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Assessment of Energy and Heat Consumption Trends and Forecasting in the Small Consumer Sector in Poland Based on Historical Data

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Abstract: The paper outlines the methodology employed for desk-based research, which involved gathering and analyzing empirical data on energy and heating consumption in the Polish small consumer sector. Secondary sources, including reports, documents, scientific publications, and public statistics, were utilized to ensure a comprehensive understanding of the subject matter. The research methodology ensured the acquisition and examination of reliable and extensive data regarding energy and heat consumption among small consumers in Poland. The study investigated consumption trends of hard coal, electricity, and natural gas in Polish households from 2006 to 2021. The findings revealed an increasing pattern in electricity and natural gas consumption, alongside a simultaneous decline in the usage of hard coal. Future consumption was estimated using trend models, and factors contributing to changes in energy consumption patterns were examined, with forecasts to 2027. To achieve decarbonization and address climate objectives, the study underscores the need to increase the proportion of renewable energy sources and boost energy efficiency. The significance of reducing household energy consumption through enhanced insulation, smart energy management systems, and low-carbon alternatives is emphasized. Additionally, the study addresses Poland's future energy plans as a proactive step toward decarbonizing the national economy. In summary, the study furnishes valuable insights into energy consumption trends and their determinants in the Polish small consumer sector.

Keywords: energy and fuel careers; energy and heating consumption; small consumer sector; Poland; renewable energy sources; decarbonization; energy transformation

Citation: Gajdzik, B.; Jaciow, M.; Wolniak, R.; Wolny, R.; Grebski, W.W. Assessment of Energy and Heat Consumption Trends and Forecasting in the Small Consumer Sector in Poland Based on Historical Data. *Resources* **2023**, *12*, 111. https://doi.org/10.3390/resources12090111

Academic Editor: Silvia Maria Zanoli

Received: 14 July 2023
Revised: 7 September 2023
Accepted: 14 September 2023
Published: 20 September 2023

1. Introduction

Energy usage and its intensity are crucial factors to consider in the path towards decarbonization because they directly impact the amount of greenhouse gas emissions that are released into the atmosphere [1]. As we continue to rely on fossil fuels for energy, we emit carbon dioxide and other pollutants into the air, contributing to global warming and climate change [2]. In order to address this problem, it is necessary to reduce our energy consumption and transition to cleaner and more sustainable sources of energy [3]. This involves both increasing the efficiency of our energy usage and adopting renewable energy technologies [4,5].

Efficiency improvements can be achieved through a variety of measures, such as upgrading insulation in buildings [6], using energy-efficient appliances, and reducing waste in industrial processes [7]. By using energy more efficiently, we can reduce the amount of energy required to meet our needs, which in turn reduces the amount of greenhouse gas emissions generated [8]. In addition to efficiency improvements, we need to transition to cleaner sources of energy, such as wind, solar, and hydroelectric power [9]. These renewable sources of energy generate electricity without emitting greenhouse gases or other pollutants, and they have the potential to meet a significant portion of our energy needs [10]. However, the transition to renewable energy will require significant investment and infrastructure changes [11]. We need to develop new technologies, build new transmission lines, and invest in storage technologies that can help us to balance the intermittent nature of renewable energy sources [12].

Heat and fuel intensity usage in households is an important aspect of energy consumption to consider in the path towards decarbonization [13]. In most households, the primary source of heat and fuel is natural gas, which emits carbon dioxide and other greenhouse gases when burned. Reducing the intensity of heat and fuel usage in households can be achieved through a variety of measures, such as improving insulation, upgrading heating systems, and adopting more efficient appliances [14]. Improving insulation can help to reduce the amount of heat that is lost through walls, windows, and roofs, which can in turn reduce the amount of fuel needed to maintain a comfortable indoor temperature [15].

Upgrading heating systems is another important step towards reducing heat and fuel intensity usage. Older heating systems may be less efficient and may emit more greenhouse gases than newer, more efficient systems [16]. Switching to a more efficient heating system, such as a heat pump, can significantly reduce the amount of energy required to heat a home. In addition to improving insulation and upgrading heating systems, adopting more efficient appliances can also help to reduce the intensity of heat and fuel usage in households [17].

By studying the energy and heat usage patterns the household sector, it becomes possible to assess the impact of renewable resources on reducing carbon emissions and achieving decarbonization goals [18]. Renewable resources, such as solar, wind, and geothermal energy, offer cleaner alternatives to traditional fossil fuel-based energy sources. The examination of energy and heat utilization intensity provides insights into how effectively renewable resources are being incorporated and utilized in the small consumer sector [19]. It helps identify opportunities for further integration of renewable energy solutions [20], ultimately contributing to the decarbonization efforts in the Poland's households and supporting the transition to a more sustainable energy future [21].

Based on an analysis of the literature, there is a research gap about the energy and heat intensity of fuels in the households, called the small consumers, especially in the context of the decarbonization of the economy. Based on this gap, the following aim was adopted: to analyze the fluctuations in the consumption of basic energy carriers (i.e., coal, natural gas, and electricity) in households on an annual basis. This paper consists of theoretical background, the presentation of data, forecasts, discussion, and the conclusion.

2. Literature Review

This literature review navigates the intricate landscape of Europe's transformative journey towards sustainable energy solutions. It begins by highlighting the strategic imperative of reducing greenhouse gas emissions in the European policies, emphasizing the pivotal role of renewable energy sources and energy efficiency investments. The review then delves into the central role of households as energy consumers, observing their increasing demands and the imperative of transitioning to clean fuels. The concept of active small consumers in the energy market emerges as a transformative force, empowered by technological advancements and consumer-centric models, fostering a transition from mere consumption to proactive energy participation. Integration into the Industry 4.0 and smart cities amplifies this paradigm shift, with digitalization, Internet of Things (IoT), and automation optimizing energy management and reducing waste. Emerging trends in the small consumer market, coupled with Polish energy transition, further exemplify the evolving energy landscape. Throughout, we underscore Europe's commitment to sustainability, where the small consumers and innovative policies are catalysts for shaping a greener and more responsible energy future.

2.1. The Strategic Direction to Reduce Emissions in European Policies

Energy and fuels are vital for social and household activities, fulfilling the needs of economies in production, communication, transport, and other areas. The current trend focuses on green energy production from renewable sources, crucial for reducing greenhouse gas emissions. The European Commission has outlined this direction in the European Green Deal [1], aiming for net-zero greenhouse gas emissions by 2050 and decoupling economic growth from natural resource use. New, stricter goals for 2030 include at least a 55% reduction in greenhouse gas emissions compared to 1990. The European Union consistently implements the "Clean Energy for All Europeans" package [2,3], with nearly all EU leaders committing to net-zero strategies by 2050 in December 2019 [4]. The Paris Agreements initiated a new phase in climate policy, emphasizing limiting the planet's average temperature increase. The strategic direction in the European Union countries is the development of renewable energy and heat sources, with investments in renewables and energy efficiency as a priority in the European policy.

2.2. Households as Energy Consumers in the European Policies

EU climate and energy policy is increasingly integrating consumers into the energy market. The current framework allows consumers to easily switch and compare energy suppliers, monitor consumption through remote reading meters, enjoy stable prices, and have access to an energy ombudsman. Households are central in the EU energy landscape, with increasing energy demands driven by higher incomes, more electrical appliances, and thermal comfort awareness. Even with efficiency improvements, such as insulated homes and low-energy appliances, total energy consumption rises [5]. In the European Union, the amount of energy consumption increased from 10,388,387.81 TJ in 2020 to 10,959,828.58 TJ in 2021 [11]. The shift to clean fuels aims to involve households as energy is a fundamental living standard. Consumers have rights, including grid access, information accessibility, and quality standards [6]. Initiatives like home renovations, photovoltaic installations, and heat pump use can reduce energy bills and environmental impacts. Residential electricity consumption in Europe accounts for 27% of total energy consumption [7]. The European climate policy package assumes consumer participation in renewable energy sources, increasing the share of renewables in the energy mix and broader electrification [8].

The EU has several programs that promote energy awareness, offer subsidies for efficient appliances [9], and promote household renewables [10,11]. With various regulations, EU countries aim to decrease coal energy consumption in households and boost renewable energy use [12,13]. These efforts enhance EU energy security and drive towards climate goals [14]. Embracing innovative solutions and promoting household energy efficiency are vital for sustainable energy progress [15,16]. As markets evolve, consumers have diverse energy choices and can become prosumers, benefiting from real-time energy information in smart cities and achieving independence from fluctuating market prices [17]. The push for increased energy efficiency is a strategic climate policy goal [18], encouraging consumers to participate in energy markets directly. This activation fosters the transition from consumer to prosumer, influenced by varying economic developments [19].

2.3. Active Small Consumers in the Energy Market

In recent years, the European Commission has been promoting transparency in the carbon footprint of products for consumer awareness [20]. Technological advancements have allowed consumers to diversify their energy sources. A consumer-centered market model was proposed in 2015, aiming to connect consumers closely with wholesale and retail markets [20]. This model supports consumers in managing their energy consumption, leading to savings and contributing to climate transformation [21]. Enabling flexible consumption involves access to price signals and incentives such as lower tariffs for reduced consumption during network congestion [20–23]. Decentralization of the energy market leads to reduced generation-consumption distance, and the microgrid sector is witnessing strong growth worldwide [24]. The decentralized model employs a 'peer-to-peer' principle [25]. Prosumers, as producers and consumers of energy, play a crucial role in reducing energy usage and promoting sustainability [26]. They generate energy through renewable sources, implement energy-saving measures, and can participate in demand response programs and community energy sharing initiatives [27], thus contributing to a reduced reliance on fossil fuels and increased sustainability [28].

2.4. Small Consumer in the Industry 4.0 and Smart Cities

Growing environmental awareness in electricity and heat consumers influences proper (sustainable) choices [29]. Climate consciousness is a key part of this awareness, allowing for purposeful activity and anticipation of environmental results [29]. The growing awareness in society leads to self-sufficiency from renewable sources, contributes to increased fuel efficiency at the household level, and fosters attitudes toward high-tech energy solutions [30].

Prosumers, who are the green group of the Polish households, show consistency in ecological behavior, such as turning off lights, buying energy-efficient appliances, and using them in ways that limit consumption [30]. This characterizes a high awareness of reducing heat and electricity consumption [30].

New technologies of the Fourth Industrial Revolution, such as the development of ICT and smart energy supply networks, ease consumer control over energy and heat consumption [31,32]. This is further supported by home digitization (e.g., smart homes) and the necessity to protect privacy through data standards and safety mitigation systems [33,34].

Industry 4.0 technologies can significantly decrease energy usage among prosumers [35]. They enable smart energy management that monitors real-time consumption [36] and adjusts energy usage based on demand [37]. Predictive maintenance [38], utilizing artificial intelligence (AI) [39] and machine learning, helps in scheduling maintenance before breakdowns [40]. Optimization in supply chain management [41], development of smart buildings [42], and manufacturing energy-efficient products [42] contribute to reducing energy waste [43].

The development of smart buildings is another key aspect of sustainability and innovation [44]. Smart buildings are designed to intelligently manage energy consumption by utilizing sensors and automation systems [45]. These technologies ensure that lighting [46], heating [47], and cooling systems [48] are only active when necessary, leading to reduced energy waste [48]. Moreover, smart buildings often incorporate renewable energy sources such as solar panels [49] and efficient insulation materials, further contributing to a sustainable future [50].

Sustainability has become deeply intertwined with the concepts of Industry 4.0 and the emerging Industry 5.0 [51]. These industrial revolutions prioritize the integration of advanced technologies, such as the IoT [52], AI [53], and automation [54]. In doing so, they aim to create smarter, more efficient, and environmentally conscious production processes [55]. By harnessing the power of digitalization [56] and real-time data analysis [57], industries are better equipped to optimize their operations, minimize waste, and make sustainable choices throughout their value chains [58]. This alignment of technology and sustainability is essential in shaping a more eco-friendly and responsible future for industrial sectors worldwide [59].

Smart cities serve as instrumental hubs for prosumers, a term used to describe individuals and businesses that actively participate in both energy production and consumption, facilitating their journey towards achieving decarbonization goals [60]. This emerging paradigm shift in energy management is critical in the broader context of sustainable urban development [61].

Prosumers contribute to the energy landscape by producing renewable energy through technologies like solar panels and wind turbines while simultaneously consuming energy for various purposes [62,63]. Smart cities empower these prosumers with a suite of tools and services designed to enhance their energy efficiency and reduce their carbon footprint [64].

Smart grids are a fundamental component of the prosumer-driven energy ecosystem within smart cities [65]. These grids are designed to be flexible and responsive [66], allowing prosumers to not only draw electricity from the grid but also sell excess energy they generate back to it [67]. This dynamic interaction encourages the use of renewable energy sources, as prosumers are incentivized to generate surplus green energy [68]. Additionally, smart grids offer energy storage solutions, such as batteries [69], which prosumers can use to store excess energy for later use or to sell it during peak demand periods. They can also implement demand response programs [69], provide real-time data on energy usage [70], and offer mobility solutions like electric bike-sharing to reduce emissions [71].

By facilitating renewable energy integration, optimizing energy use, and promoting sustainable mobility [72], smart cities help prosumers become more energy-efficient, reduce their carbon footprint, and contribute to a more sustainable future [73].

2.5. Trends and Developments in the Small Consumer Market

For consumers to benefit financially from new opportunities, they need to have access to smart systems and to electricity and heat supply contracts based on dynamic prices linked to the market [74]. In addition to consumers adapting their consumption to price signals [75], new offtake response services are now emerging [76], where market players offer an aggregation and management service for fuel consumption, paying them compensation for flexibility [77,78]. Recently, the following trends can be observed in markets where consumers (households/small consumer market) are actively involved:

– saving energy and heat by investing in technologies that provide energy from renewable sources (own renewable energy and heat sources),
– the need to purchase boilers that reduce CO_2 emissions (certified boilers),
– thanks to the internet and new "smart" technologies, citizens' access to information and services in a diversified energy and heat market is increasing,
– solutions offered by energy technology and transmission network service providers are increasingly personalized, and
– legal protection of consumer rights.

These directions are included in the package of documents entitled "Clean Energy for All Europeans".

In the small consumer sector, the key trends, driving regulations seeking to change consumer perceptions of electricity and heat, are as follows:

– market liberalization and high prices for energy and fuels produced from coal [79],
– increased demand for renewable energy (transitioning towards clean energy and a low-carbon/zero-carbon economy by 2050) [80],
– increasing climate awareness of consumers,
– increased share of distributed energy sources in the total market,
– consumers' access to various forms of energy and heat savings,
– increased proportion of network usage charges and taxes, and in particular additional charges in the final household electricity and heat bills [81], and
– houses and network modernization and infrastructure investments using smart technologies [82].

The small consumer sector, such as households and small businesses, can achieve a better level of decarbonization by taking several actions [83]. Small consumers can reduce their carbon footprint by decreasing their energy consumption [84]. This can be achieved by using energy-efficient appliances and light bulbs, turning off electronics when not in use, and improving insulation and weatherization of their homes. They can switch to renewable energy sources such as solar, wind [85], or geothermal power or purchasing green energy from a provider [86].

Small consumers can reduce their carbon footprint by using sustainable modes of transportation such as walking, cycling, or using public transport instead of driving a car. They can also switch to electric or hybrid vehicles [87]. This group of consumers can reduce their carbon footprint by reducing waste and recycling as much as possible. They can also compost organic waste and avoid single-use products [88].

Small consumers can advocate for policies that promote sustainable practices and educate their communities on the importance of decarbonization [89]. They can join local environmental organizations [90], attend community events [91], and engage in conversations with their peers and policymakers [92,93].

Poland's inclusion in these trends is necessary and inevitable, both because of the Paris Agreement, to which Poland is a signatory, and because of its membership of the European Union and the need to become involved in the implementation of European energy policy. It is also necessary due to the increasing level of awareness among the public to reduce emissions from coal combustion. For years, the Polish energy sector has been based on indigenous energy resources, namely hard coal and lignite. Electricity generation in Poland takes place primarily in thermal power plants fired by hard coal and lignite (over 70% of energy in Poland is generated from coal) [94]. The size of resources varies from year to year not only as a result of exploitation and changes in the recognition and documentation of resources, but also as a consequence of changes in the assessment of the resources of developed mineral deposits resulting from the principles of market economy and restructuring activities (out of 160 hard coal resources in Poland, 64 were undeveloped in 2018) [95]. A significant part of thermal coal mines is unprofitable due to difficult mining and geological conditions and irrational organization of work. The closure of mines in Poland has been going on for three decades. Compared to the 1990s, the number of mines has decreased from 70 to 21 and coal production has fallen from almost 180 million tons to less than 62 million tons (2019) [96]. In 2021, Poland also decided that the last thermal coal mine will close in 2049 [97]. By reducing coal mining, the Polish government plans to build a nuclear power plant (the first in Poland). In addition, the Polish energy plan (until 2030) assumes a strong diversification of energy sources and investment in renewable energy technologies [98]. The Polish Energy Policy is subordinated to the policies of the EU, of which Poland is a member. The Polish Energy Policy until 2030 is a priority in the area of energy and heat management [99].

3. Materials and Methods

In this study, the desk research methodology was used to collect and analyze empirical data on the intensity of energy and heat fuel consumption in the small consumer sector in Poland. This method consists of collecting and evaluating information from secondary sources, such as documents, reports, scientific publications, and other materials available online or in libraries. The aim of the desk research was to gain a full understanding of the problem under study.

3.1. Background

3.1.1. Emissions in the Economy

The European Green Deal (COM2019, 640 final) [1] is a policy framework where the primary goal is to achieve climate neutrality for the European Union by 2050. This means that the aim is to reduce greenhouse gas emissions to zero in all areas where this is possible, including the small consumer sector. Greenhouse gas emissions (in terms of CO_2) on average across the EU are emitted by three sectors, whose share in 2021 was similar: industry—22%, energy (electricity and heat production)—20%, and households—20.5%. In Poland, the proportions were different: by far the largest number of emissions was generated by the energy sector, with 33.6% of total emissions, followed by industry, with a share almost half as large (16%), households, with 14%, and agriculture, with 13.5% of total emissions [100]. Figure 1 shows the emission situation in Poland and the European Union.

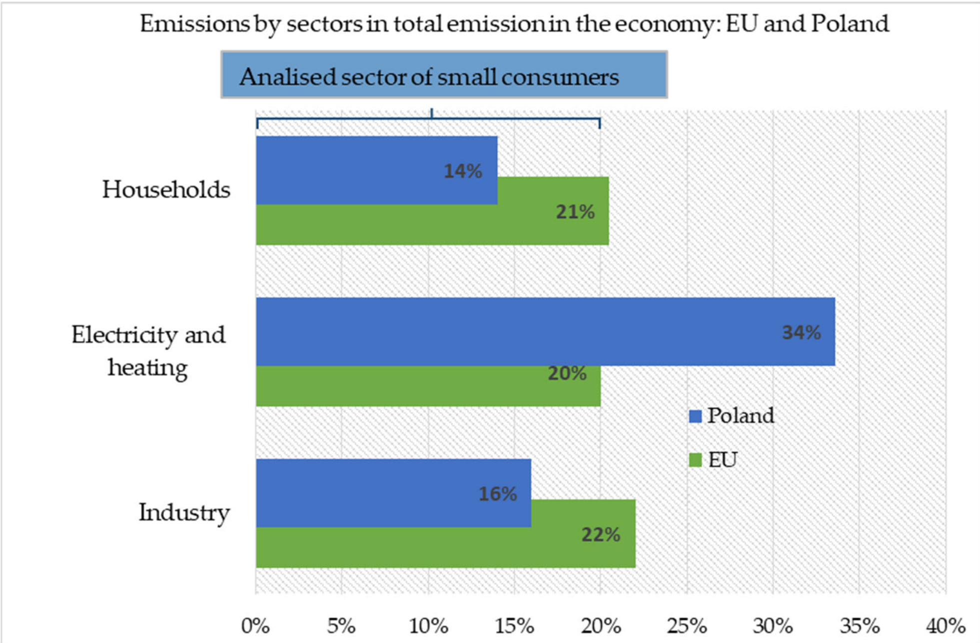

Figure 1. Emissions in the economy: a comparison between Poland and the EU as a whole. Source: [100].

This different structure of greenhouse gas emissions in Poland and the entire EU, according to economic activity, primarily results from the fact that in Poland, the majority of electricity and heat (both from professional power plants and household sources) is produced from highly emitting coal. In 2021, hard coal accounted for 62% of greenhouse gas emissions from power generation and heating, brown coal accounted for 31% of emissions, and gas accounted for the remaining 6% of emissions [101] (Figure 2).

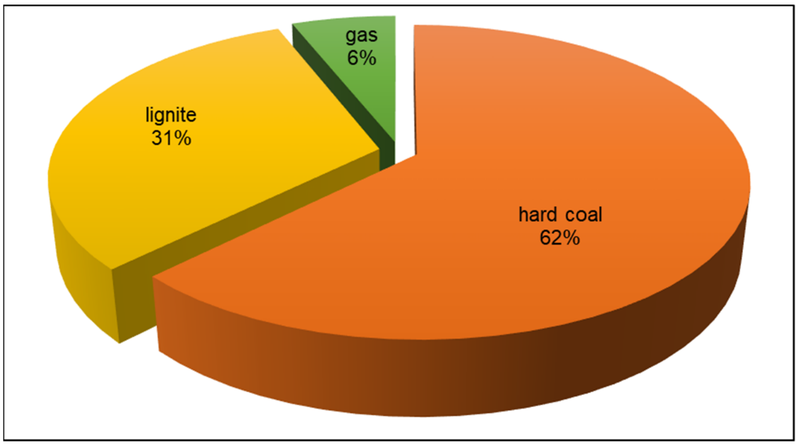

Figure 2. Sources of greenhouse gas emissions in Poland. Source: [101].

3.1.2. Sources of Electricity in Poland

In Poland, decarbonization primarily means moving away from coal, which plays a significant role in power generation and heat production (sectors collectively referred to as the energy sector), as well as in certain other areas of economic activity, and is the main source of greenhouse gas emissions. The structure of electricity production in Poland at the end of 2020 was unfavorable for net-zero transitions, as over 70% of the energy was derived from coal [101,102]. Figure 3 shows the sources of electricity in Poland. In 2021, the installed capacity of coal-based electricity accounted for 66% of all power generation capacity in the power sector (with 48% from hard coal and an additional 18% from brown coal), renewable energy sources accounted for 27% of the capacity, and gas accounted for 6% [103].

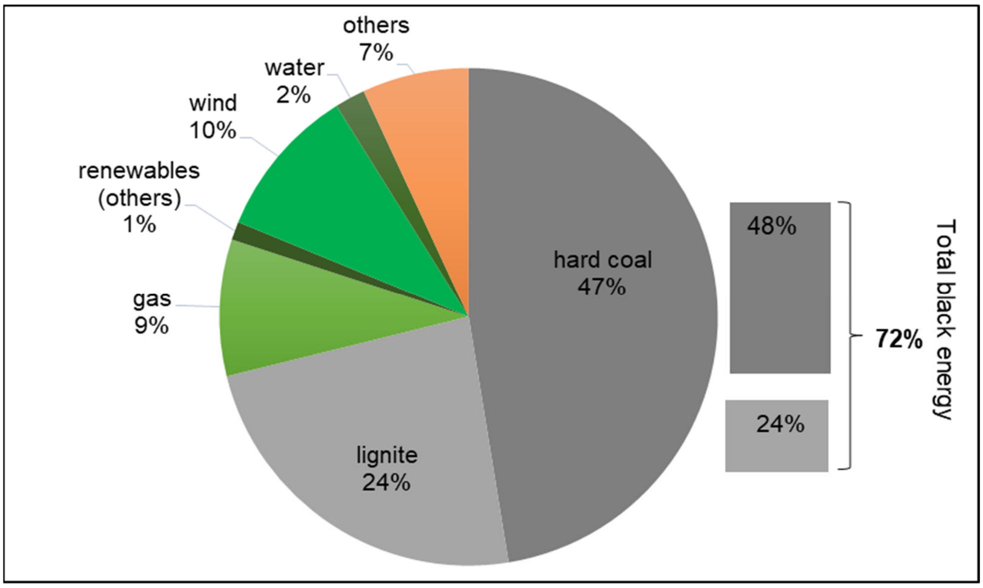

Figure 3. Sources of electricity in Poland. Source: [102–104].

According to Eurostat [105], the sources of energy in Poland differ significantly from those in the EU (Table 1). Poland exceeds the EU indicators for non-renewable energy. Poland also does not have nuclear power plants, and the renewable energy markets are still developing. In 2020, nuclear power plants (almost 25%) and gas-fired power plants (21%) had the largest shares in electricity generation in the EU. Wind turbines (14%), hydroelectric power plants (13%), and biofuels (6%) had the highest shares among renewable energy sources in the EU, while solar energy had the lowest share (5%) (Table 1). In Poland, the structure of fuel consumption for electricity production was completely different: fossil fuels (hard coal, brown coal, and gas) had a dominant share, accounting for as much as 81% of the energy produced. Renewable energy sources contributed a total of 18.4% of the energy, with wind energy accounting for the highest share at 10% of the total production. Electricity generated from biomass made a relatively significant contribution, accounting for almost half of that sum. Photovoltaic energy played a minor role, contributing only 1.2% to the total production, despite nearly doubling in production in 2020 [104,105].

Table 1. Sources of electricity in Poland and EU in total production (2020).

Source	Poland	27 Countries of EU
Coal	81.3%	35.6%
Wind	10.0%	14.3%
Solar energy	1.2%	5.2%
Water	1.9%	13.5%
Bioenergy	5.3%	5.8%
Atom	-	24.6%
Others	0.3%	1.0%

Source: [104].

Due to the continued dominance of coal in the economy and its high emissions, Poland contributes significantly to high air pollution levels in the entire EU. Poland's share of total greenhouse gas emissions in the EU was 12.6% in 2021, higher than the previous year (11%). This placed Poland in second place, nearly tied with Italy and France, which had similar shares (around 11%) [105]. Carbon dioxide (CO_2) is the gas that contributes the most to high emissions in Poland. In 2021, it accounted for nearly 81% of the total greenhouse gas supply. Its share in greenhouse gas emissions in the entire EU was also high at 78%, with Poland emitting almost 15% of the EU's greenhouse gases. The remaining portion of greenhouse gas emissions in Poland mainly came from methane and nitrous oxide, accounting for approximately 11.5% and 6.3%, respectively [106].

According to the Ministry of Climate and Environment, hard coal is the primary source of energy for 3.8 million out of 15 million households in Poland (statistics from 2020, retrieved from the Open Data portal on 9 August 2022). Furthermore, 4.3-million households use coal for heating purposes. One in four households in Poland relies on coal for heating [107]. The proportion of households using hard coal for heating and other household functions in Poland is quite high, at 25.33% of the total number of households in the country [108]. However, the policy of decarbonization in the industry and consumer markets in Poland, consistently implemented since joining the EU, has contributed to a decrease in the number of households using coal for heating. In 2018, according to data from the Central Statistical Office, 36.7% of households used hard coal. At that time, the estimated number of households in Poland was 14.4 million, meaning that approximately 5.5 million households used coal. Interest in coal has declined in the past two decades. Prior to Poland's EU membership, over 40% of households used hard coal for heating buildings and homes. Currently, the percentage of households using hard coal has dropped to 25% [108].

When considering the sources of heating in households across the European Union, Poles predominantly rely on hard coal and other solid fuels. On average, coal accounted for only 2.5% of final energy consumption in the households in EU countries (data from 2021). However, this figure is elevated in four countries: Poland (24.6%), Ireland (11.6%), the Czech Republic (8.9%), and Bulgaria (4.2%). Additionally, the 2% threshold was exceeded in Lithuania (2.4%). In the remaining EU countries, coal accounts for less than 1% of energy consumption in households. In 2020, 40.3% of the coal and other solid fuels consumed in Poland were used for heating homes, once again the highest in the EU. Ireland ranked second (17.2%), followed by the Czech Republic (14.2%). The primary source of energy for households in the EU is natural gas (31%), with 18% of households in Poland using it [109].

In 2021, households accounted for 27% of final energy consumption in the EU. Natural gas (33.5%) and electricity (24.6%) covered the majority of energy consumption in EU households. Renewables accounted for 21.2%, followed by oil and petroleum products (9.5%) and derived heat (8.6%). A small proportion (2.5%) was still covered by coal products (solid fossil fuels) [110]. The main use of energy in EU households is for heating homes (64.4% of final energy consumption in the residential sector), followed by water heating (14.5%). Lighting and most electrical appliances account for 13.6% of electricity consumption (excluding heating, cooling, or cooking systems). Cooking devices consume 6.0% of household energy, while other end-uses and space cooling account for 1.1% and 0.5%, respectively. Therefore, space and water heating represent 78.9% of the final energy consumed by households [110].

Poland accounts for 87% of the coal burned in households in the EU, specifically in the small consumer sector. Poland has a building stock of 14.2-million buildings, with single-family residential buildings being the most numerous, reflecting the specific characteristics of the Polish construction sector, including a dispersed ownership structure, difficulties in systematically reaching owners, and financing the modernization of existing buildings. Almost 80% of the housing stock is privately owned, which is one of the highest shares in Europe [111]. Table 2 presents the structure of Polish buildings.

Table 2. Characteristics of the Polish construction resources.

Single-Family Residential Buildings	Multi-Family Residential Buildings	Public Buildings	Production Buildings, Warehouses	Collective Accommodation Buildings	Other * Buildings	Total Buildings
5,604,000	553,000	420,000	5,116,000	3900	2,491,000	14,187,900
39.50%	3.90%	2.96%	36.06%	0.03%	17.56%	100%

Source: [112]. * Others building: summer houses, temporary residence, etc.

The total area of buildings in Poland is 1562 million sqm and as much as 68% of this area belongs to the residential sector (Figure 4).

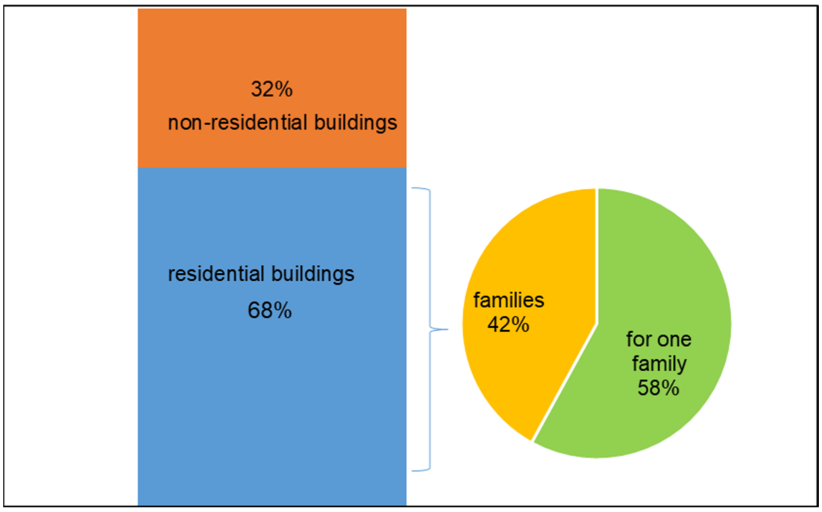

Figure 4. Types of building in Poland. Source: [112].

Buildings vary greatly in terms of energy efficiency, considering both their function and the year they were put into use. The energy standard of existing buildings is a result of their age, usage patterns, construction work conducted, applied building technologies and products, as well as the requirements that were in place during their construction. Gradual tightening of technical requirements, particularly regarding energy efficiency and thermal insulation, along with technological advancements, contribute to improving the energy efficiency of buildings. Households in the small consumer sector rely on two main forms of heat and energy distribution: district heating and individual heat and energy (non-systematic). In the coming years, Poland will develop its system of district heating supply. Currently, the structure of many small consumer sector consumers does not have access to district heating [113].

3.1.3. Challenges of the Polish Energy Policy

In Poland, the district heating sector consumes approximately 26 million tons of coal annually. Half of this consumption is attributed to households [114]. Poland's heating system relies heavily on coal, with an annual consumption of around 24–26-million tons. Household heating alone accounts for up to 12 million tons of coal. From the perspective of the entire EU, Poland stands out as an extreme case in terms of coal burning in individual buildings [114]. In Poland, 47% of households heat their homes using solid fuels, and 76% of heat is generated in individual heating installations. The remaining 24% is produced in district heating systems, of which 80% is inefficient. Annually, the heating sector emits 68-million tons of CO_2, which accounts for a quarter of the national emissions. The low emissions (from sources below 40 m) from individual heat sources in approximately 5-million buildings in Poland are one of the main causes of poor air quality. About 3.5-million buildings are supplied with heat from low-efficiency coal-fired sources. Meanwhile, old, and inefficient boilers and stoves are the main sources of smog that Polish cities and villages struggle with [114]. The main coal suppliers are the Polish companies (mines), owned by the State Treasury. Further, 80–90% of coal in households comes from State Treasury companies [115]. Poland needs around 10–12-million tons of raw coal for individual households during the heating season, while Polish mines are capable of extracting 3–4-million tons, leaving a shortfall of 6–8 million tons. In 2022, Poland imported a total of 20-million tons of coal, with PGE "Paliwa and Węglokoks" companies importing 14.4-million tons [115]. In 2022, both the EU and the Polish market experienced a significant increase in energy carrier prices due to various factors such as post-pandemic economic recovery and Russia's armed invasion of Ukraine. The Polish government decided to halt coal imports from Russia. Following the introduction of sanctions, there was a supply gap in the coal market for households, leading to coal shortages and prices exceeding 780 EUR per ton in private depots. During that period, households in Poland applied for the coal allowance introduced as part of regulations aimed at increasing the country's energy security. The coal allowance (670 EUR) was granted to households whose primary heating source was a solid fuel boiler, fireplace, air heater, kitchen range, coal stove, or solid fuel tile stove, fueled by coal, briquettes, or pellets containing at least 85% coal [116]. Local governments also implemented a coal distribution system to ensure low prices for coal in households. In 2022, nearly 2-million tons of coal were distributed to consumers through local governments. This described situation occurred in Poland during the winter season of 2022.

Apart from the high coal consumption in households, another significant problem in Poland is the low-energy efficiency of residential buildings. According to the "Healthy Homes Barometer" prepared for Velux, 58% of Poland's building stock consists of buildings older than 40 years, and only 10% have energy certificates of class A or B [117]. This means that the majority of Polish single-family homes have a low or very low energy standard and, consequently, high heat demand. The biggest problem lies in rural single-family buildings. Poland is implementing the government's Clean Air program, but the achieved 15% improvement in energy efficiency may be insufficient; it should be at least 30% [114].

Another challenge is the maintenance of the district heating network in Poland. Poland has one of the most developed district heating networks in Europe, with a length of nearly 21,500 km. However, 80% of them are energetically inefficient according to the EU's energy efficiency directive [114]. External conditions and the technical condition of pipelines contribute to the high maintenance costs of the district heating system [118]. In the Polish district heating market, there are plants that do not meet EU efficiency criteria, which effectively excludes them from financial support.

The situation in the Polish heating sector hinders the achievement of the common EU goals and the reduction of greenhouse gas emissions in heating and energy sectors by 43% by 2030 (compared to 2005 levels). On July 14, 2021, the European Commission presented a legislative plan on new reduction targets, along with a proposal to revise and expand the currently functioning EU ETS system (Emissions Trading System) to cover the building and transportation sectors [119]. Buildings are the largest energy consumer in Europe, accounting for 40% of energy consumption and 36% of greenhouse gas emissions in the EU. This is due to the fact that the majority of buildings in the EU are not energy-efficient and still rely predominantly on fossil fuels. Over 85% of currently occupied buildings will still be standing in 2050 when Europe aims to achieve climate neutrality [120]. Based on an Impact Assessment, the Commission has proposed a 55% emission reduction target by 2030 compared to 1990 levels. The EU ETS has proven to be an effective tool in reducing emissions in existing sectors, with emission reductions of around 35% in installations covered by the system in 2019 compared to 2015. About 30% of emissions related to building heating are already indirectly or directly covered by the ETS system. The extension of the ETS system to new sectors appears to be necessary but will involve significant costs for households. According to a report by the Polish Economic Institute in collaboration with the European Roundtable on Climate Change and Sustainable Transition and Cambridge Econometrics, achieving the targeted 40% emission reduction in the construction and transportation sectors is possible with prices reaching over 170 EUR/ton CO_2 in 2030, resulting in costs of 1.112 trillion EUR for EU households between 2025 and 2040 [121].

Decarbonizing the building sector will require a comprehensive strategy to improve the energy efficiency of small consumers. Developing prosumer energy and micro-installations for household use, building thermal modernization, upgrading outdated energy grids, energy storage, and the expansion of biogas plants are urgent actions that will accelerate the decarbonization of the small consumer market. Prosumer energy represents a significant opportunity for small consumers to achieve energy independence. According to the Polish Society of Power and Environmental Engineering (PTPiREE), by the end of 2021, the total number of prosumer micro-installations connected to the distribution grid in Poland reached 854,000 with a total capacity exceeding 6 GW [122]. The micro-installation market in Poland is growing, and consumers are becoming increasingly aware of energy and heat-saving possibilities [123].

In Poland, decarbonization primarily involves the process of moving away from coal, which is long and costly. This process is being implemented across all sectors of the economy [124]. The Polish Economic Institute and the Energy Forum estimate that decarbonizing the entire heating sector will cost over 123-billion EUR by 2030. Experts emphasize the need for a comprehensive decarbonization strategy for industry and consumers—without it, Poland will struggle to fulfil its EU climate policy commitments. According to the Polish Energy Policy (PEP) [125], it is assumed that the use of thermal coal in the Polish economy will end in 2049, which means a decrease in the share of coal use in households and an increasing share of systemic power generation [126]. In Poland, decarbonization primarily means moving away from coal, which plays a significant role in power generation and heat production, and this entails the closure of mines. According to decarbonization scenarios and agreements between trade unions and mine owners (agreements between representatives of the Government and the Inter-Union Protest-Strike Committee of the Silesian-Dąbrowa Region, September 2020), the closure of mines will be phased (with a mine being closed every few years). A total of 14 mines have been scheduled for closure between 2021 and 2049, ending coal mining by 2049 [127].

Although decarbonization efforts are becoming increasingly common globally, there are still many challenges. Only a holistic approach will allow for the complete decarbonization of the small consumer sector. The Paris Agreement, adopted in 2015 during the COP21 climate summit and signed by Poland, sets the main goal of limiting the average global temperature increase to below 2 °C, preferably to 1.5 °C above pre-industrial levels. Achieving this goal means that global net anthropogenic greenhouse gas emissions will reach zero by around 2050, with no additional emissions being released into the atmosphere. The significance of the small consumer sector in achieving climate neutrality is important. Data shows that buildings account for 38% of global CO_2 emissions, with 28% coming from building operations and the remaining 10% attributed to the energy consumed in the production of materials and technologies used in the construction sector (embedded carbon footprint). As technologies for reducing the energy consumption of buildings during their use continue to develop, the importance of the embedded carbon footprint will increase [128–130].

Reaching a net-zero level of greenhouse gas emissions by 2050 must be a result of a balance between reduced emissions through decarbonization, carbon dioxide removal, and remaining carbon dioxide emissions, which are likely to persist even after 2050 in certain geographic areas and processes.

Across the EU, the share of electricity generated from renewable sources reached its highest level in history in 2020, reaching 39% of total energy production and surpassing fossil fuel electricity generation (36%) for the first time. However, preliminary data for 2021 indicate that this trend was not sustained, as fossil fuels once again became the largest source of electricity [126].

3.2. Steps of the Analysis and Data

Five key steps were taken to ensure the effectiveness and efficiency of secondary research (Figure 5). First, the research topic was identified by reviewing the literature on energy intensity and consumption of heat fuels in the small consumer sector in Poland. Secondly, official statistics have been identified as the primary data source for their reliability, completeness and comparability over time. Third, existing data on energy and heat consumption in Poland was collected and summarized in a table. Fourth, data was combined and compared to identify trends and patterns. Finally, the data was analyzed to gain insight into the development of the phenomenon under study.

Figure 5. Secondary research process. Source: own elaboration.

The research topic (step 1) was determined on the basis of a literature review in the field of energy intensity and consumption of heat fuels in the selected sector of small consumers in Poland. The subject of the research is important in the context of the energy and climate policy pursued by the European Union, including Poland. The European policy aims to improve energy and heat efficiency and combat climate change through better management, market development and implementation of innovative technologies. However, there is a research gap in the area of energy and heat fuel consumption in households, especially in the context of decarbonization in Poland.

As the basic source of data in the study (step 2), official statistics were used, specifically the annual publications of "Consumption of fuels and energy carriers" of the Central Statistical Office. The mission of official statistics is "providing credible, reliable, independent and high-quality statistical information on the state and changes taking place in society, the economy and the natural environment, responding to the needs of domestic and international users" [131]. With such a mission defined, the researcher may treat statistical publications as an excellent (qualitatively) source of secondary data. Energy and heat consumption in Poland has been well documented for many years. The data sources are the publications "Consumption of fuels and energy carriers", published annually by the Statistics Office (GUS) in the series "Statistical information" [132]. GUS data is considered the most reliable source of statistical data. Their advantage is completeness and comparability over time. The publications from which the data for our study were obtained are also characterized by high accuracy and quality of information. Quality in official statistics is based on the definition of quality in the European Statistical System [133] and is defined on the basis of six quality components. An in-depth analysis of these components has led to the conclusion that quality in statistics is not limited to the accuracy of the data, but also encompasses the usability of the data for those using the statistics in research and decision-making processes.

In steps 3 and 4 of the research process, data on energy and heat consumption in Poland were compiled and presented in Table 3. These are the input data for the analyzes carried out at further stages of the study. One table summarizes the available data for 16 years (2006–2021). The tabular compilation of time series enables the comparison of the level of consumption (in natural units) in households of the following energy carriers: hard coal (in thousand t), electricity (in GWh), natural gas (in TJ), heat (in TJ), liquefied petroleum gas (in thousand t), fuel oil (in thousand t).

Table 3. Consumption of fuels and energy carriers in Polish households (2006–2021).

Year	Hard Coal (Thousand t)	Electricity (GWh)	Natural Gas (TJ)	Heat (TJ)	Liquified Petroleum Gas (Thousand t)	Fuel Oil (Thousand t)
2006	10,830	26,022	138,685	190,000	450	300
2007	10,230	26,369	132,622	180,000	460	450
2008	10,600	27,115	131,450	175,000	450	300
2009	10,780	27,534	134,822	177,500	440	300
2010	11,900	28,614	148,427	195,000	440	105
2011	10,640	28,258	129,246	175,000	500	110
2012	11,020	28,318	141,397	180,000	500	87
2013	10,770	28,442	143,189	176,000	470	80
2014	9900	28,083	131,598	163,000	490	70
2015	9750	28,280	132,202	162,500	465	70
2016	10,350	28,909	145,148	163,000	490	70
2017	10,200	29,181	151,972	164,000	500	70
2018	10,050	29,284	149,111	157,000	500	80
2019	8500	29,393	152,348	152,000	530	65
2020	8670	30,027	160,833	152,700	500	66
2021	8000	30,590	191,171	170,000	475	98
average	*10,136.88*	*28,401.19*	*144,638.8*	*170,793.8*	*478.75*	*145.06*

Source: own elaboration based on data from the Statistics Office in Poland (in Polish: GUS) [131].

Data from Table 3 are presented in Figure 6.

From the gathered data, it can be concluded that starting from 2006, the consumption of hard coal by households in Poland has been consistently decreasing. In 2006, it amounted to 10,830 tons, while in 2021, it reached 8000 tons. Periodically, there were temporary increases in hard coal consumption, for example, in 2010, 2012, and 2016–2018. However, the overall trend throughout the entire period was declining.

In the case of electricity consumption in the sector of small consumers we can observe an increasing trend over the analyzed years from 2006 to 2021. In all year, the amount of electricity consumption was bigger comparing to previous year. In the first year of the analysis (2006) electricity consumption was 26,022 GWh and in the last one (2021) is on the level of 30,590 GWh. The average consumption among analyzed years is 28,401 GWh.

The consumption of natural gas in households experienced fluctuations over the years. While there were fluctuations, there was an overall increasing trend in natural gas consumption. It ranged from 128,622 TJ in 2007 to 191,171 TJ in 2021. This can be attributed to the popularity and convenience of natural gas as a cleaner alternative to other fossil fuels.

The consumption of heat in households showed a relatively stable trend with slight fluctuations. It ranged from 152,000 TJ in 2019 to 195,000 TJ in 2010. The relatively stable trend can be attributed to the consistent demand for heating purposes in households.

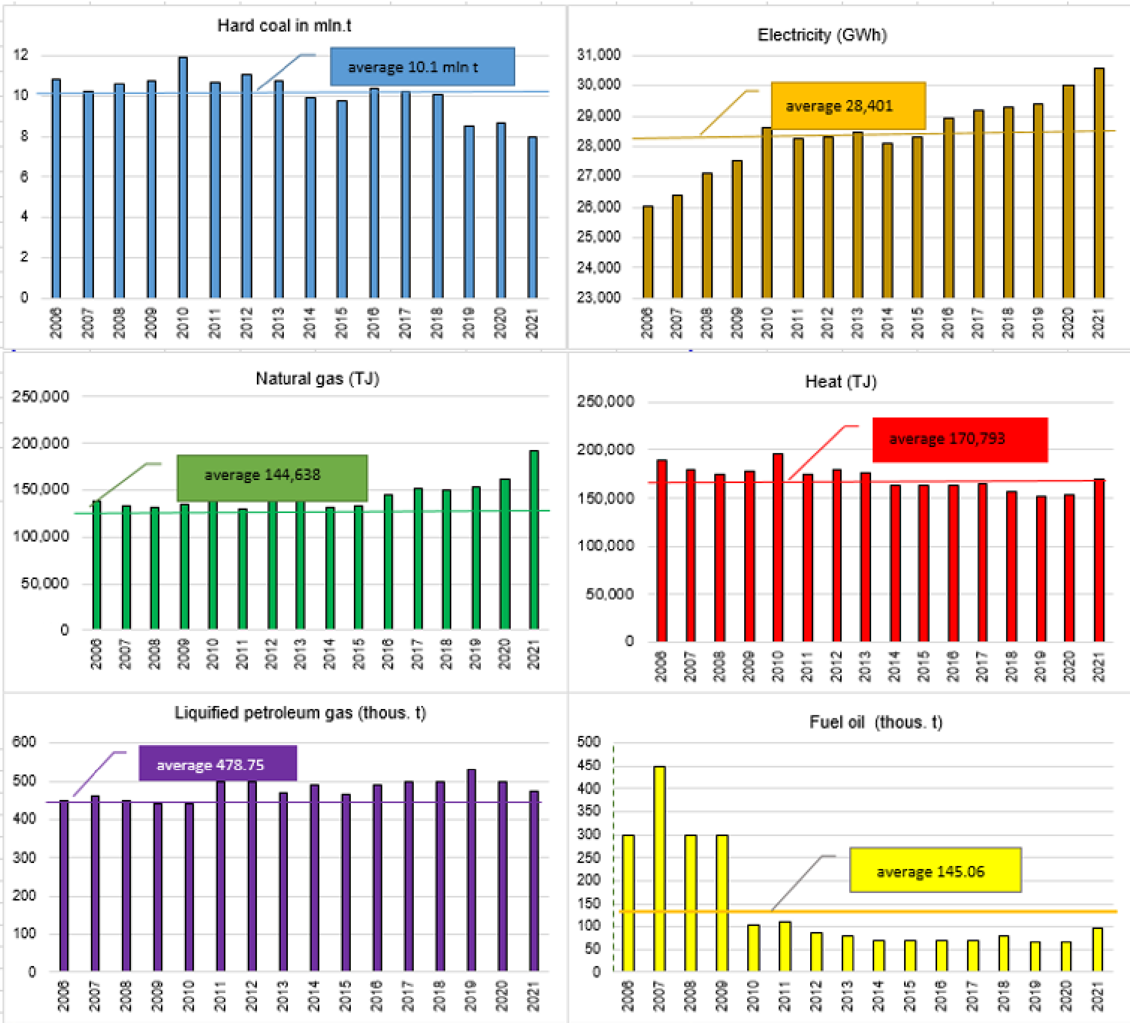

Figure 6. Consumption of fuels and energy carriers in Polish households (2006–2021). Source: own elaboration based on data in Table 3.

The consumption of LPG in households showed some fluctuations but remained relatively stable over the years. It ranged from 440,000 tons in 2009 to 530,000 tons in 2019. LPG is commonly used for cooking and heating purposes in households.

The consumption of fuel oil in households displayed a declining trend. It decreased from 450,000 tons in 2006 to 98,000 tons in 2021. This decline can be attributed to the phasing out of fuel oil and the adoption of alternative energy sources for heating purposes.

Compiled data on energy and heat consumption in Poland were analyzed (step 5) in order to determine the dynamics of changes in energy and heat consumption, the trend of changes in the consumption of hard coal, electricity, and natural gas as the main energy carriers in Polish households, the average rate of change in the analyzed area and forecasts based on the designated trend function of the consumption of these energy carriers in the sector of small consumers in Poland (Figure 7). The analysis was carried out using time series enabling comparison and identification of trends. The methods used in the analysis belong to the canon of knowledge about the methods used in the analysis of changes in market phenomena over time. Analysis methods have been used for many years by market researchers in various scientific areas [134–139].

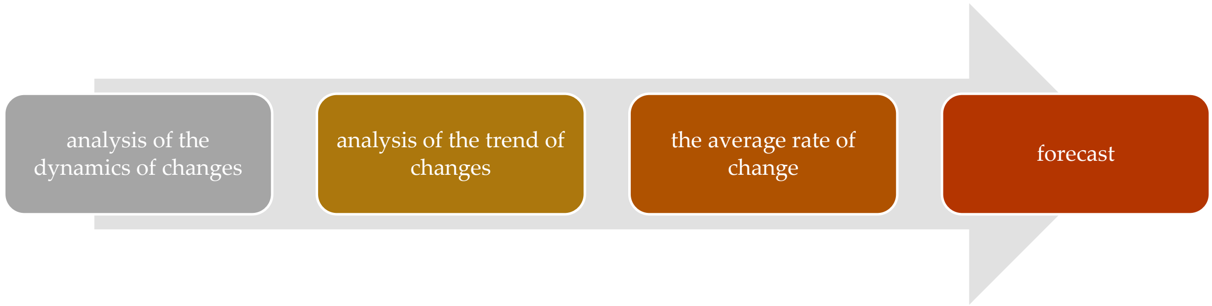

Figure 7. Statistical data analysis path in our study. Source: own elaboration.

The collected data was meticulously analyzed using fixed base indexes and chained indexes. Subsequent to this, trend functions were determined utilizing Equations (1)–(3), the outcomes of which are represented by Equations (5), (7), and (9). As a subsequent refinement, the average rate of change over the studied domain was computed via Equation (4), the results of which are depicted by Equations (6), (8), and (10). Ultimately, consumption forecasts for specific energy carriers were deduced based on the defined trend function, accompanied by forecast errors. For computational purposes, Microsoft Excel for Microsoft 365 MSO (version 2308 build 16.0.16731.20052) 64-bit was used.

In conclusion, the research methodology ensured the collection and analysis of reliable and comprehensive data on the consumption of energy and heat fuels in the sector of small consumers in Poland, which makes them a valuable contribution to the existing literature on the subject.

3.3. Limitations of the Paper

The gathered analytical material is based solely on secondary data concerning the consumption of selected energy carriers in households and does not take into account factors influencing the change in the level of energy carrier consumption. A comprehensive analysis would require the inclusion of primary data on these factors. The scope of available data allowed for basic analysis of changes in the studied phenomenon over time, including trend function analysis, indexes, and average rates of change. The use of aggregate statistics involves accepting the fact that historical data does not cover the current period (in our analysis, data ends in 2021). Data for 2022 will be published in government statistics only at the end of this year. The prepared forecasts of energy carrier consumption in households may be subject to error due to the use of the only applicable method in this case, which is trend extrapolation. Moreover, it should be taken into account that trend extrapolation is used for forecasting, but its accuracy in predicting long-term trends, especially in a rapidly evolving energy landscape, may be limited.

4. Results of the Analysis

The present study aimed to analyze the trends in the consumption of the primary energy carriers-hard coal, electricity, and natural gas in Polish households. The analysis was conducted using indexes of changes on a fixed basis with a base year of 2006 and on a variable basis. The study covered a time frame of 16 years, from 2006 to 2021.

The results indicate that over the 16-year period, there has been an upward trend in the consumption of electricity and natural gas, while the consumption of hard coal has been on a decline in the household sector in Poland. Notably, the highest increase in natural gas consumption was observed in 2021, with an increase of nearly 40% compared to 2006. In contrast, the consumption of hard coal recorded a decrease of over 10% in the same period. Additionally, the analysis revealed a remarkable increase of over 40% in electricity consumption in households over the 16-year period (Figure 8).

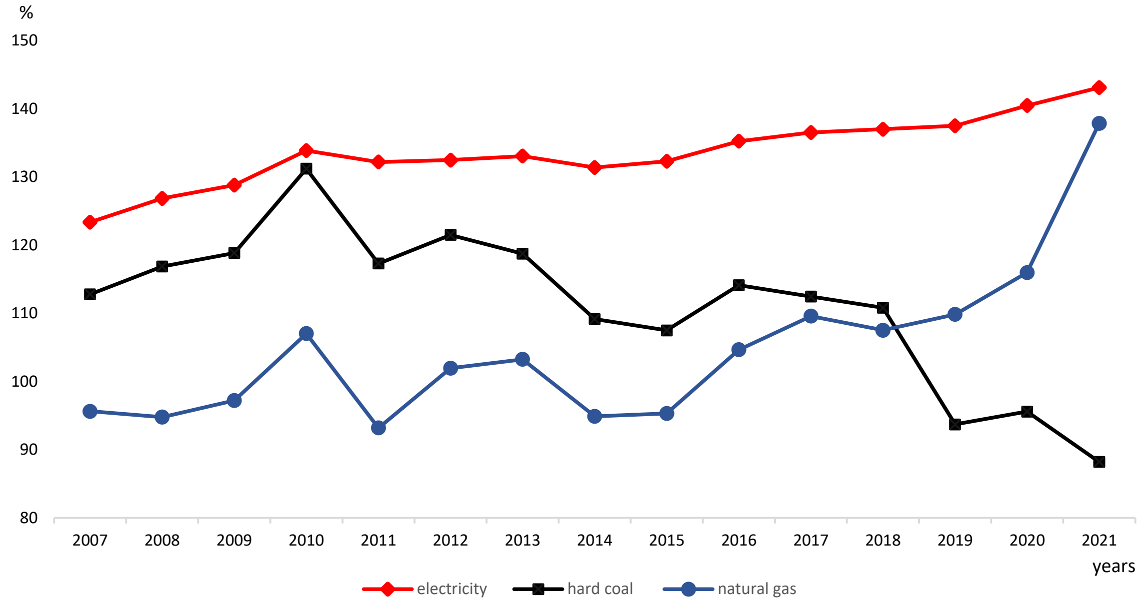

Figure 8. Indexes of fuels and energy carriers consumption in Polish households (2006 = 100). Source: Own elaboration based on data from Table 3.

The aim of this study was to analyze the fluctuations in the consumption of basic energy carriers, namely hard coal, natural gas, and electricity, in households on a yearly basis. The analysis revealed significant fluctuations in the consumption of hard coal and natural gas, whereas the consumption of electricity remained relatively constant over the years. From 2009 to 2018, the consumption of hard coal and natural gas showed a similar pattern, with an increase of 10% in 2010 and a decrease of 15% in the following year. However, in 2019, a significant difference in the consumption of these energy carriers was observed, with a decrease of 15% in the consumption of hard coal and a slight increase in the consumption of natural gas compared to 2018. Furthermore, the analysis revealed a significant increase of nearly 20% in the consumption of natural gas in 2021, compared to 2020. This was accompanied by a decrease of nearly 10% in the consumption of hard coal in the sector of small consumers during the same period (Figure 9).

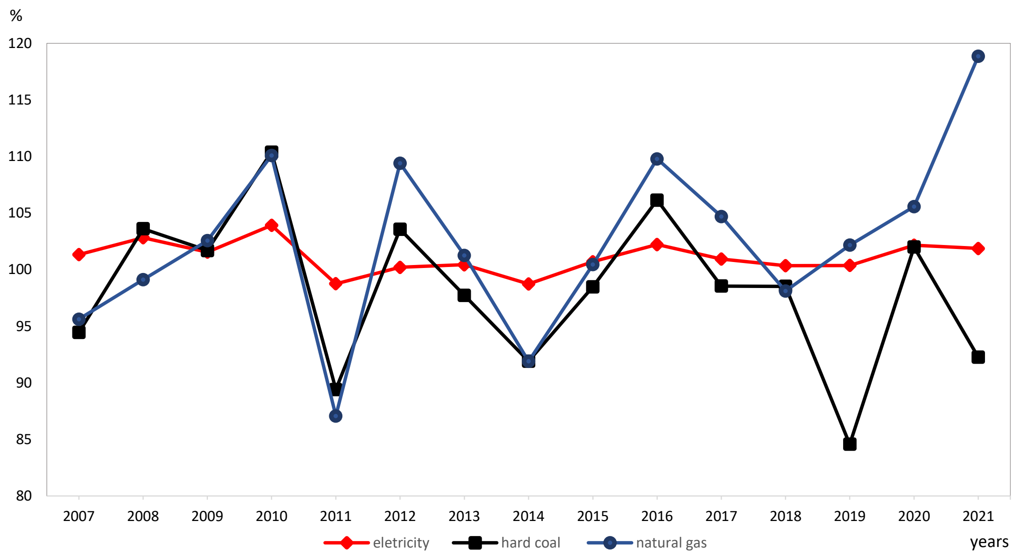

Figure 9. Indexes of fuels and energy carriers consumption in Polish households (Previous year = 100). Source: Own elaboration based on data from Table 3.

The findings of this study provide valuable insights into the dynamics of energy consumption in Polish households.

Subsequently, trend functions were estimated based on data concerning the consumption of coal, electricity, and natural gas in households. A developmental trend model was used to estimate the functions. The developmental trend model belongs to a particular class of econometric models where the variability of the explanatory variable is described by a specific explanatory variable, which is time. The time variable is not causally related to the endogenous variable and is treated as a synthetic indicator of changing conditions that determine the development of the analyzed phenomenon [136]. The most commonly used method for extracting trends is the analytical method, which involves expressing the developmental trend using a specific mathematical function [137]. Three different Equations (1)–(3) were used to estimate the trend function due to the different consumption patterns of individual energy carriers.

$$Y_t = \alpha_0 + \alpha_1 t + \xi_t. \tag{1}$$

$$Y_t = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \xi_t \tag{2}$$

$$Y_t = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \alpha_3 t^3 + \xi_t \tag{3}$$

The previously presented indexes are used to analyze a selected time series exclusively in relation to a given pair of years. However, when analyzing the dynamics of market phenomena, it is often necessary to evaluate changes in a given phenomenon throughout the entire observation period. To this end, the geometric mean of the chain index value over the analyzed period is used, which is referred to as the average rate of change in the level of the phenomenon over time [137]. The average rate of change in energy consumption was estimated for selected energy carriers. Due to the long time series, the geometric mean in logarithmic form was used (4):

$$log\bar{y}_g = \frac{1}{n-1}\sum_{i=2}^{n}(log\ y_n - log\ y_1) \tag{4}$$

The level of coal consumption in the sector of small consumers from 2006 to 2021 showed a clear downward trend (Figure 10). Due to the significant variability of hard coal consumption among households from 2006 to 2021, a quadratic trend function was used to estimate the trend function. After calculations were performed, the following Equation (5) was obtained:

$$\hat{y}_t = -23.71t^2 + 240.67t + 10,308 \tag{5}$$

The high coefficient of determination R_2 = 0.7949 indicates a good fit.

Based on the data regarding the consumption of hard coal, the average rate of change was estimated to be (6):

$$\bar{y}_g = 0.9269 \tag{6}$$

This indicates that the consumption of hard coal in households decreased on average by 7.3% per year from 2006 to 2021.

The consumption of electricity in households shows a clear increasing trend over the years, with minor fluctuations (Figure 11). The analysis of the distribution of the endogenous variable allowed for the use of a linear function to estimate its parameters. The structural parameters of the function were determined using the method of least squares, using the system of normal equations. After the calculations, the function takes the following form (7):

$$\hat{y}_t = 240.64t + 26,356 \tag{7}$$

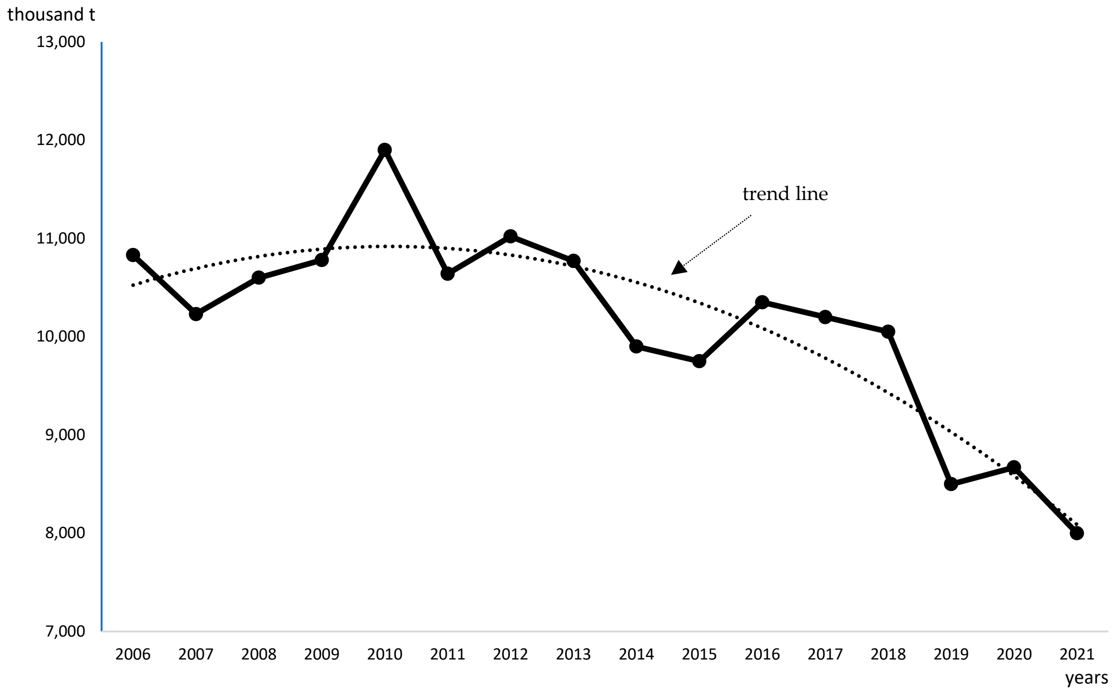

Figure 10. Consumption of hard coal in Polish households in years 2006–2021 (thousand t). Source: Own elaboration based on data from Table 3.

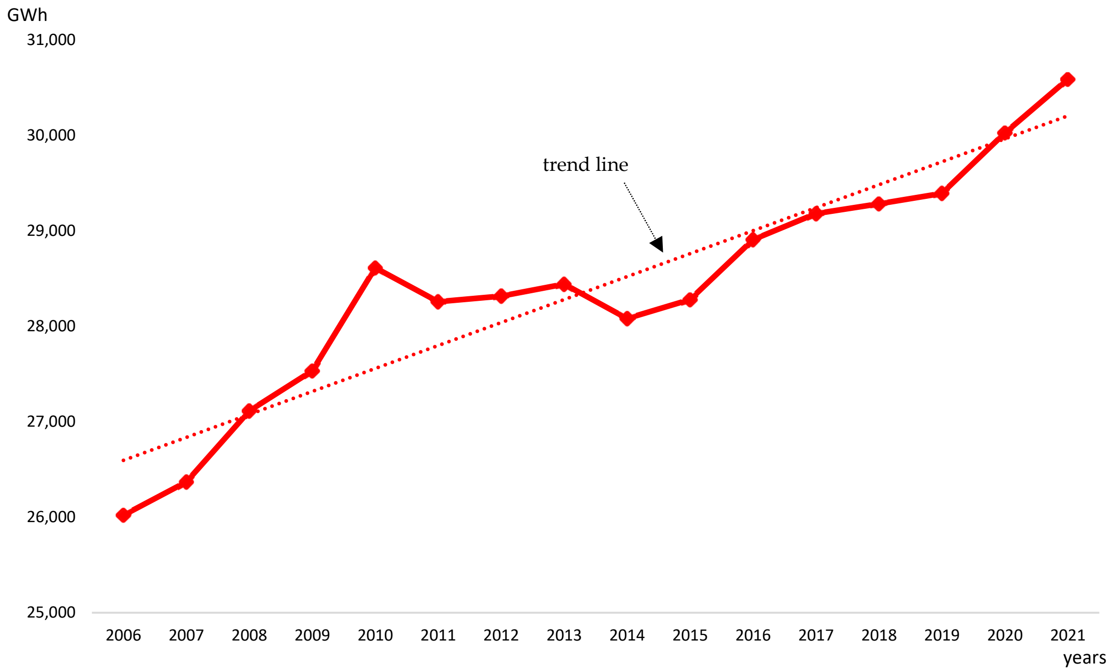

Figure 11. Consumption of electricity in Polish households in years 2006–2021 (GWh). Source: Own elaboration based on data from Table 3.

In the given context, a high coefficient of determination (R_2 = 0.877) indicates a very good fit.

Based on the data concerning the consumption of electricity, the average rate of change was estimated to be (8):

$$\overline{y}_g = 1.0968 \tag{8}$$

This means that the electricity consumption in households increased on average by 9.7% annually from 2006 to 2021.

The consumption of natural gas in households displayed significant fluctuations from 2006 to 2015. However, since 2015, there has been a clear upward trend in its consumption (Figure 12). To determine the trend function, a third-degree polynomial trend was utilized due to the high variability in natural gas consumption and the notable surge in consumption in recent years. Upon performing the necessary computations, the resulting function can be expressed in the following form (9):

$$\hat{y}_t = 55.37t^3 - 1028.6t^2 + 5698.7t + 128,370 \quad (9)$$

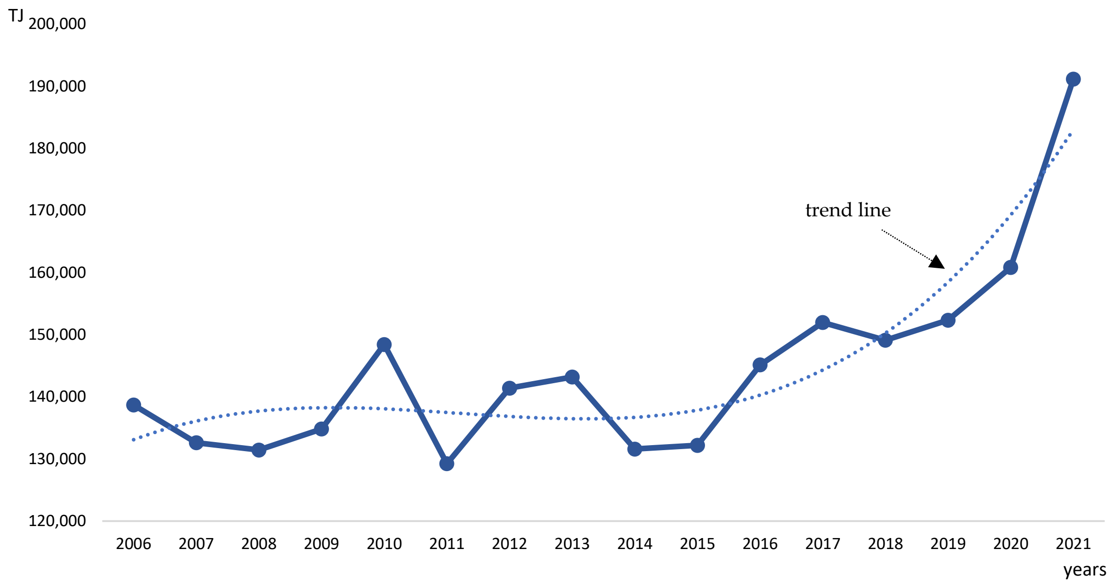

Figure 12. Consumption of natural gas in Polish households in years 2006–2021 (TJ). Source: Own elaboration based on data from Table 3.

The obtained high value of the correlation coefficient, specifically R_2 = 0.8188, serves as evidence of a well-fitted function. Based on the data concerning the consumption of natural gas in households, the average rate of change was also estimated (10), which is:

$$\overline{y}_g = 1.0404 \quad (10)$$

From 2006 to 2021, the consumption of natural gas in households increased on average by 4.04% per year.

On the basis of the calculated trend functions, it is anticipated that there will be a continued decrease in coal consumption among households, while the utilization of electricity and natural gas is expected to increase. The authors acknowledge that the prepared forecasts are subject to error and cannot be considered as a definitive basis for decision-making. Nevertheless, the estimated projections provide an overview of the further development of energy consumption in selected energy carriers in households.

Forecasting based on trend models involves estimating the analytical form of the trend function from detailed data and the estimation of the model parameters. The forecast based on the estimated trend model is obtained by multiplying the vector of time variable values t for the forecast period by the vector of estimates of the structural parameters of the model [138]. Trend models are well-suited for medium-term forecasting (up to 5 years) when the development of the phenomenon over time exhibits durable and systematic one-way changes, with limited random effects [139]. The estimated trend functions have enabled the preparation of energy carrier forecasts for 2023 and 2024. It is worth noting that data on the consumption of individual energy carriers for 2022 are not yet available. However, the authors have not made a forecast for the year that has passed. For the subsequent years, by substituting t = 18 into the trend function for 2023, t = 19 for 2024, t = 20 for 2025, t = 21 for 2026 and t = 22 for 2027 the projections were obtained (Table 4). For the prepared forecasts, accuracy was calculated using the MAPE (Mean Absolute Percentage Error) measure and RMSE (Root Mean Square Error) measure. These indicators were selected because they are among the most popular and commonly used in such forecasts. The indicators are as follows: for hard coal, it is 3.57% (MAPE), 443.14 t (RMSE); for electricity, it is 1.18% (MAPE), 415.49 GWh (RMSE); and for natural gas, it is 4.13% (MAPE), 6385.47 TJ (RMSE).

Table 4. The forecast of consumption of fuels and energy carriers in Polish households for 2023–2027.

Forecast for	Hard Coal	Electricity	Natural Gas
	(thousand t)	(GWh)	(TJ)
2023	6961.26	30,687.52	220,598.00
2024	6325.03	30,928.16	245,103.50
2025	5641.40	31,168.80	273,864.00
2026	4910.37	31,409.44	307,211.67
2027	4131.94	31,650.08	345,478.76

Source: Own elaboration based on data from Table 3.

Based on calculations, it is anticipated that there will be a continued decrease in the consumption of hard coal among households. In contrast, the utilization of electricity and natural gas is projected to rise. While the authors acknowledge that the prepared forecasts are subject to errors and should not be regarded as a decisive basis for decision making, the estimates provide an outline of the further progression of energy consumption in selected energy carriers within households.

It is evident from the findings that there have been significant shifts in the energy consumption patterns in households over the analyzed years. The increase in the consumption of natural gas and electricity can be attributed to various factors such as technological advancements, changes in lifestyle, and increased affordability. On the other hand, the decrease in the consumption of hard coal can be attributed to the environmental concerns associated with the use of fossil fuels.

Overall, the present study provides insights into the trends and patterns of energy consumption in households, which can be useful for policymakers and stakeholders in the energy sector to design effective policies and strategies for sustainable energy use.

Comparing the obtained data with the heat supply demand forecasts for residential buildings, which can be found in the heat sector strategy for Poland until 2030, we can observe that both in this strategy and in the presented research analyses, it is estimated that the heat demand for buildings constructed before 2020 will continue to increase in the coming years. A different situation is observed for buildings constructed after 2020, due to their construction technology being adapted to the new requirements of the European Union. However, considering that the majority of residential buildings in Poland were constructed before 2020 and the proportion of new buildings will increase slowly, it can be expected that there will be an increase in heat demand in the near future [140].

5. Discussion

The article examines changes in energy consumption within Polish households over 16 years. Notably, hard coal consumption decreased, aligning with the EU's fossil fuel phase-out efforts to combat emissions [141]. Hard coal is a highly polluting fuel, releasing substantial CO_2 and pollutants. Decreasing its use aids in decarbonizing the economy and climate change mitigation [142].

Additionally, electricity use rose among small consumers, in line with the EU's shift to renewable energy and electrification strategy. Renewable sources like wind and solar minimize greenhouse gas emissions, including from electric vehicles that can reduce transport emissions. The increase in natural gas consumption aligns with the EU's low-carbon goals, emphasizing security and affordability. Natural gas emits fewer pollutants than coal or oil. It is considered a transitional energy source and renewable natural gas from organic waste is being developed [143].

These trends align with the EU's decarbonization policies, promoting cleaner energy. However, more is needed to achieve ambitious climate targets, including higher renewable energy adoption and improved efficiency. In the EU, both coal production and consumption have decreased. K. Stala-Szulgaj's findings show reduced coal usage for energy and increased gas usage from 1990 to 2014 [144]. In the European households, coal use fell by 3.7% yearly from 2005 to 2021, attributed to alternatives like natural gas and renewables. Poland's coal reduction was faster at 7.3% annually [145–147].

Natural gas consumption in the European households grew 1.3% yearly over 16 years, driven by affordability and cleaner fuel policies. Poland experienced even faster growth at 4.04% yearly [148–150].

The European and Polish households have shifted energy consumption in the last 16 years, decreasing hard coal use and increasing electricity and natural gas consumption. This cleaner and more efficient transition results from technology, consumer preferences, and environmental concerns [35,151]. These trends will likely continue due to ongoing EU policies promoting renewables and emission reduction [152,153]. This aligns with the EU's decarbonization strategy, including future options like oil and hydrogen [143].

Several factors drive this shift. Increased natural gas availability and lower prices compared to coal have made it appealing, especially in urban areas with gas pipelines. Household income and demographics also play a role [154]. Economic growth enables more households to afford switching to natural gas [155], with younger and urban residents favoring its modernity [156]. Environmental awareness further propelled change, as cleaner natural gas gained traction due to coal's environmental impact. Government policies also contributed by reducing emissions and supporting renewables.

Electricity consumption in the household sector has risen due to accessible and affordable electrical devices. Higher incomes enabled owning appliances like air conditioners and TVs, boosting electricity demand. Electricity consumption growth trend is not rapid (by 3% in 2027 compared to 2023—Table 4). Rising household electricity consumption in Poland results from factors like accessible appliances, building modernization, electric car usage, and low electricity prices. However, to meet climate goals, Poland must shift from fossil fuels to renewables like wind and solar, necessitating significant clean energy infrastructure investment and sustainable consumption patterns. In the analysis performed (Table 4) on the basis of forecasts, trends in fuel diversification will not be radical. Although coal consumption will decline, most Polish households will replace coal with variable gas. The process of changing residential heating systems from coal stoves to gas stoves began several years ago and is still continuing. In 2027, compared to 2023, the decrease in coal consumption by small consumers will be 40% (calculated based on forecasts in Table 4). In the same period there will be an upward trend for gas. In 2027, variable natural gas consumption will increase by almost 57%, compared to the forecast in 2023 (Table 4).

The growing trend of modernizing older buildings and constructing new houses with better insulation and heating systems has also led to an increase in electricity consumption in households. While these improvements can help reduce energy consumption for heating, they can also lead to an increase in the use of electrical appliances and devices, such as electric heating systems, which can increase electricity consumption [157]. The use of electric cars has also slightly increased in Poland, but this effect is not enough to have an impact on the energy demand in the whole society [158]. As more people switch to electric cars, their electricity consumption at home for charging these vehicles increases [159].

In the analysis it was observed that the heat consumption is stable in Poland, but in last years the trend was slightly decreasing. The first reason can be connected to the COVID-19 pandemic. The COVID-19 pandemic, which emerged globally in early 2020, has had profound effects on various aspects of daily life, including energy consumption patterns. Lockdowns, travel restrictions, and remote work arrangements led to changes in energy demand and usage. During the pandemic, many people started working from home, resulting in reduced energy consumption in commercial buildings and offices. This shift from commercial to residential energy consumption could have contributed to the observed decrease in overall household energy consumption. Additionally, economic uncertainties and reduced income during the pandemic might have led to more cautious energy consumption behavior among households. The second reason can be connected with warmer winters which are observed in last years. Climate variability, including warmer winters, can influence energy consumption patterns for heating purposes. Warmer weather during winter months can lead to decreased demand for heating, as households require less energy to maintain comfortable indoor temperatures. Consequently, a milder winter climate in recent years could have contributed to lower energy consumption for heating purposes, thereby influencing the observed trend.

Poland's low electricity costs encourage household consumption due to its affordability compared to other European countries [160,161].

Significant fluctuations in hard coal and natural gas usage were observed from 2019 to 2021 due to government policies and the rise of renewable sources [162]. Incentives for converting coal to gas and increased renewable availability led to these shifts [163,164]. Notably, the COVID-19 pandemic affected household energy use, reducing coal consumption due to economic slowdown [165] while increasing natural gas usage as people stayed home [166]. However, after the pandemic period, energy prices rose sharply (energy crisis), which also provided an incentive for small consumers to save electricity consumption. However, after the pandemic period, energy prices rose sharply (European energy crisis), which also provided an incentive for small consumers to save electricity consumption. Coal prices rose nearly 2.5 times in 2021 (Acorn Macro Consulting) [167]. In Poland, more than 3-million people use coal to heat their homes [168]. In the Polish government's plans, as well as the social agreements already concluded, the process of closing mines (despite access to coal seams in Poland) is being implemented, and a deadline of 2049 has been set for the end of coal mining from mines in Poland (Social Agreement, GOV. PL, 28 May 2021, Katowice) [169].

The study's implications highlight a declining trend in hard coal use, aligning with the EU's move away from fossil fuels. Electricity consumption increased (about 3%), in line with the EU's electrification and renewable strategy. This signals an opportunity for expanding renewable energy generation. Natural gas fluctuations followed by an upward trend underscore the need for sustainable sourcing and utilization, focusing on energy efficiency and innovative technologies. Based on realized forecasts, in 2027, natural gas consumption will increase by almost 57%, compared to 2023. Furthermore, the study underscores building efficiency improvements through insulation, ventilation, and energy management systems to reduce emissions and integrate renewables by curbing overall energy demand. Of the 6.9 million residential buildings, 6.3 million were single-family houses in Poland. The annual energy demand for heating and hot water for each building is-depending on the materials used to construct the building-from about 53,000 to about 60,000 kWh. Comprehensive thermal modernization of such a house using mineral wool, including insulation of the exterior walls, roof, replacement of exterior carpentry and insulation of the ceiling above the basement, can reduce energy demand from about 68 to about 73% [168].

Poland's potential nuclear power plant suggests diversification of energy sources, with challenges like project duration, financing, location, and supply chain management [168]. The study highlights hard coal consumption's 16-year decrease, a positive move toward decarbonization due to its emissions and pollution. Rising electricity and natural gas use is attributed to technology, lifestyle, and modernization [170–172]. Policymakers must balance these shifts to ensure a smooth transition to sustainability, keeping in mind low costs and health benefits [173].

The study underscores decarbonization's importance in households, as their activities contribute to carbon emissions. Strategies promoting renewables, energy efficiency, and low-carbon tech can notably reduce emissions. Rising electricity use aligns with EU electrification goals, encouraging renewables like solar and wind [174,175]. However, natural gas consumption requires careful management due to its lower emissions but still significant impact [176]. When we assess Poland's reduction in hard coal consumption in relation to the European Union's decarbonization policy, we find a noteworthy alignment with the EU's overarching objective of gradually eliminating high-carbon fuels [177]. This synchronicity is particularly significant considering the EU's ambitious aim to achieve climate neutrality by 2050 [178]. Furthermore, Poland's rising electricity generation trends are in line with the European Union's targets for expanding renewable energy sources [179]. This demonstrates Poland's commitment to adopting cleaner and more sustainable energy practices that contribute to the EU's broader environmental goals [180]. However, it is worth noting that Poland's increasing reliance on natural gas presents certain challenges. This shift raises concerns, as the European Union has placed a strong emphasis on energy efficiency and the promotion of renewable gases [181] as part of its strategy to combat climate change. Consequently, Poland's energy choices may warrant further consideration and adjustment to better align with the EU's sustainability objectives [182].

The problems connected with energy consumption by small consumers and households were analyzed on the European Union level by Matuszewska-Janica et al. [183]. The results obtained by the authors clearly demonstrate significant differentiation among EU countries in terms of households. This confirmed the assumption of considerable divergence among EU countries concerning the characteristics related to households. Authors have found that climate have an impact on the energy consumption in particular countries. On the basis of this observation, they thought that distinct energy policies should be pursued by the particular countries. Our analysis is in accordance with this assumption and on the basis of the analysis of the Polish households. As such, we prepared policies and forecast results specify for the Polish conditions.

While the paper emphasizes Poland's transition away from hard coal, it also suggests that Poland's shift towards renewable energy sources is less pronounced than in certain other European countries. For example, Shoeib et al. [184] found that countries like Sweden have achieved a significant indirect share of renewable energy in total consumption, signifying a substantial commitment to renewables. The paper alludes to the impact of energy policies on consumption patterns. Poland's historical reliance on coal for energy production, as indicated by the 70% coal-based energy production, might distinguish it from countries that have invested earlier and more extensively in renewable energy sources. This is visible when we compare Poland and Germany. Jałowiec et al. [185], on the basis of the analysis of the Polish and German policies towards decarbonization and energy usage, think that Germany is poised to emerge as the dominant player in the era of energy transition. A similar assumption can be found in the analysis prepared by Chudy-Laskowska and Pisula [186].

6. Conclusions

6.1. Summary of the Research

The study aimed to analyze the consumption trends of hard coal, electricity, and natural gas in Polish households from 2006 to 2021. The analysis revealed that over this 16-year period, there has been an upward trend in the consumption of electricity and natural gas, while the consumption of hard coal has been on a decline. Notably, the highest increase in natural gas consumption was observed in 2021, with an increase of nearly 40% compared to 2006. Additionally, the analysis revealed significant fluctuations in the consumption of hard coal and natural gas from 2009 to 2018, with a decrease in the consumption of hard coal and a slight increase in the consumption of natural gas in 2019. The findings provide valuable insights into the dynamics of energy consumption in households.

The study also used a developmental trend model to estimate the functions and three different functions were used to estimate the trend function. The average rate of change in the level of the phenomenon over time was also calculated using the geometric mean of the chain index value. The results showed that coal consumption in households had a clear downward trend, while electricity consumption showed a clear increasing trend with minor fluctuations. Natural gas consumption displayed significant fluctuations until 2015, after which there was a clear upward trend. The study provides trend functions and average rates of change for each energy carrier to aid policymakers in making informed decisions regarding energy policies in Poland.

The paper discusses the trends and patterns of energy consumption in households and forecasts the future consumption of selected energy carriers, including hard coal, electricity, and natural gas. The authors used trend models to estimate the analytical form of the trend function and project future consumption. The findings suggest that there will be a continued decrease in the consumption of hard coal, while the utilization of electricity and natural gas is expected to increase. The study highlights the significant shifts in energy consumption patterns over the years and identifies various factors contributing to the changes, including technological advancements and environmental concerns. The insights from this study can be valuable for policymakers and stakeholders in the energy sector to design effective policies and strategies for sustainable energy use. However, the authors acknowledge that the forecasts are subject to errors and should not be regarded as a definitive basis for decision making.

The reduction in hard coal usage in households aligns with the EU's efforts to phase out fossil fuels, while the increase in electricity consumption is consistent with the EU's strategy of electrifying the economy and shifting towards renewable energy sources. Moreover, the increase in natural gas consumption by households is in line with the EU's efforts to transition to a low-carbon economy while ensuring energy security and affordability. These trends reflect a shift towards cleaner and more efficient sources of energy, contributing to the overall goal of reducing greenhouse gas emissions and transitioning to a low-carbon economy. However, further efforts are needed to accelerate this transition and achieve the Polish ambitious climate targets, including increasing the share of renewable energy and improving energy efficiency. The phenomena of decreasing hard coal usage and increasing natural gas usage are also present in EU households, but the change in Poland is more significant. The shift from hard coal to natural gas has been driven by changes in household income and demographics, the availability and affordability of natural gas, and environmental concerns.

In 2017, emissions related to buildings—mainly their heating and air-conditioning processes—accounted for 11% of Poland's emissions (46 $MtCO_2$ e). 84% came from the residential sector and 16% from the commercial sector. Emission reduction activities in this area can be divided into two categories. First, the energy efficiency of the building envelope can be increased with better insulation, which reduces energy consumption for both heating and cooling buildings. Improving a building's insulation is one of the most effective ways to increase energy efficiency. This reduces the amount of heat that escapes to the outside, thus reducing the energy required to heat the building [167].

To reduce the carbon footprint of households on the path towards decarbonization it is also possible to implement ventilation systems with heat recovery allowing heat to be recuperated from exhaust air and transferred to supply air. This reduces the energy required to heat the air. Moreover, replacing old furnaces with modern condensing boilers or heat pumps allows more efficient use of energy, resulting in lower heating costs.

An important method of reducing households' energy consumption is also the installation of intelligent energy management systems-smart systems allow precise management of a building's energy consumption. They can be used to control temperature, lighting, as well as household appliances, allowing efficient use of energy.

Secondly, the use of high-carbon energy sources can be reduced by replacing coal-, gas- or oil-fired boilers and stoves with appliances powered by low-carbon alternative energy sources. Leverage for household climate neutrality is renewable energy sources, obtained from two sources: (1) devices installed in homes that generate energy and heat for their own needs, or (2) external sources. Increasingly installed photovoltaic installations in Poland allow the production of electricity from solar radiation. This reduces the amount of electricity drawn from the grid.

The future of energy in Poland is also a nuclear power plant (planning stage, the plant will be built in Pomerania, and will be put into operation at the end of this decade). Poland does not presently have a nuclear power plant, and its energy production to date has been 70% from coal [140]. It must be taken into account, however, that investments in nuclear power usually give rise to serious challenges regarding the duration of projects and the means to finance them, location, preparatory work, and securing contracts with suppliers.

The results of the study underscore the importance of renewable and sustainable energy usage in the context of decreasing hard coal consumption, increasing electricity demand, and evolving patterns of natural gas usage in households. They provide valuable insights for policymakers and stakeholders to formulate strategies and initiatives that promote the adoption of renewable energy sources, improve energy efficiency, and ultimately contribute to the decarbonization and sustainability goals of the country.

6.2. Future Research

In future research and analyses, the authors plan to obtain primary data regarding the factors determining the consumption of energy carriers in households, including their awareness of environmentally friendly behaviors and planet conservation. Future analyses could be based on a predictive model that considers internal factors (within households, such as environmental awareness, financial and technical resources) and external factors (in the surrounding environment, such as air temperature, political and legal conditions). Future analyses could be expanded (provided that the data is available) to include additional dimensions: spatial (provinces, regions) and subjective (other countries). It would be interesting to compare energy consumption in Poland with other European Union countries, particularly those in Central and Eastern Europe.

Author Contributions: Conceptualization, B.G., M.J., R.W. (Robert Wolny) and R.W. (Radosław Wolniak); methodology, B.G., M.J. and R.W. (Robert Wolny); software, B.G., M.J, R.W. (Robert Wolny) and R.W. (Radosław Wolniak); validation, B.G., M.J. and R.W (Robert Wolny).; formal analysis, B.G., M.J., R.W. (Robert Wolny) and R.W. (Radosław Wolniak); investigation B.G., R.W. (Robert Wolny) and M.J.; resources, B.G., M.J., R.W. (Radosław Wolniak), R.W. (Robert Wolny) and W.W.G.; data curation, B.G., M.J. and R.W. (Robert Wolny); writing—original draft preparation, B.G., M.J., R.W. (Radosław Wolniak) and R.W. (Robert Wolny); writing—review and editing, B.G., R.W. (Radosław Wolniak) and M.J.; visualization, B.G., M.J., R.W. (Radosław Wolniak) and R.W. (Robert Wolny); supervision, B.G., M.J., R.W. (Robert Wolny) and W.W.G.; funding acquisition, B.G., M.J., R.W. (Robert Wolny) and R.W. (Radosław Wolniak). All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Silesian University of Technology: 13/010/RGJ23/0074, 11/040/BK_223/0029, 11/040/RGJ23/0032, 11/040/BK_223/0029 and 13/990/KPW21/0166.

Data Availability Statement: The data presented in this study are available on request.

Conflicts of Interest: The authors declare no conflict of interest.

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