	0.244	0.322	0.315	0.267
Italy	0.533	0.524	0.495	0.466	0.438
Ireland	0.696	0.638	0.560	0.495	0.447
Hungary	0.320	0.319	0.310	0.286	0.272
Greece	0.607	0.631	0.634	0.577	0.476
Germany	0.772	0.727	0.696	0.609	0.566
France	0.049	0.055	0.044	0.043	0.041
Finland	0.365	0.335	0.354	0.310	0.264
Estonia	1.095	1.108	1.007	0.758	0.539
Denmark	0.810	0.634	0.647	0.465	0.389
Czechia	0.673	0.638	0.632	0.595	0.556
Cyprus	0.712	0.697	0.697	0.676	0.632
Croatia	0.660	0.605	0.445	0.514	0.473
Bulgaria	0.483	0.516	0.451	0.437	0.385
Belgium	0.193	0.192	0.221	0.188	0.184

Austria	0.138	0.148	0.140	0.133	0.118

The annual carbon emissions for the average household in the analysed countries were determined based on the values of grid electricity emissions factors and electricity consumption for 2019. Figure 4 shows that Norway, Serbia, and Cyprus exceed the average value of 1.66 tCO_2e/year significantly, while average households in 22 countries emit less than 2 tCO_2e/year.

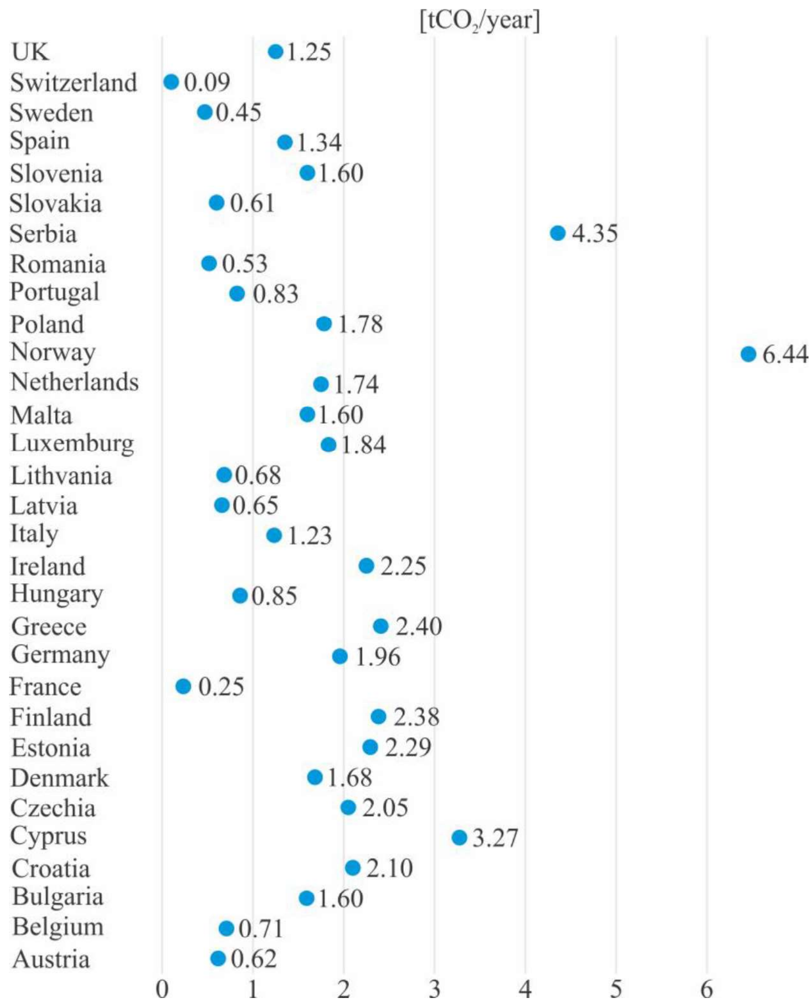

Fig. 4 Annual carbon emissions from electricity consumption by an average household

The annual electricity cost (including taxes) of the average household in Europe varies significantly. It ranges from around €240 in Romania to €2,832 in Norway as can be seen in Figure 5. The introduction of an indicator of electricity costs per amount of carbon dioxide generated shows that “the most expensive emissions” are in Switzerland, France and Sweden, which are the countries with lowest annual carbon emissions and relatively expensive household electricity. Serbia, Poland, Estonia, and Bulgaria are on the other side. They produce the majority of their electricity using fossil fuels. It is interesting to notice that the indicator is almost 110 times higher in Serbia than in Switzerland.

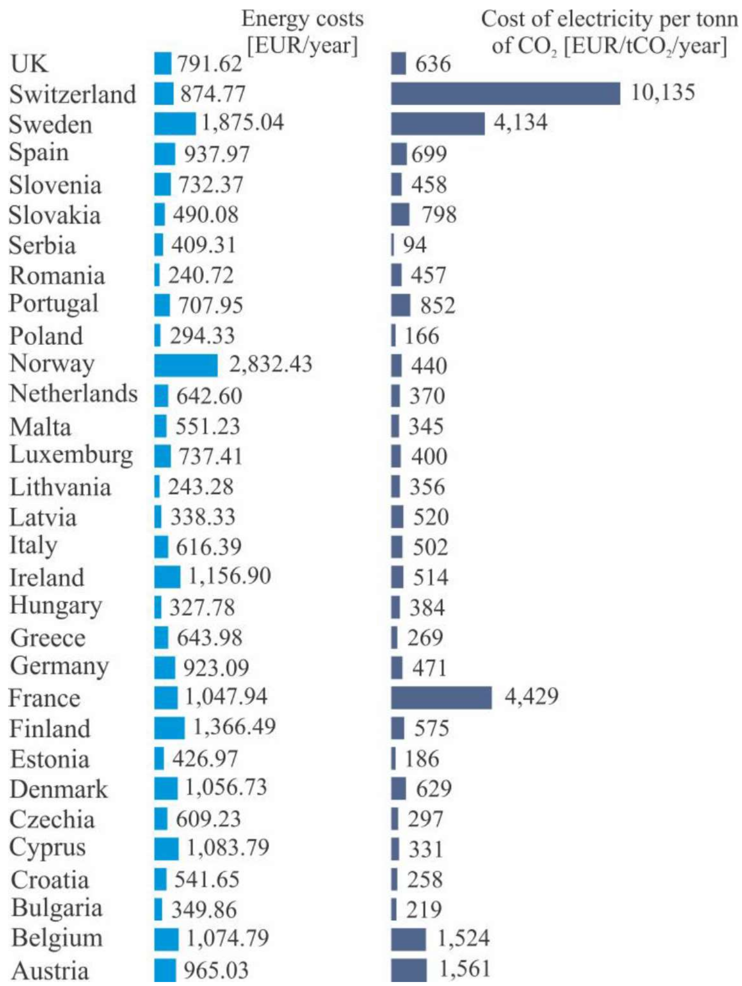

Fig. 5 Financial indicators of electricity use

The data on carbon offsetting projects were determined based on the offers from the organizations which trade VCO. For each of the categories (Table 5), the price range of VCO was determined. Although it is possible to find information that VCO can be purchased at lower prices, through an extensive analysis of over 80 projects, the authors of the study could not find more favourable options than the ones presented. Most projects (33) are related to afforestation, land use and agriculture, followed by RES projects (26). The cheapest VCO origin from energy efficiency including water supply and RES projects while the most expensive VCO are related to waste disposal. The majority of carbon offsetting projects is implemented in Africa and Asia (each > 30%), while only 3% are implemented in Europe and Australia.

Tab. 5 Number of carbon offsetting projects by category and VCO price range

Project type	Number of projects	VCO price range [EUR/tCO_2e]	
		min	max
Energy efficiency and water supply	15	6.79	23.65

Waste disposal	6	8.86	65
Afforestation, land use and agriculture	33	13	60.8
Renewable energy sources	26	6.79	21.6

The proportion of additional carbon offsetting costs in electricity costs was calculated using Equation 4. The maximum (60.8 EUR/tCO_2e) and minimum values (6.79 EUR/tCO_2e) of VCO were taken from Table 5. Figure 6 shows that the amount a household pays for purchased electricity would typically not increase greatly if they bought VCO in the lowest price range. This additional cost would be less than 5% in all countries except Serbia (7.21%). Based on a public opinion poll conducted in Denmark [38], it can be said that citizens are willing to purchase VCO for this price. More than 40% of the participants in the survey stated that they would be willing to contribute an additional 2.5% or more to offset their emissions. These data were confirmed in Poland [62], where household owners were willing to pay an additional 4.5% for green electricity. Also, a group of academic citizens in the UK was ready to allocate up to 26% to offset emissions [63]. However, buying VCO which are in a higher price range would considerably raise the financial burden for households in European countries. The exceptions are Switzerland, France, and Sweden, where this cost would be less than 2%. This especially relates to average households in Serbia where their additional cost for carbon offsetting would amount to 69% of electricity costs. This disparity in VCO shares can be attributed to two factors. Serbian electricity is mostly produced from coal, and it is significantly cheaper than in other European countries. In contrast, typical household emissions in Switzerland, France, and Sweden are substantially lower, while electricity prices are over 1.5 times higher.

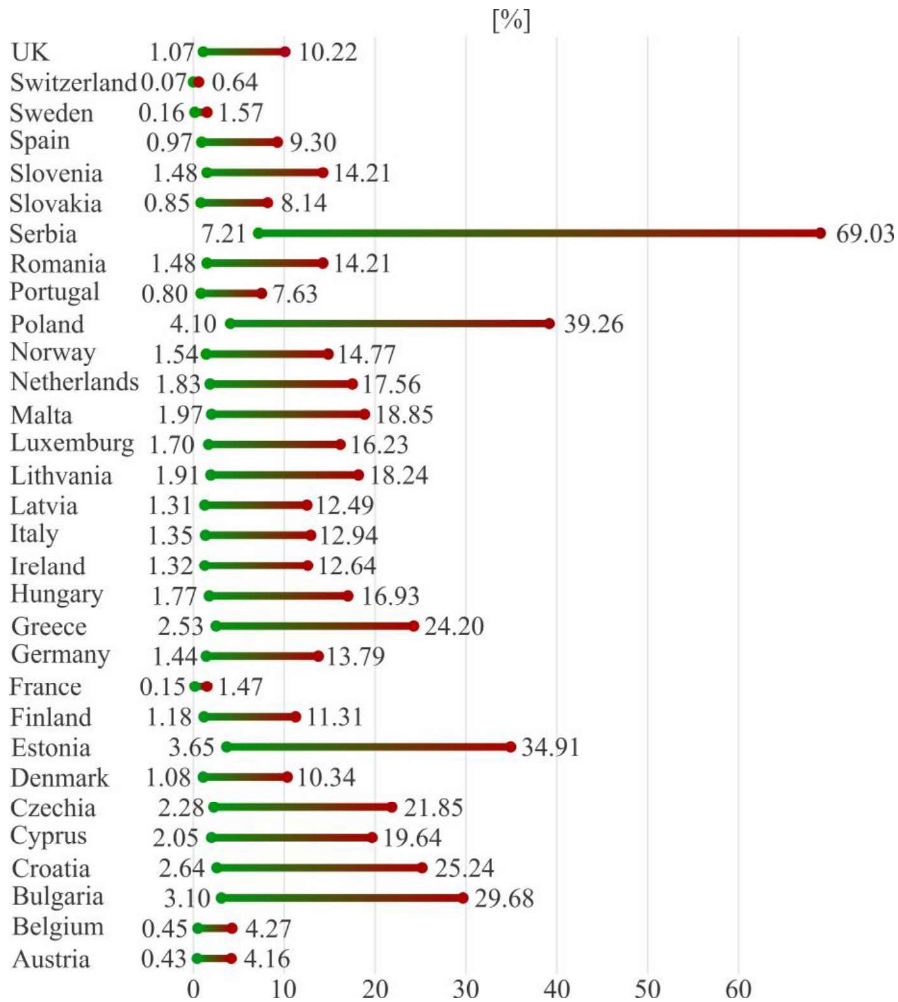

Fig. 6 Range of additional carbon offsetting costs in electricity costs

4.0 Conclusion

Analysing the collected data on electricity use in European households, it can be concluded that there is a relative inequality in electricity consumption, costs, and carbon emissions in European countries as a result of electricity use from the grid. Without a doubt, it can be said that the measures taken in the past years have helped to lower household electricity consumption. A decrease in the grid electricity emissions factor and a variation in the price of electricity in countries where the value of this factor is significant are to be anticipated in the coming years as a result of the transition to RES.

For grid-connected European households seeking to reduce their carbon footprint of electricity use, there are several options including buying guarantees of origin (as renewable energy certificates) alongside its electricity or generating electricity from locally available renewable energy sources. In case they want to completely decarbonise its electricity use, those options are not sufficient since 100% renewable electricity doesn't mean zero-carbon electricity. Therefore, carbon offsetting and buying VCO can be considered as an option.

Since Europe is a part of a more developed world and most voluntary carbon offset programs related to energy efficiency and water supply, waste disposal, afforestation, land use and agriculture and RES occur in developing countries, the social benefits are apparent. As was emphasised in [64], the carbon offsetting initiatives are carefully chosen, and their effects on the avoidance or reduction of greenhouse gasses have been regularly and transparently reported.

Although the costs of carbon offsetting vary significantly depending of the project type, it has been demonstrated that VCO may be obtained with very little effect on the overall cost of electricity. This shows that voluntary carbon offsetting can be a practical solution for achieving a carbon-neutral household in Europe.

The study analyses price range in European countries since the citizens do not fully understand all options for voluntary carbon offsetting. A clear presentation of VCO costs in the total electricity costs can encourage citizens to invest in global CO2 emission reduction, especially in countries where the price ratio is relatively low.

To raise the level of individual carbon offsetting in the household sector, policymakers and carbon offset suppliers can use the results of the study to design marketing strategies that will promote the purchase of VCO. In the long term, increased citizen initiative can motivate decision-makers and governments to implement similar, transparent, and voluntary actions in their countries.

Finally, future research should include analysing European citizens' attitudes toward voluntary carbon offsetting and estimating their willingness to pay for VCO taking into account the results from the study.

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