Energy and Heat Consumption Trends and Forecasting

Subjects: Industrial Relations & Labor

Contributor: Bożena Gajdzik , Magdalena Jaciow , Radosław Wolniak , Robert Wolny , Wieslaw Wes Grebski

The research 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.

energy and fuel careers | energy and heating consumption | small consumer sector

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 energy consumption and transition to cleaner and more sustainable sources of energy [3]. This involves both increasing the efficiency of 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].

2. 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.

3. 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].

4. 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][21][22][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].

5. 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].

6. 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].

References

1. European Green Deal. Komunikat Komisji do Parlamentu Europejskiego, Rady Europejskiej, Rady, Komitetu Ekonomiczno-Społecznego i Komitetu Regionów, Bruksela 11 December 2019, COM(2019)640 Final. Available online: https://eur-lex.europa.eu/legal-content/pl/TXT/?uri=CELEX%3A52019DC0640 (accessed on 15 June 2021).
2. Clean Energy for All Europeans—Unlocking Europe's Growth Potential. IP_16_4009. European Commission, Brussel, 2016. Available online: https://europa.eu/rapid/press-release_IP-16-4009_en.htm (accessed on 15 April 2023).
3. European Comisssion. Komunikat Prasowy; Czysta Energia dla Wszystkich Europejczyków, Czyli Jak Wyzwolić; European Comisssion: Brussels, Belgium, 2016.
4. Potencjał Wzrostu Europy, Bruksela 30 November 2016. Available online: https://ec.europa.eu/commission/presscorner/detail/pl/ (accessed on 15 March 2023).
5. Porozumienie Paryskie do Ramowej Konwencji Narodów Zjednoczonych w Sprawie Zmian Klimatu, Sporządzonej w Nowym Jorku Dnia 9 Maja 1992 r., Przyjęte w Paryżu Dnia 12 Grudnia 2015 r., Dz.U. 2017, poz. 36. Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20170000036, (accessed on 15 April 2023).
6. OECD. Greening Household Behaviour. The Role of Public Policy. 2011. p. 22. Available online: http://www.oecdilibrary.org/environment/greening-household-behaviour_9789264096875-en (accessed on 10 March 2023).
7. Consumer Laws in Poland. Available online: https://www.ure.gov.pl/pl/konsumenci/zbior-praw-konsumenta (accessed on 13 March 2023).
8. Eurostat. Energy Consumption in Households. Eurostat 2020. Available online: https://ec.europa.eu/eurostat/statistics-explained/%20index.php (accessed on 10 March 2023).
9. Fredriksson, G.; Zachmann, G. The Distributional Effects of Climate Policies. In The European Energy Transition; Nies, S., Ed.; Agenda for the Twenties; Claeys & Casteels Publishers BV: Deventer, The Netherlands, 2020; p. 88.
10. Adams, A.; Jumpah, E.T.; Dramani, H.S. Dynamics of Clean and Sustainable Households' Energy Technologies in Developing Countries: The Case of Improved Cookstoves in Ghana. Sustain. Futures 2023, 5, 100108.
11. Piao, X.; Managi, S. Household energy-saving behavior, its consumption, and life satisfaction in 37 countries. Sci. Rep. 2023, 13, 1382.
12. Wilson, L. Average Household Electricity Consumption—2023. Available online: https://shrinkthatfootprint.com/average-household-electricity-consumption/ (accessed on 11 August 2023).
13. Best, R. Equitable reverse auctions supporting household energy investments. Energy Policy 2023, 177, 113548.
14. Brewer, D. Household responses to winter heating costs: Implications for energy pricing policies and demand-side alternatives. Energy Policy 2023, 177, 113550.
15. Kumar, P.; Caggiano, H.; Shwom, R.; Felder, F.A.; Andrews, C.J. Saving from home! How income, efficiency, and curtailment behaviors shape energy consumption dynamics in US households? Energy 2023, 271, 126988.

16. Su, S.; Ding, Y.; Li, G.; Skitmore, M.; Menadue, V. Temporal dynamic assessment of household energy consumption and carbon emissions in China: From the perspective of occupants. Sustain. Prod. Consum. 2023, 37, 142–155.
17. Tete, K.H.S.; Soro, Y.M.; Sidibé, S.S.; Jones, R.V. Urban domestic electricity consumption in relation to households' lifestyles and energy behaviours in Burkina Faso: Findings from a large-scale, city-wide household survey. Energy Build. 2023, 285, 112914.
18. Energy Prosumers in Europe Citizen Participation in the Energy Transition. EEA Report. No 01, 2022. Available online: https://www.eea.europa.eu/publications/the-role-of-prosumers-ofTH_AL_22_007_EN_N_EnergyProsumersinEurope.pdf (accessed on 20 January 2023).
19. Campos, I.; Marín-González, E. People in transitions: Energy citizenship, prosumerism and social movements in Europe. Energy Res. Soc. Sci. 2020, 69, 101718.
20. Oberst, C.A.; Schmitz, H.; Madlener, R. Are Prosumer Households That Much Different? Evidence from Stated Residential Energy Consumption in Germany; FCN Working Paper No. 24/2016 December 2016, revised March 2018; FCN: Berlin, Germany, 2016; Available online: https://www.researchgate.net/profile/Hendrik-Schmitz-2/publication/324030375_Are_Prosumer_Households_That_Much_Different_Evidence_from_Stated_Residential_Energy_Consumption_in_Germany/links/5aba04e445851515Prosumer-Households-That-Much-Different-Evidence-from-Stated-Residential-Energy-Consumption-in-Germany.pdf (accessed on 30 March 2023).
21. Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012; pp. 34–35. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02012L0027-20200101&from=NL, (accessed on 15 August 2023).
22. 7 Komunikat Komisji do Parlamentu Europejskiego, Rady Europejskiego Komitetu Ekonomiczno-Społecznego i Komitetu Regionów, Stworzenie Nowego Ładu Dla Odbiorców Energii , COM(2015)339 Final, Bruksela. 2015. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:52015DC0339&from=EN (accessed on 26 May 2021).
23. Lilliu, F.; Loi, A.; Recupero, D.-R.; Sisinni, M.; Vinyals, M. An uncertainty-aware optimization approach for flexible loads of smart grid prosumers: A use case on the Cardiff energy grid. Sustain. Energy Grids Netw. 2019, 20, 100272.
24. Egert, R.; Daubert, J.; Marsh, S.; Mühlhäuser, M. Exploring energy grid resilience: The impact of data, prosumer awareness, and action. Perspective 2021, 2, 100258.
25. Goulden, M.; Bedwell, B.; Rennick-Egglestone, S.; Rodden, T.; Spence, A. Smart grids, smart users? the role of the user in demand side management. Energy Res. Soc. Sci. 2014, 2, 21–29.
26. Building Finland's Largest Industrial Microgrid. News Press. Schneider Electric. Available online: https://www.schneider-electric.com/en/about-us/press/news/corporate-2018/building-finlandlargest-industrial-microgrid.jsp (accessed on 20 March 2023).
27. Zhao, Z.; Luo, F.; Zhang, C.; Ranzi, G. A social relationship preference aware peer-to-peer energy market for urban energy prosumers and consumers. IET Renew. Power Gener. 2022, 16, 688–699.
28. Cseres, K. The Active Energy Consumer in EU Law. Euro. J. Risk Regul. 2018, 9, 227–244.
29. Milčiuvienė, S.; Kiršienė, J.; Doheijo, E.; Urbonas, R.; Milčius, D. The Role of Renewable Energy Prosumers in Implementing Energy Justice Theory. Sustainability 2019, 11, 5286.
30. Słupik, S. Conscious energy consumer in the silesian voivodeship in the field of survey. Stud. Ekonomiczne. Zesz. Nauk. Uniw. Ekon. Katowicach 2015, 232, 215–224.
31. Gajdzik, B.; Jaciow, M.; Wolniak, R.; Wolny, R.; Grebski, W.W. Energy Behaviors of Prosumers in Example of Polish Households. Energies 2023, 16, 3186.
32. Lang, B.; Botha, E.; Robertson, J.; Dolan, R.; Kietzmann, J. How to grow the sharing economy? Create Prosumers! Australas. Mark. J. 2020, 28, 56–58.
33. Farhangi, H. The path of the smart grid. IEEE Power Energ. Mag. 2009, 8, 18–28.

34. Hargreaves, T.; Nye, M.; Burgess, J. Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. Energy Policy 2013, 52, 126–134.
35. Koskela, T.; Väänanen-Vainio-Mattila, K. Evolution towards smart home environments: Empirical evaluation of three user interfaces. Pers. Ubiquitous Comput. 2004, 8, 234–240.
36. Hoenkamp, R.; Huitema, G. Good standards for smart meters. In Proceedings of the 2012 9th International Conference on the European Energy Market, Florence, Italy, 10–12 May 2012; pp. 1–6.
37. Urbano, E.M.; Martinez-Viol, V.; Kampouropoulos, K.; Romeral, L. Future european energy markets and industry 4.0 potential in energy transition towards decarbonization. Renew. Energy Power Qual. J. 2020, 18, 190–195.
38. Arana-Landín, G.; Uriarte-Gallastegi, N.; Landeta-Manzano, B.; Laskurain-Iturbe, I. The Contribution of Lean Management—Industry 4.0 Technologies to Improving Energy Efficiency. Energies 2023, 16, 2124.
39. Salonitis, K. Manufacturing Energy Efficiency and Industry 4.0. Energies 2023, 16, 2268.
40. Bhagwan, N.; Evans, M. A review of industry 4.0 technologies used in the production of energy in China, Germany, and South Africa. Renew. Sustain. Energy Rev. 2023, 173, 113075.
41. Gupta, P.; Tomar, A. Industry 4.0 Based Efficient Energy Management in Microgrid. J. Sci. Ind. Res. 2023, 82, 287–296.
42. Patra, B.; Nema, P.; Khan, M.Z.; Khan, O. Optimization of solar energy using MPPT techniques and industry 4.0 modelling. Sustain. Oper. Comput. 2023, 4, 22–28.
43. Matsunaga, F.; Zytkowski, V.; Valle, P.; Deschamps, F. Optimization of Energy Efficiency in Smart Manufacturing Through the Application of Cyber-Physical Systems and Industry 4.0 Technologies. J. Energy Resour. Technol. Trans. ASME 2022, 144, 102104.
44. Bernat, T.; Flaszewska, S.; Lisowski, B.; Lisowska, R.; Szymańska, K. Facing Environmental Goals for Energy-Efficiency Improvements in Micro and Small Enterprises Operating in the Age of Industry 4.0. Energies 2022, 15, 6577.
45. Wolniak, R.; Saniuk, S.; Grabowska, S.; Gajdzik, B. Identification of energy efficiency trends in the context of the development of Industry 4.0 using the Polish steel sector as an example. Energies 2020, 13, 2867.
46. Grzybowska, K.; Gajdzik, B. Optimization of equipment setup processes in enterprises. Metalurgija 2012, 51, 555–558.
47. Gajdzik, B. Comprehensive classification of environmental aspects in a manufacturing enterprise. Metalurgija 2012, 51, 541–544.
48. Gajdzik, B.; Wolniak, R.; Grebski, W.W. Electricity and heat demand in steel industry technological processes in Industry 4.0 conditions. Energies 2023, 16, 787.
49. Gajdzik, B.; Wolniak, R.; Grebski, W.W. An Econometric Model of the Operation of the Steel Industry in Poland in the Context of Process Heat and Energy Consumption. Energies 2022, 15, 7909.
50. Gajdzik, B.; Wolniak, R. Digitalisation and innovation in the steel industry in Poland—Selected tools of ICT in an analysis of statistical data and a case study. Energies 2021, 14, 3034.
51. Gajdzik, B.; Sroka, W.; Vveinhardt, J. Energy Intensity of Steel Manufactured Utilising EAF Technology as a Function of Investments Made: The Case of the Steel Industry in Poland. Energies 2021, 14, 5152.
52. Gajdzik, B.; Sroka, W. Resource Intensity vs. Investment in Production Installations—The Case of the Steel Industry in Poland. Energies 2021, 14, 443.
53. Gajdzik, B.; Wolniak, R.; Grebski, W.W. Process of transformation to net zero steelmaking: Decarbonisation scenarios based on the analysis of the Polish steel industry. Energies 2023, 16, 3384.
54. Zheng, S.; Huang, G.; Lai, A.C.K. Coordinated energy management for commercial prosumers integrated with distributed stationary storages and EV fleets. Energy Build. 2023, 282, 112773.
55. Liu, D.; Qi, S.; Xu, T. In the post-subsidy era: How to encourage mere consumers to become prosumers when subsidy reduced? Energy Policy 2023, 174, 113451.

56. Postnikov, I. Methods for the reliability optimization of district-distributed heating systems with prosumers. Energy Rep. 2023, 9, 584–593.
57. Wang, X.; Wang, Z.; Mu, Y.; Deng, Y.; Jia, H. Rolling horizon optimization for real-time operation of prosumers with Peer-to-Peer energy trading. Energy Rep. 2023, 9, 321–328.
58. Manna, C.; Sanjab, A. A decentralized stochastic bidding strategy for aggregators of prosumers in electricity reserve markets. J. Clean. Prod. 2023, 389, 135962.
59. Gajdzik, B.; Grabowska, S.; Saniuk, S.; Wieczorek, T. Sustainable Development and Industry 4.0: A Bibliometric Analysis Identifying Key Scientific Problems of the Sustainable Industry 4.0. Energies 2020, 13, 4254.
60. Grabowska, S.; Saniuk, S.; Gajdzik, B. Industry 5.0: Improving humanization and sustainability of Industry 4.0. Scientometrics 2022, 127, 3117–3131.
61. Carayannis, E.G.; Dezi, L.; Gregori, G.; Calò, E. Smart Environments and Techno-centric and Human-Centric Innovations for Industry and Society 5.0: A Quintuple Helix Innovation System View Towards Smart, Sustainable, and Inclusive Solutions. J. Knowl. Econ. 2022, 13, 926–955.
62. Chen, Y.; Tanaka, M.; Takashima, R. Death spiral, transmission charges, and prosumers in the electricity market. Appl. Energy 2023, 332, 120488.
63. Lopez, H.K.; Zilouchian, A. Peer-to-peer energy trading for photo-voltaic prosumers. Energy 2023, 263, 125563.
64. Liu, Y.; Zhang, Y.; Cheng, G.; Zhu, J.; Che, Y. Grid-friendly energy prosumers based on the energy router with load switching functionality. Int. J. Electr. Power Energy Syst. 2023, 144, 108496.
65. Peng, D.; Xiao, H.; Pei, W.; Sun, H.; Ye, S. A novel deep learning based peer-to-peer transaction method for prosumers under two-stage market environment. IET Smart Grid 2022, 5, 430–439.
66. Wang, J.; An, Q.; Zhao, Y.; Hu, Q.; Tan, C.-W. Role of electrolytic hydrogen in smart city decarbonization in China. Appl. Energy 2023, 336, 120699.
67. Feng, Y.; Liao, H.-T.; Bu, M. Responsible Decarbonization for Smart Cities: A People-Centered Agenda. In Proceedings of the 2022 IEEE European Technology and Engineering Management Summit, E-TEMS 2022, Bilbao, Spain, 9–11 March 2022; pp. 202–207.
68. Kinelski, G. Smart-city trends in the environment of sustainability as support for decarbonization processes. Polityka Energetyczna 2022, 25, 109–136.
69. Nagano, N.; Furubayashi, T.; Nakata, T. Quantitative analysis of energy supply and demand structure for regional decarbonization: A case study on Miyako city, Iwate prefecture and the Miyako smart community project. Stud. Reg. Sci. 2020, 50, 227–241.
70. Kobashi, T.; Yamagata, Y.; Yoshida, T.; Ahl, A.; Aleksejeva, J. Smart city and ICT infrastructure with vehicle to X applications toward urban decarbonization. In Urban Systems Design Creating Sustainable Smart Cities in the Internet of Things Era; Elsevier: Amsterdam, The Netherlands, 2020; pp. 289–333.
71. Volpato, G.; Carraro, G.; Cont, M.; Rech, S.; Lazzaretto, A. General guidelines for the optimal economic aggregation of prosumers in energy communities. Energy 2022, 258, 124800.
72. Ren, Z.; Verbič, G.; Guerrero, J. Multi-period dynamic tariffs for prosumers participating in virtual power plants. Electr. Power Syst. Res. 2022, 212, 108478.
73. Li, R.; Yan, X.; Liu, N. Hybrid energy sharing considering network cost for prosumers in integrated energy systems. Appl. Energy 2022, 323, 119627.
74. Zomorodi Moghadam, A.; Javidi, M.H. Designing a two-stage transactive energy system for future distribution networks in the presence of prosumers' P2P transactions. Electr. Power Syst. Res. 2022, 211, 108202.
75. Lomascolo-Pujadó, A.; Martínez-García, H. Contribution to Collaborative Electricity Microgrid Management Strategies of Domestic Prosumers. Renew. Energy Power Qual. J. 2022, 20, 635–640.

76. Tostado-Véliz, M.; Rezaee Jordehi, A.; Icaza, D.; Mansouri, S.A.; Jurado, F. Optimal participation of prosumers in energy communities through a novel stochastic-robust day-ahead scheduling model. Int. J. Electr. Power Energy Syst. 2023, 147, 108854.
77. Chen, X.; Wei, T.; Hu, S. Uncertainty-aware household appliance scheduling considering dynamic electricity pricing in smart home. IEEE Trans. Smart Grid 2013, 4, 932–941.
78. Final Report: Demand Side Flexibility Perceived Barriers and Proposed Recommendations European Smart Grids Task Force. 2019. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/eg3_final_report_demand_sside_flexiblity_2019.04.15.pdf (accessed on 26 May 2021).
79. TSO—DSO Report an Integrated Approach to Active System Management with the Focus on TSO-DSO Coordination in Congestion Management and Balancing. 2019. Available online: https://cdn.eurelectric.org/media/3797/tso-dso_report_-_an_integrated_approach_to_active_system_management-2019-030-0255-01-e-h-B31641F6.pdf (accessed on 20 March 2023).
80. Koirala, B.P.; Araghi, Y.; Kroesen, M.; Ghorbani, A.; Hakvoort, R.A.; Herder, P.M. Trust, awareness, and independence: Insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems. Energy Res. Soc. Sci. 2018, 38, 33–40.
81. Staniszewska, Z. Kto Dyktuje Ceny Prądu? Konsument Jako Główny Uczestnik Rynku Energii Elektrycznej w Pakiecie „Czysta Energia Dla Wszystkich Europejczyków". In Szanse i Zagrożenia Dla Uczestników Rynku Energii; Materna, G., Król, J., Eds.; INP PAN: Warsaw, Poland, 2021; pp. 93–110. Available online: https://ebp.inp.pan.pl/xmlui/bitstream/handle/123456789/729/materna_krol_szanse_i_zagrozenia_dla_uczestnikow_rynku_energii.sequence=3&isAllowed=y (accessed on 24 March 2023).
82. Electricity Production, Consumption and Market Overview. Eurostat 2020. Report. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_production,_consumption_and_market_overview#Household_electricity_consumption (accessed on 23 October 2020).
83. European Green Deal. The EU Renewable Energy Target Declared by the European Parliament in 2018 for 2030 is 32% (Article 3 of the RED II Directive); Commissioner Ursula Von Der Leyen's proposal is to increase it to at least 50%, Communication from the European Commission of December 11, 2019 European Green Deal. Available online: https://eur-lex.europa.eu/PL/legal-content/summary/renewable-energy.html, (accessed on 19 June 2023).
84. Eurostat. Electricity Price Statistics. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics#Electricity_prices_for_household_consumers (accessed on 23 October 2020).
85. Tomaszewski, R.; Sieć do Zmiany. Jak Zreformować Polski Sektor Dystrybucji Energii Elektrycznej, Polityka Insight, Research, Fundacja Przyjazny Kraj, Warszawa. 2019. Available online: https://www.politykainsight.pl/prawo/_resource/multimedium/20182100 (accessed on 26 May 2021).
86. Li, J.; Ge, S.; Xu, Z.; Wang, C.; Cheng, X. A network-secure peer-to-peer trading framework for electricity-carbon integrated market among local prosumers. Appl. Energy 2023, 335, 120420.
87. Gržanić, M.; Capuder, T.; Zhang, N.; Huang, W. Prosumers as active market participants: A systematic review of evolution of opportunities, models and challenges. Renew. Sustain. Energy Rev. 2022, 154, 111859.
88. Chaudhry, S.; Surmann, A.; Kühnbach, M.; Pierie, F. Renewable Energy Communities as Modes of Collective Prosumership: A Multi-Disciplinary Assessment Part II—Case Study. Energies 2022, 15, 8936.
89. Borowski, P.F. Digital Transformation and Prosumers Activities in the Energy Sector. Lect. Notes Netw. Syst. 2023, 549, 129–150.
90. Muqeet HAMunir, H.M.; Javed, H.; Muhammad, S.; Jamil, M.; Guerrero, J.M. An Energy Management System of Campus Microgrids: State-of-the-Art and Future Challenges. Energies 2021, 14, 6525.

91. Sdrignola, P.; Ricci, M.; Ancona, M.A.; Gianaroli, F.; Capodaglio, C.; Melino, F. Modelling a Prototype of Bidirectional Substation for District Heating with Thermal Prosumers. Sustainability 2023, 15, 4938.
92. Almarzooqui, A.H.; Osman, A.H.; Shabaan Nassar, M. An Exploratory Study of the Perception of Peer-to-Peer Energy Trading within the Power Distribution Network in the UAE. Sustainability 2023, 15, 4891.
93. Tenti, P.; Caldognetto, T. Integration of Local and Central Control Empowers Cooperation among Prosumers and Distributors towards Safe, Efficient, and Cost-Effective Operation of Microgrids. Energies 2023, 16, 2320.
94. Cheng, M. Sharing economy: A review and agenda for future research. Int. J. Hospitality Manag. 2016, 57, 60–70.
95. Bessa, R.J.; Rua, D.; Abreu, C.; Gonçalves, C.; Reis, M. Data economy for prosumers in a smart grid ecosystem. In Proceedings of the e-Energy'18: The Ninth International Conference on Future Energy Systems, Karlsruhe, Germany, 12–15 June 2018; pp. 622–630.
96. Steinhoff, J. Transformacja polskiej energetyki jako konsekwencja European Green Deal. In Ekonomiczne Skutki Pandemii; based on PSE; Błach, J., Barszczowska, B., Eds.; Akademia WSB: Dabrowa Górnicza, Poland, 2021; pp. 251–256. Available online: https://www.rynekelektryczny.pl/produkcja-energii-elektrycznej-w-polsce/ (accessed on 10 October 2020).
97. Gawlik, L. (Ed.) Węgiel Dla Polskiej Energetyki w Perspektywie 2050 Roku–Analizy Scenariuszowe; GIPH: Katowice, Poland, 2013.
98. Szpor, A.; Ziółkowska, K. The Transformation of the Polish Coal Sector; GSI Report; International Institute for Sustainable Development: Winnipeg, MB, Canada, 2018.
99. Gawlik, L.; Mokrzycki, E. Dylematy Krajowej Energetyki: Energia Konwencjonalna Czy Odnawialna? In Szanse i Zagrożenia dla Uczestników Rynku Energii; ILS PAS Publishing House: Warsaw, Poland, 2021; pp. 55–74.