Appendix No. 4b

Self-Report

Attachment to the application for habilitation in the field of social sciences / management and quality science (in English)

PhD Mariusz Niekurzak

Krakow, May 2023

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1. Name and surname

Mariusz Niekurzak

2. Diplomas, academic degrees:

- 2012 - PhD diploma in technical sciences in the discipline of production engineering, awarded by the resolution of the Council of the Faculty of Management of the AGH University of Science and Technology in Krakow of February 23, 2012.

  Title of the doctoral dissertation: "*Application of simulation methods to shorten the rolling cycle of steel strips using the roll wear model*"

  Supervisor: PhD Wiktor Kubiński, professor AGH University of Science and Technology
- II. 2012 - certificate of completion of 4-year full-time doctoral studies in the field of technical sciences - materials engineering at the Faculty of Metal Engineering and Industrial Computer Science of the AGH University of Science and Technology in Krakow.
- VI. 2008 - Master's degree, obtained in the field of Management and Production Engineering in the field of logistics management at the Faculty of Management of the AGH University of Science and Technology in Krakow.
- V. 2003 - mechanical technician diploma, Mechanical Technical School in Staszów.

3. Information on previous employment in scientific units:

- 1.03.2012 - currently - assistant professor at the Department of Business Informatics and Management Engineering at the Faculty of Management of the AGH University of Science and Technology in Krakow.
- 1.10.2010 - 28.02.2012 – assistant at the Department of Operations Research at the Faculty of Management of the AGH University of Science and Technology in Krakow.

4. Discussion of the achievements referred to in Art. 219 section 1 point 2 of the Act:

4.1. Title of scientific achievement

Four scientific achievements were submitted for the habilitation procedure. These achievements were appropriately divided thematically as part of the scientific effects obtained in individual research areas. The list of achieved achievements is presented in a single-thematic series of 12 publications under the collective title:

"Strategy for managing the energy transformation of local sectors of the economy"

Four key scientific achievements in the field of management and quality science as part of research on the energy transformation:

I. The use of tools in the field of management and quality science in professional and prosumer power engineering.

Achievement 1: development of a proprietary decision-making model for energy management as part of short-term forecasts.

- **Commercial power engineering:**

[H1] Niekurzak M. (2022). Forecasting wind capacity using gauss regression models based on nuclear functions. *Energy Market*, no. 4, pp. 61-71.

CiteScore = 1,1 (2022); MEiN: 70
ISSN 1425-5960

[H2] Niekurzak M. (2023). The use of quantitative methods as measures for forecast electricity demand on the local market in a short time horizon. *Electrotechnical Review*, T. 99, no.3, pp. 86-93.

IF = 0.244 (2011); MEiN: 70
DOI:10.15199/48.2023.03.13

- **Prosumer energy:**

[H3] Niekurzak M. (2021). The potential of using renewable energy sources in Poland taking into account the economic and ecological conditions. *Energies*, 14, 7525.

IF: 3.252 (2021); MEiN: 140
DOI: 10.3390/en14227525

[H4] Niekurzak M., Lewicki W., Brelik A. (2022). The challenges for social and economic policy related to the energy transformation - analysis of profitability and minimizing the risk of deciding to invest in a home micro-installation. *European Research Studies Journal*, vol. XXV, 4, pp. 144-159.

IF = 1,57 (2021); MEiN: 100
DOI: 10.35808/ersj/3072

[H5] Niekurzak M., Kubińska-Jabcoń E. (2021). Analysis of the return on investment in solar collectors on the example of a household: the case of Poland. *Frontiers in Energy Research*, vol. 9, no. 660140, 1-12.

IF: 3.858 (2021); MEiN: 100
DOI: 10.3389/fenrg.2021.660140

II. The use of tools in the field of management and quality science in agriculture.

Achievement 2: development of a proprietary modified and integrated allocation assessment model for improving energy efficiency results in agriculture as an effective tool towards a sustainable economy.

[H6] Niekurzak M. (2021). Analysis of the possibilities of development and use of the potential of agricultural biogas for energy purposes in Poland. *Science - technology - technology: publishing series AGH, T.2.* Publishers AGH, Krakow. ISBN: 978-83-66727-48-9. s. 135-148.

IF = lack; MEiN: 80
DOI: 10.7494/978-83-66727-48-9_9

[H7] Niekurzak M. (2021). Determining the unit values of the allocation of greenhouse gas emissions for the production of biofuels in the life cycle. *Energies*, 14, 8394.

IF: 3.252 (2021); MEiN: 140
DOI: 10.3390/en14248394

III. The use of tools in the field of management and quality science in construction.

Achievement 3: development of a proprietary business model based on knowledge management and environmental management in terms of a holistic approach to the construction sector in the conditions of energy transformation.

[H8] Wróblewski P., Niekurzak M. (2022). Assessment of the possibility of using various types of renewable energy sources installations in single-family buildings as part of saving final energy consumption in Polish conditions. *Energies*, 15, 1329.

IF: 3.252 (2022); MEiN: 140
DOI: 10.3390/en15041329

[H9] Niekurzak M., Mikulik J. (2023). Business models in terms of the strategy for sustainable management in economic entities taking into account the energy transformation. *Energies*, 16(11), 4281.

IF: 3.252 (2023); MEiN: 140
DOI: 10.3390/en16114281

IV. The use of tools in the field of management and quality science in industry.

Achievement 4: development of a proprietary model, built for enterprises in the metallurgical industry, supporting the calculation of energy consumption broken down into electricity and natural gas, and construction of an algorithm to monitor the sources of emissions of harmful compounds into the atmosphere on the example of a thermal waste treatment plant.

[H10] Niekurzak M., Kubińska-Jabcoń E. (2021). Production line modelling in accordance with the Industry 4.0 concept as an element of process management in the iron and steel industry. *Management and Production Engineering Review*, vol. 12 no. 4, pp. 3-12.

CiteScore = 2.3 (2021); MEiN: 70
DOI: 10.24425/mper.2021.139990

[H11] Niekurzak M., Mikulik J. (2021). Modeling of energy consumption and reduction of pollutant emissions in a walking beam furnace using the expert method – case study. *Energies*, 14, 8099.

IF: 3.252 (2021); MEiN: 140
DOI: 10.3390/en14238099

[H12] Kubińska-Jabcoń E., Niekurzak M. (2019). Methods of limiting selected ecological risk types in the municipal waste incineration plant. *Managerial Economics*, vol. 20, no. 1, pp. 43-56.

CiteScore: 1.3 (2019); MEiN: 40
DOI: 10.7494/manage.2019.20.1.43

The total ***Impact Factor*** for the works listed in the scientific achievement is: ***21.932***, for other journals without IF the ***CiteScore*** is ***3.4***. The total number of points according to the Ministry of Education and Science classification is: **1,270**.

According to the list of the Ministry of Education and Science, 10/12 articles are assigned to the discipline of management and quality sciences. Two articles [H1 and H2] were intentionally placed by the author in reputable energy periodicals, which, according to the list of the Ministry of Education and Science, go beyond the scope of the discipline in question. By publishing articles in them, the author presents industry specialists with a methodology on how to use tools and methods qualified to the discipline of management and quality sciences to solve selected problems related to energy management and management in a wider time horizon.

The author's experience related to education and conducting interdisciplinary scientific research in the fields of social sciences on management and quality as well as technical sciences in production engineering resulted in the presentation of a collective scientific compendium of knowledge combining both these scientific disciplines. Expertise in aspects of management and engineering enabled the author to build effective models for making operational and strategic decisions by enterprises as part of their energy transition activities.

The works included in the scientific achievement, together with the scope of individual contribution to their creation and the percentage share, are presented in Appendix No. 5. Copies of the works constituting the basis for initiating the habilitation procedure, together with the co-authors' statements specifying the individual contribution of each of them to the creation of co-authored works are included in Appendix No. 7 (Declarations co-authors) and Appendix 6 (Copies of publications constituting a scientific achievement).

A guide to articles included in a single-thematic series

The aim of the work [**H1**] was to develop and test prognostic methods to increase the accuracy of wind power prediction using artificial intelligence methods. The study investigated the potential of various Gaussian process regression (GPR) models based on kernel functions. In particular, the proposed models are dedicated to short-term prediction. The analysis was based on the operation of 6 wind farms located in Poland. A total of 120 sets of input data were selected for training and testing the proposed models, and then their impact on the change in

the accuracy of the forecasts was verified. As a result of the conducted research, various structures of forecasting models were proposed and tested in order to select the most advantageous variant. The comparison of the developed models based on the GPR method indicated that the superlative model was the Pearson Universal Kernel (PUK) model. Results GPR-PUK model predictions in the form of error rates, scatterplots, tables and Taylor charts turned out to be the most accurate and are consistent with real values, which allowed to verify the feasibility and effectiveness of using this model to forecast wind farm power.

The aim of the article [**H2**] was to build an hourly model of the system for short-term forecasting of electricity demand on the local market of the Krakow area in 2019-2022. Including quantitative methods. The time series representing the hourly system-wide electricity demand was decomposed. A comprehensive statistical analysis of the data was performed in order to select the best optimization method used to select the optimal coefficients of the developed method of estimating the quality of forecasts. In addition, the results of numerical experiments aimed at determining the impact of the y parameter value on the quality of forecasts for different forecast horizons, and the relationships between the amount of historical data and the quality of forecasts were established. Due to the periodic nature of the examined time series, a detailed analysis of seasonality and periodicity of a given signal was carried out using spectral analysis and autocorrelation. This analysis allowed the author to create an effective tool for accurate local electricity demand forecasting in the time horizon "an hour before delivery". On the basis of data from the distribution company, the built system was verified. An analysis of profits and losses after applying the selected forecasting model was made. The proposed concept of the model is an effective analytical tool for the analyzed problem, which will help operators of energy companies to effectively support their decisions in forecasting the demand for electricity.

The aim of the article [**H3**] was to present the collective results of research on the profitability of using various renewable sources in Poland with the greatest development potential. The research methodology was based on the concepts of discounted inflows and outflows defined as cash flows. The work defines and calculates the economic parameters of various investment projects, i.e.: net capital value (NPV), internal rate of return (IRR) and payback period (PBT). The economic assessment of the use of renewable energy technologies was supplemented with an assessment of ecological benefits. The ecological criterion adopted in the work was the assessment of the potential and costs of reducing greenhouse gas emissions as a result of replacing fossil fuels with renewable energy technologies. The analyzes and research of the Polish energy market with the use of the presented models showed that the project in their implementation is fully economically justified and will allow investors to make a rational decision on the right selection of specific RES for their investment.

The aim of the article [**H4**] was to analyze the profitability and minimization of the risk of making a decision to invest in a home PV micro-installation. Particular emphasis was placed on the determinants of the boundary conditions at which there is an investment and economic justification for potential investors to make business decisions in the implementation of the project of electricity production for their own needs. The economic methods used allowed to calculate the market value of the investment with the assumed boundary criteria and to determine the economic efficiency of the investment. The tests were carried out in April-March

2021-2022 on a test PV installation in a household. The approach to empirical research allowed authors to calculate the actual productivity based on actual data from the PV installation. The obtained data took into account highly correlated individual installation conditions, which are often overlooked in the literature. Obtaining this data allowed the authors to indicate directions for improvement that may contribute to a more reliable assessment of the profitability of the tested installations.

The aim of the article [**H5**] was to present the results of research on the return on investment in solar collectors for single-family houses in Poland. The research was carried out on the basis of the legal conditions applicable to micro-installations in the light of the amendment to the RES Act. Based on the constructed economic model used to assess the profitability of the investment consisting in increasing the area of solar collectors, it was shown that the operation of the installation will bring measurable economic benefits in the form of a reduction in the amount of energy purchased annually in the amount of 6,756 kWh and benefits ecological in the form of reducing carbon dioxide emissions to the atmosphere by 2.4-3.6 Mg per year. The obtained results have been generalized, which allows them to be used in the process of selecting the size of the collector surface for similar installations.

The aim of the article [**H6**] was to analyze the raw material base for obtaining biogas from bio-waste and to determine the efficiency of agricultural biogas for energy purposes on the basis of a general mass balance. The important position of agriculture in the economy makes it important the direction of development of renewable energy sources is the acquisition and use of biogas. The existing sources of biogas (landfills, sewage treatment plants, agricultural biogas plants) are only a small part of its production capacity. Currently, biogas can be produced in energy biogas plants only from biomass, e.g. silage, corn or cereals. Based on the collected data and assumptions, calculations were made to estimate the energy potential of biogas produced from agricultural raw materials, taking into account the general mass balance. In order to determine the demand for the basic substrate, i.e. maize silage, the following were determined: the required daily biogas production for the cogeneration unit with the assumed power, the daily biogas production from cattle slurry, the daily biogas production from organic waste was calculated and the daily demand for maize silage was estimated and on this basis, the cultivation area was determined. Large-scale production of biogas can increase the energy security of the country, reduce the state's gas deficit, become independent of gas imports and meet EU obligations regarding the production of biofuels and energy from RES.

The aim of the article [**H7**] was an analysis of the allocation method and other factors influencing the result of greenhouse gas emissions for biodiesel. Thanks to the allocation methods, i.e. the distribution of the total greenhouse gas emissions between each of the products resulting from the production of biofuel, it is possible to reduce the emission of these gases by up to 35% compared to the production and combustion of fuels derived from crude oil. As part of the work, the biodiesel production process was analyzed in terms of greenhouse gas (GHG) emissions. Based on the obtained results, key factors affecting the level of emissivity of the biodiesel production process were identified. In order to assess the sensitivity of the results of the adopted allocation method, emission calculations were performed as part of the work GHG when adopting the allocation method based on mass, energy and financial shares. The article discusses recent advances that potentially enable a sustainable energy transition, green economy

and carbon neutrality in the biofuels sector. The work showed that the technology used for the production of biodiesel is of great importance for sustainable development. The possibility of using renewable raw materials for the production of fuels leads to a reduction in the consumption of minerals and lower emission of pollutants. It has been shown that during the combustion of biodiesel, the amount of gases released, with the exception of nitrogen oxides, which is an increase by 13%, of other components is significantly lower: CO2 - 78%, CO - 43%, SO2 100%, PM10 - 32% and volatile hydrocarbons - 63%. In addition, biodiesel was found to biodegrade 5 times faster in the environment than diesel.

The aim of the article [**H8**] is to develop a model of heat supply for buildings with almost zero energy consumption, with an indication of the importance of heat losses and gains in heating installations. The article presents the assumptions and results of the analysis of the use of energy installations in residential buildings using RES resources to balance energy consumption in various areas of its use. Calculations were made of the impact of the use of installations using renewable energy sources on the energy performance of a building with different quality partitions and the improvement of energy efficiency. As part of the research, the calculation model of heat loads in buildings was validated based on the PN-EN ISO 52016-1:2017-09 standard. Based on this model, load conditions for new generation buildings were proposed and heat sources for energy-saving buildings were recommended. Thanks to this method, it is possible to control heat gains and losses from indoor and outdoor installations insulating shell of the building. The results of the research allow the selection of the most advantageous variant of the replacement of installations for residential buildings from the point of view of economic profitability, and also allow to determine the possibility of meeting national obligations in the field of reducing final energy consumption and increasing the share of renewable energy sources in meeting its demand in accordance with the imposed Poland with EU obligations.

The aim of the article [**H9**] was to present the results of research on the importance of energy transformation management in various economic sectors. Barriers and benefits of implementing a knowledge management and environmental management system in enterprises were considered. These factors are necessary for effective planning and proper functioning of enterprises. Knowledge becomes the main and most dynamic factor responsible for the development of a given company, while environmental management ensures it achieves high economic efficiency of production with respect for environmental rules and regulations. The article presents the results of the functioning of knowledge-based enterprises in contemporary conditions characterized by constant changes in the environment in terms of energy transformation. As part of own research, an algorithm was built on the basis of which the essential elements of the energy policy strategy were defined Polish enterprises in various sectors of the economy. In the holistic approach, a model of functioning of knowledge-based enterprises was built and tested. On its basis, a prosumer/customer business model was built on the example of a photovoltaic installation. The study was conducted using the methods of economic measurement models. These methods allowed to calculate the market value of the investment with the assumed boundary criteria and to determine its effectiveness. The research was carried out in 2020-2022 on the example of a real PV installation. The developed business model showed that the project of its implementation is fully economically justified and will

allow investors to make rational investment decisions in various economic areas as part of the ongoing energy transformation.

The aim of the article [**H10**] was to develop a logistic model of the system on the example of a hot-rolled steel strip rolling mill, taking into account the subsystems of material flow and storage, on which experiments were carried out to obtain results on how the implementation of the Industry 4.0 solution will improve the efficiency and productivity of the analyzed production line and lower energy costs. In addition, the areas of implementation of the concept in question were presented, and the potential advantages of implementation in the analyzed area were discussed enterprise. Attention was focused on the development opportunities of a company that introduces modern technical solutions. The presented article aims to disseminate the idea of Industry 4.0 in Polish energy-intensive enterprises from the manufacturing industry sector.

The aim of the article [**H11**] was to build a model of energy consumption divided into electricity and natural gas in a walking furnace depending on the length of the rolling campaign and the established rolling program. The final result of the work is a model enabling calculation of energy costs of material processing depending on: steel grade and ingot mass, heating time in the furnace, thickness and band width. The results of the work can be widely used in the implementation of projects optimizing energy consumption on the hot rolling mill. This algorithm is the basis for developing a proposal for a set of minimum requirements characterizing the best available environmental techniques for walking beam kilns placed in hot rolling, taking into account the requirements set out in national legal regulations and the recommendations described in BREF reference documents. This information should be taken into account when preparing an application for an integrated permit, as well as when determining the level of permissible emissions. Based on the constructed algorithm, it was shown that the analyzed projects, depending on their type and technical specification, will bring measurable economic benefits in the form of a reduction in the amount of energy consumed on an annual basis and environmental benefits in the form of reduction of carbon dioxide emissions into the atmosphere. The constructed algorithm verified in the real conditions of the rolling mill will contribute to the fulfillment of energy and emission obligations towards the EU.

The aim of articles [**H12**] was to present a model of ecological risk management and its monitoring on the example of a municipal waste incineration plant. The research indicated the basic ones differences between ecological risk and environmental risk, an algorithm was built to manage and monitor ecological risk. In addition, using the matrix, weighting and FTA methods, the main threats related to ecological risk were determined and ways of minimizing it were proposed. The articles address the issue of environmental management systems as effective instruments for reducing environmental risk in the enterprise. It presents the origin of the concept of risk and ecological risk, focusing on the process of managing it in business practice. A practical example of the use of an environmental management system to reduce the environmental risk of operations was the waste incineration plant in Krakow.

The criterion which guided the author in the selection of journals for the evaluation of scientific achievements was primarily: their publication recognition. On the domestic market, these are magazines, such as "*Electrotechnical Review* - 1919", *Metallurgist* - 1929", " *Power*

engineering - 1947", "*Energy Market* - 1995", "*AGH Monographs* - 1950". Among foreign journals, the focus was mainly on the selection of those that have a very wide open access to reach as many recipients as possible and are recognizable and recognized in the global scientific community, e.g. Energies, Frontiers in Energy Research, Management and Production Engineering Review, Sustainability, etc. In order to reach a wide audience, 11 out of 12 articles were written in English. In the case of six articles, I was the sole author, in the remaining ones I was the corresponding author, who was responsible for responding to the reviewers' comments and making corrections to the articles. As part of co-author research, I was their originator, I developed the methodology, research concept and organized access to all research materials. In each of the articles included in the scientific achievement, I had a leading role in formulating the research problem, creating the research hypothesis, preparing and implementing research, data analysis, calculations, and in the development and interpretation of the results. In addition, I prepared manuscripts and edited and proofread their final versions. Co-authored publications that I have indicated were created, among others, by: in cooperation as part of scientific cooperation with employees of: Military University of Technology in Warsaw, West Pomeranian University of Technology in Szczecin, University of Szczecin, University of Economics and Information Technology in Krakow, Jagiellonian University in Krakow, Krakow University of Technology, Silesian University of Technology in Katowice, University of Ardahan, International Islamic University Malaysia, University of IT and Emerging Sciences Peshawar, Peter the Great St. Petersburg Polytechnic University as well as with the co-workers of the parent university, i.e. the AGH University of Science and Technology in Krakow. The scope of data for research articles was obtained from plants located in the city of Krakow: ArcelorMittal Poland S.A. Kraków Branch, Hot Rolling Mill; Heat and Power Plant in Kraków, PGE Energia Ciepła Branch No. 1 in Kraków; Waste Thermal Treatment Plant in Krakow and from private household installations on which measurement experiments were carried out.

The series of publications [H1-H12] submitted in the habilitation procedure, according to the author's knowledge, is a comprehensive scientific study defining the methods of energy management in various sectors of the economy, setting directions for their development as part of the energy transformation of Poland and the region. Decision-makers, operational managers of enterprises often lack comprehensive tools, models and indicators to develop a practical approach to effective energy management. In this context, many models and algorithms have been developed for enterprises to improve environmental and socio-management aspects in relation to energy consumption and reduce the negative impact of CO2 emissions on the environment.

4.2. Introduction to the essence of the research problem - major scientific achievements

From the beginning of my scientific career, I have been researching aspects of management and production engineering in various sectors of the economy. For 5 years I started to be particularly interested in the aspects of the development of renewable energy sources (RES). The development of renewable energy sources is currently a priority objective of the European Union's climate, energy and environmental policy, which is reflected in EU and government strategies and programmes. I have noticed numerous reasons for economic entities to change

their management methods, including energy management. These premises are: progressive anthropopression, excessive exploitation of natural resources at the expense of future generations, depletion of fossil resources, increase in investment costs of construction of conventional power plants, increasing emission limits, and stringent environmental protection regulations. Changes in the management process reflect the transformation of the way of thinking in management energy and the interpretation of phenomena that accompany it. Passive, low-emission, energy-saving and effective technologies are indicated as the foundation of a new way of energy management energy, such as renewable energy sources.

Environmental pollution and the depletion of conventional fuel resources and the fact of global warming are among the main problems facing humanity in the 21st century. The process of producing energy from fossil fuels is largely responsible for anthropogenic emissions of greenhouse gases, acid rain and other negative effects on health and the environment. Fossil fuels were the source of as much as 83% of the energy consumed in Poland in 2022. This value is 5 times higher than the value of energy derived from RES. This puts Poland in the infamous, first place in Europe in terms of drawing energy from fossil fuels. As a result, electricity generated in Poland is also the most "polluted" in the EU. To produce 1 kWh of energy, 724 grams of CO2 must be emitted, which is 3 times more than the European average. It is worth noting that in 2022 Poland was one of the largest coal producers in Europe, which entails numerous negative consequences for our planets, among others ozone hole, imbalance of biological life, soil and air pollution. This is one of the reasons why the air in Poland is one of the most polluted in Europe. According to the 2020 Clean Heat Report prepared by the Ministry of Climate, solid fuel-fired coal-fired boilers are still the most frequently used source of heat in Poland and are responsible for approx. 42% of particulate matter. In addition, the overriding EU goal is to achieve 32% of energy from renewable sources by the end of 2030 and to reduce greenhouse gas emissions from 40% to 55%. In order to achieve the energy and emission targets imposed by the EU in Poland, it is necessary to consider the development of renewable energy technologies as a priority in the energy sector. Poland must embark on the path of the "green revolution", i.e. energy transformation, and start rebuilding its economy and energy sector towards renewable energy sources as soon as possible. This is due to the accident a number of factors. In addition to the obligations obliging Poland to further increase the share of RES in the gross final energy consumption, in the overall EU economy it is also necessary to increase energy efficiency by saving primary energy consumption by 13.6 Mtoe compared to the forecast of demand for fuels and energy from 2007 and contribute to the EU-wide reduction of greenhouse gas emissions by 20%. In addition, the issue of record prices for CO2 emission allowances should be taken into account, which should change the approach to the economics of energy production. The transformation of the national economy towards RES will require meeting numerous challenges in order to obtain stable electricity supplies. It should be noted that in 2018 electricity consumption in Poland increased by approximately 1.7% and thus reached the highest level in the history of our country - 171 TWh. At the same time, domestic production amounted to 165.3 TWh, falling by 0.3% compared to the previous year. As a result of these processes, we had to import 5.7 TWh of energy from Ukraine, Sweden and Lithuania. Due to the growing demand for electricity, with the electrification of subsequent sectors of the economy, i.e. transport, heating, industry), there is a need for multi-billion investments in new

generation sources and modernization of the existing ones. One of the ways to improve the level of Poland's energy security and reduce its harmful impact on the environment is the wider use of alternative energy sources, and at the regional level. Without a long-term energy policy, the Polish energy sector faces a drift and the risk of economically unsuccessful investments in RES. The position of the scientific community is clear - avoiding a climate catastrophe is possible only by achieving global climate neutrality, i.e. a balance between the emission and absorption of greenhouse gases. The need to meet EU Directives and National Indicative Targets (NIT) forces Poland to increase the use of renewable energy sources. This goal can be achieved using various technologies that differ in labor intensity, efficiency, quality and costs.

The subject matter of the research undertaken as part of the scientific activity falls within the discipline of management and quality sciences. Due to the multifaceted nature of scientific problems, it combines issues in the field of energy, the efficiency of manufacturing processes and technologies, their operation as well as the organization and management of manufacturing processes in various sectors of the economy. The research problem focused on socio-economic and economic aspects related to the formation of harmful emissions of dust and gases and the possibility of undergoing energy transformation, taking into account renewable energy sources in various economic areas. Figure 1 presents the author's weighted decision-making model for managing the energy transformation, on the basis of which research aimed at achieving the set goal of work in various economic areas was carried out.

The literature review shows that, despite the quality of various studies in the field of energy transition management, scientists have not yet conducted research related to the inefficiency and inefficiency of economic systems in the entire production chain against the background of specific case studies of enterprises. The consequence is the lack of comprehensive research and process synergy that could be achieved by combining various environmental and technological aspects and conditions, including determining the nature and intensity of the links between the factors under study. Despite the wide range of existing knowledge in each of these areas considered separately, there are a number of problems that require a comprehensive individual approach to the assessment of sustainable energy management and the use of complementary research methods. In this context, many methods and practices have been developed for each sector of the economy to assess environmental aspects, socio-economic issues with regard to the effective management of energy consumption to reduce pollutant emissions. The basis for the conclusion was the description of the state of economic and social phenomena within the subject matter, including the determination of the nature and intensity of the links between the factors under study.

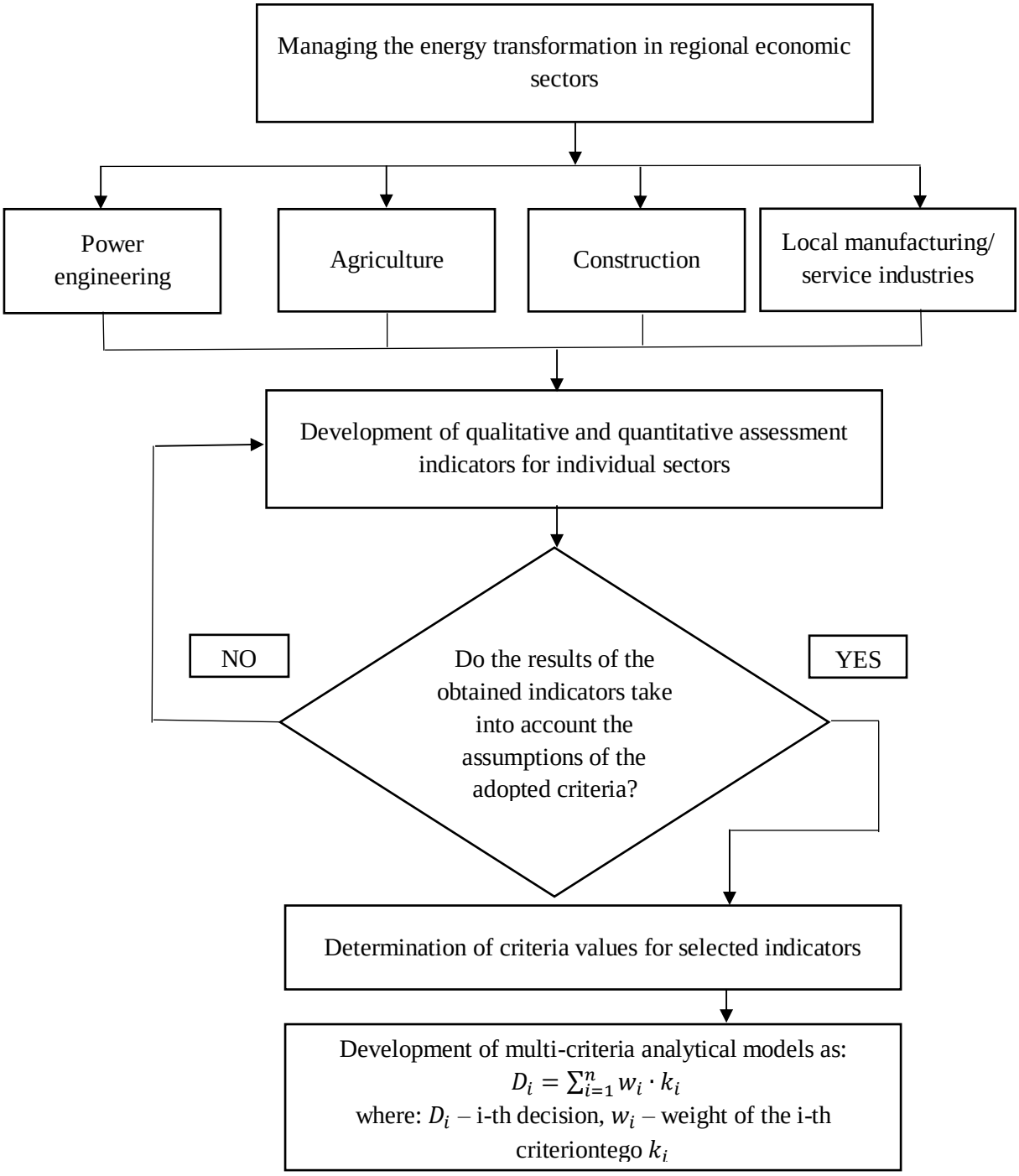

Fig. 1. Weighted decision-making model for managing the energy transition.

The series of 12 publications contains many scientific achievements carried out individually and different for each of the four sectors of the economy as part of the ongoing energy transformation. The developed integrated assessment methods include activities in production systems and private entities aimed at minimizing their environmental impact, meeting social expectations, while maximizing economic benefits. The author presents a list of four main scientific achievements that are the subject of initiating the habilitation procedure below. Other significant achievements described individually for each sector of the economy are presented in point 4.4. self-report.

- ✓ **Four main scientific achievements in the field of management and quality science, along with a description of the construction of models as part of research on the energy transformation:**

I. Scientific achievement 1 from the "Energy" sector

The **decision model** was built for power plants on the local market and concerns the hourly forecasting of the electricity demand system. The purpose of the model is to support decision makers in making energy management decisions as part of short-term forecasts. The model was built in response to the need to effectively manage a given enterprise, reduce the costs of purchase and sale of electricity in the balancing segment. Thanks to artificial intelligence solutions, an effective model was built that allows to obtain accurate forecasts of electricity demand in the time horizon "an hour before delivery". The model contains an innovative tool designed by the author with the use of an expert system and fuzzy logic rules to support decision makers in making decisions about including or excluding a given hour in the balancing system. This model analyzes the forecast error from an hour earlier and the differences between forecast and the actual value in the previous day. Based on this information, it assesses the balancing risk of the selected hour.

The construction of a decision model for energy balancing on the hourly market as part of short-term forecasting was based on 5 main stages:

1. Calculation of the forecast for the trading day *n*.

   At this stage, a forecast of electricity demand for each hour of the next day should be made. The result is a graph containing 24 forecasts for each hour. This schedule is valid for the *n-1* trading day.

2. Calculation of the forecast for $y(t)^1$.

   At this stage, the forecast should be calculated for each subsequent hour of the day *n*. The forecast should be made using the SARIMA model, which guarantees the smallest forecast error obtained, and thus best corresponds to real conditions. Then, the obtained result $y(t)^1$ should be compared with the forecast obtained in stage 1. If less energy has been ordered than it results from the forecast $y(t)^1$, proceed to the next stage 3, otherwise further calculations should be completed, because the forecast we have too much energy.

3. Calculation of the forecast error.

   At this stage, the modulus of the relative percentage error of the forecast *X* should be calculated. As a reference value, we take the result of the model's forecast for one hour ahead $y(t)^1$.

$$X = \left|\frac{y(t)^1 - y(t)^{24}}{y(t)^1}\right| \cdot 100\% \qquad (1)$$

If X is less than 1%, we finish further calculations, because it follows from the forecast that we have a safe buffer in the price band on the balancing market. If X is greater, proceed to the fourth step.

4. Calculation of the missing energy Δy(t) that is necessary to balance the hour *t*.

At this stage, the model, using expert knowledge, makes a decision related to checking whether the hour *t* for which the forecast is prepared is an hour with an increased risk of forecasting, e.g. peak evening hours, holidays, etc.

$$\Delta y = y(t)^1 - y(t)^{24} \tag{2}$$

As part of the decision support for the model, an expert system based on fuzzy logic methods was developed. The rules of this system can be changed along with the experience gained. The basis of this system is the analysis of the percentage error for the demand *y*(t) against the actual demand the day before at *t y*(t-24) and the percentage error of the actual demand *y*(t-1) for the forecast. The number of linguistic variables both input and output was set to five. The model output range was assumed to be from 0 to 1. The answer range for which the YES decision on balancing for an hour with increased risk will be made is the range (0-0.5). Outside this range, you should decide NO. The higher the output value, the greater the risk of making a wrong decision.
The result of the model calculations is the amount of missing energy to balance hour *t*. If *t* is not an hour with an increased risk of forecasting, go to step 5.

5. Purchase of missing energy Δy(t) on the local market.

The final stage is the decision to purchase or produce the missing amount of energy. If the distribution company has its own energy sources and the ability to start them quickly, it should be done and the balancing should be completed for hour *t*. If not, energy must be purchased from a local producer, e.g.

An important step at this point in the model is also to determine the price for each hour on the exchange. The model determines the price based on the price for a given hour based on the energy available on the exchange multiplied by the price adjustment factor *K*c. In order to satisfy both sides of the transaction, this factor should be greater than 1. The optimal value for both sides of the transaction is 1.2, then it brings profits. On the other hand, for the price factor *Kc* = 1.4, the model starts to generate losses.

The application of the balancing model will result in a decrease in energy purchased or sold on the balancing market beyond the range of ±1%. This will result in more favorable price negotiations, thanks to which you can have energy to meet local needs without surplus, and this will reduce the production of harmful emissions into the atmosphere by reducing the carbon footprint used for energy production.

The proposed concept of a decision-making model is an effective analytical tool that will help operators of energy companies to effectively support their decisions in forecasting demand for electricity.

II. Science Achievement 2 from the "Agriculture" sector

A modified and integrated allocation assessment model was developed to improve energy efficiency performance in agriculture as an effective tool towards a sustainable economy. This model is based on the diagnosis of the energy condition, the use of optimization tools, the identification of indicators and the assessment of sustainable energy management of production systems using the LCA (Life Cycle Assessment) method. This model makes it possible to track the biodiesel production process, determine all components during the cultivation of the raw material and, on its basis, identify significant factors influencing the level of emissivity. In addition, this model makes it possible to assess the sensitivity of the results of the adopted allocation method and perform calculations of GHG (greenhouse gas) emissions. The main effect of the model is to perform calculations based on different allocation methods and determine the overall mass balance of the entire production process based on shares in mass, energy and finance.

The modified allocation assessment model was built using an expert system, the skeleton and framework of which was developed on the basis of an analysis of production processes and conducted research in this area:

1. The raw material base first assessment model allows to determine the overall mass balance for the entire production process. On this basis, it estimates the total energy content and emissions for the biodiesel and by-products produced.
2. In the next step, based on the yield and energy content, the model allows to determine the energy share of individual production substrates.
3. On the basis of the data obtained with the use of multi-criteria optimization tools, the proposed model calculates the shares in its individual production stages.
4. The result of the optimization is obtaining a division of the total energy and the resulting emission from the obtained raw materials for the production of the finished product according to previously calculated shares.
5. The result of the calculations is the determination of:
   - the quantity of the finished product and all by-products produced,
   - a database of products available on the market that can be replaced by by-products generated during production,
   - the proportion to which the products in question can be replaced by by-products,
   - environmental burden in the form of calculations of GHG (greenhouse gas) emissions from the replaced products.
6. The final effect of the model is to assess the sensitivity of the results of the modified allocation method on the basis of the obtained shares: mass, energy and financial.

The model was verified in real conditions on the example of a technological installation for the production of biodiesel from rapeseed oil by transesterification and methanol recovery. The allocation of GHG emissions was carried out at individual stages of production of the final

product and by-products, after which these products were still processed at subsequent stages. The total GHG emission and the allocation for the main product and by-product were calculated taking into account the total emission related to all input substrates: on the basis of physical quantities (mass, energy content), on the basis of economic quantities and on the basis of an extensive system in which unrelated activities were also calculated with the product's life cycle. The result of the research was the calculation of GHG emissions according to a modified model by the author, taking into account:

- total emissions due to the fuel used,
- emissions from the extraction and/or cultivation of raw materials,
- emissions on an annual basis due to changes in the amount of the carbon element due to a change in land use,
- emission caused by technological processes,
- emissions caused by transport and distribution,
- emissions caused by the fuel used,
- carbon stock emission saving value in the soil thanks to better agricultural management,
- reducing emissions from carbon capture and storing it in deep geological structures,
- reducing emissions from carbon capture and replacement,
- reduction of emissions due to increased production of electricity as a result of cogeneration.

The model in use conditions showed that the allocation of pollutants allows to reduce the total GHG emission in the life cycle of the main product (biodiesel) by about 31%, because the emission is divided between it and the by-product (glycerine). It is worth noting that the allocation was calculated only for one stage. The model can be used to calculate allocations for the remaining production steps, i.e. separation of methyl esters and the glycerin fraction, purification of methyl esters and purification of the glycerin fraction.

The proposed model has implications for the Polish economy. The practical use of the model gives an opportunity to develop new solutions that can be used in the energy transformation process, both at the local, regional or state level as part of the activities of the sector related to agriculture.

III. Science Achievement 3 from the "Construction" sector

The business model was built on the basis of knowledge management and environmental management in terms of a holistic approach to the construction sector in the conditions of energy transformation. The business model in this project can be understood as a set of business flexibility strategies undertaken by households in relation to electricity consumption, aimed at generating economic benefits. These strategies may result from a combination of various instruments in order to obtain economic benefits from various sources of income and savings. The main sources of savings on your energy bill are reduced electricity costs by taking advantage of your own flexibility and ability to invest in renewable energy sources. The proposed model defines the ways of developing the energy system with the use of local and

regional resources of renewable energy sources. The construction of the model was preceded by the built algorithm, taking into account the relevant criteria and conditions defining the construction sector as an element of the energy policy strategy based on thermo-modernization standards. On its basis, a prosumer/customer business model was built on the example of a photovoltaic installation. This model, using economic measures and multi-criteria analyses, enables:

- calculation of the market value of the investment,
- determining its effectiveness,
- assessment of the development and life cycle of buildings, taking into account the changing socio-economic conditions,
- providing knowledge about the possibilities of their design in the framework of sustainable construction technology,
- the use of appropriate RES resources to balance energy consumption in various areas of its use, taking into account the quality of building partitions.

The methodology of the developed business model led to the determination of such economic parameters of the investment project as: net capital value (NPV), internal rate of return (IRR) and payback period (PBT). The developed calculation sheet made it possible to assess the profitability of any investment, assuming specific data on the amount of investment outlays, the method of their financing, operating costs, tax burdens, the method of depreciation and revenues over a period of up to 20 years. The model is supplemented by the ability to calculate economic benefits from the use of renewable energy technologies in construction. The ecological assessment criterion adopted in the paper was the assessment of the potential and costs of reducing greenhouse gas emissions as a result of replacing fossil fuels with renewable energy technologies.

The effectiveness of the model has been verified in the real conditions of the installation's operation. Using simulation tools, the calculation model in the building was validated based on the PN-EN ISO 52016-1:2017-09 standard. On this basis, the model proposes load conditions for new generation buildings and recommends a specific heat source. In the case of a photovoltaic installation, an important advantage of the presented business model is the creation of high social value and the possibility of obtaining effective environmental protection. Analogous models can be built for: biogas plants, energy, transport and industry, taking into account legal, environmental, social, technical and management criteria and conditions. The proposed business model in the knowledge-based economy makes it possible to respond to flexible adaptation to frequent changes on the energy market and to the changing needs of customers. In addition, this model fully corresponds to the pillars of the economy based on knowledge, creating innovative solutions and gives opportunities for the development of technology and entrepreneurship at the regional level.

IV. Science Achievement 4 from the "Industry" sector

The management model was built for a steel company and concerns: calculation of energy consumption divided into electricity and natural gas. The proposed model (Figure 2) makes it

possible to calculate the energy costs of material processing depending on: steel grade, ingot weight, heating time in the furnace, band thickness and width.

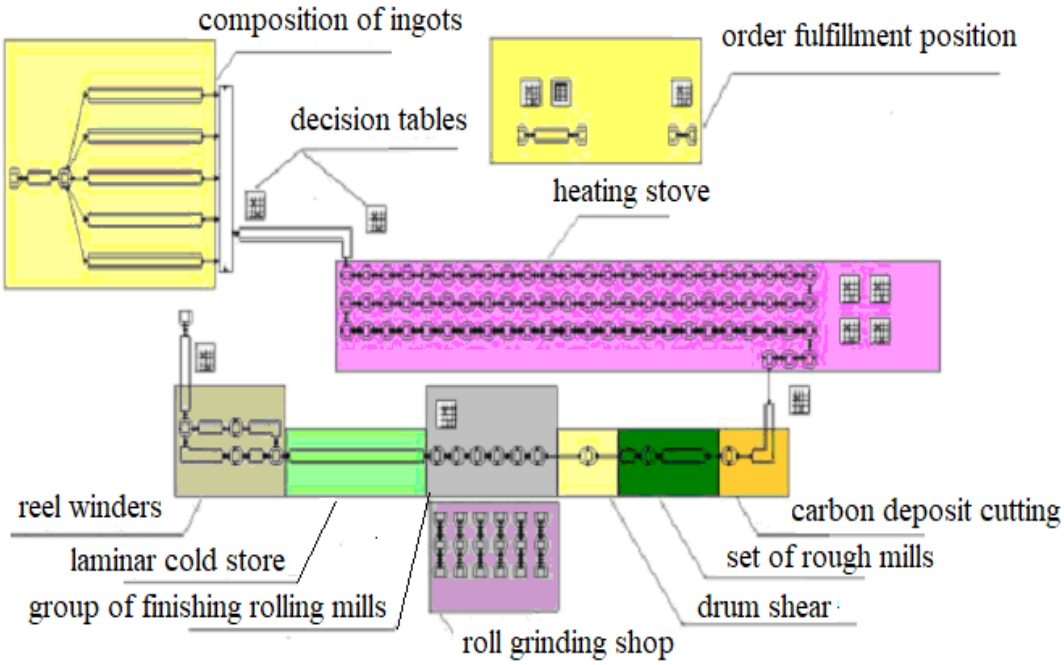

Fig. 2. Management model of the system in a steel strip rolling mill.

The structure of the developed management model:

- developed rules with the use of artificial intelligence tools based on an expert system make it possible to forecast the times of heating ingots to the desired rolling temperature in the walking furnace in its individual zones along with the corresponding electricity consumption.

  The results obtained in the author's model using expert methods make it possible to compare them with the results of measurements made in industrial conditions. The measure of evaluation of the obtained results for evaluation is the error: relative, mean and mean square.

- the model, thanks to the use of intelligent decision structures, enables supervision of the furnace heating zone and proposes, depending on the production process, the most economically optimal curve for heating and annealing ingots in a walking furnace.

  The data obtained in this way from the model make it possible to calculate the energy costs of material processing depending on: steel grade and weight ingot, baking time in the furnace, thickness and band width.

- The final result of the model is the determination of ways to prevent or reduce the impact of harmful compounds from production processes on the environment by introducing sustainable production techniques based on environmental standards.

The ID3 machine learning algorithm used in the model was used to develop the knowledge base of the rule-based expert system. The system is based on heating zones in the furnace and technological parameters of the rolling process. Through the SQL query language, data

describing the parameters and technological capabilities of given tools are retrieved from the created system module and added to the knowledge base of the expert system in the form of facts. The inference module of the expert system, based on the production rules and information encoded in the knowledge base, using backward search strategies, determines the predicted heating times. The Nexpert artificial intelligence package from Neuron Data was used to build a prototype of such a system. The skeleton expert system included in the package is the structure of the system. The program developed as part of the work, in the PC-Shell system, consists of a set of instructions written in the Sphinx language. The knowledge base of the system was built as a declarative representation of knowledge based on the principles of rational preparation of the production program and includes many decision-making rules. In a similar way, you can increase the knowledge base with new criteria that will significantly affect the effective making of operational decisions at the level of production planning.

Based on the obtained model parameters, an algorithm for calculating electricity consumption depending on the type of material was proposed:

$$EE_i = 9{,}7603 \cdot 10^{-1} - 2{,}5353 \cdot 10^{-2} \cdot g + 4{,}8474 \cdot 10^{-4} \cdot g^2 - 2{,}9422 \cdot 10^{-4} \cdot s + 6{,}0274 \cdot 10^{-8} \cdot s^2 + 1{,}4676 \cdot 10^{2} \cdot w + 2{,}8632 \cdot 10^{-4} \cdot w^2$$

where:

EE_i - electricity consumption depending on the type of material, kWh/Mg,
g - final sheet thickness, mm,
s - final sheet width, mm,
w - mass of the ingot, Mg.

The correctness of the electricity consumption model compared to the actual electricity measurements for the period of two months was verified in real conditions and amounted to 99.97%. On the other hand, the correctness of the natural gas consumption model, compared to the actual measurements for the period of six months, amounted to 99.76%. High compliance allows the model to be used in real conditions of the rolling mill, taking into account its extension by the amount of energy consumption depending on the profile and grade of hot-rolled sheets and strips.

A significant innovation of the model enables:

- determination of cost-energy dependencies between individual profiles and steel grades in active production,
- tracking energy consumption and processing costs depending on the currently produced assortment,
- real-time verification of market prices for individual steel grades and profiles,
- introduction of innovative BAT techniques and the possibility of assessing the company's ability to meet the requirements of sustainable energy management.

The developed model is not only of theoretical but also practical importance, as it makes it possible to use it for specific decision-making problems, thanks to which decision-makers can obtain possible and acceptable variants of scenarios for introducing technological changes. The model allows us to conclude that it is a comprehensive tool for making rational "energy" decisions accompanying the production processes of the company, which in the context of its functioning in the changing conditions of the 21st century may give it a chance for continuous improvement and survival in the dynamically changing environment of energy transformation. The model is the basic source of information for making effective operational technological decisions by energy-intensive enterprises:

- as part of current, short-term planning decisions (8 hours),
- for the purposes of long-term production planning (1-2 months).

A detailed description of the publications in which the use of the presented models is presented along with conclusions and recommendations can be found on pages 33-52 of this self-report.

4.3. Hypothesis, scientific purposes and research methods

The conducted research was aimed at verifying the research hypothesis put forward by the author, according to which:

"Achieving climate neutrality through the introduction of innovative management models requires the active involvement of the regional industry and the end user of energy in the development of low-emission energy transformation through the introduction of innovative, socially acceptable technologies"

Bearing in mind the EU climate and energy regulations imposed on the Polish energy sector in relation to climate protection, it should be stated that the lower consumption of fossil fuels in Poland will allow for more intensive development of the energy sector obtained from renewable energy sources and should make this part of the energy sector particularly prospective and attractive to investors .

The detailed objectives of the work in the light of considerations on the issues of renewable energy were:

1. Recognition of the importance, level, structure and development conditions of renewable energy sources in Poland.
2. Determining the possibilities of using and managing renewable sources by various economic entities as part of the energy transformation.
3. Indication of the main problems and challenges facing the Polish energy sector in terms of ongoing socio-economic changes and progressive degradation of the environment.
4. Assessment of costs related to projects in the renewable energy sector.
5. Analysis of legal and systemic conditions supporting the development of RES.

Achieving the main objective required the implementation of specific tasks, including:

a) construction of a decision model and calculations affecting the efficiency and economic viability of using various renewable energy sources with the greatest development potential in Polish households,

b) identification and analysis of possible economic, social and environmental effects as well as directions of transformation of the Polish energy sector in the perspective of 2050,

c) determination of the degree of risk and construction of an algorithm for the management model of electricity and natural gas consumption for the local industry, which allowed the development of a proposal for a set of minimum requirements characterizing the best available techniques (BAT) for metallurgical plants, waste incineration plants and power industry, which are among the largest CO2 emitters in the world southern region of Poland,

d) performing calculations and building an integrated model for evaluating the allocation for transport through its electrification and distribution of GHG emissions between products generated in the production of biofuels, which will enable the reduction of emissions of these gases by up to 35% compared to the production and combustion of fuels derived from crude oil,

e) development of a business model to control heat gains and losses from installations inside and outside the building's insulation jacket. This model will enable the appropriate selection of RES resources to balance energy consumption in various areas of its use, taking into account the quality of the building partitions used.

Achieving the goal and verifying the hypothesis was possible by searching for answers to the following questions:

1. Is it possible to implement the reconstruction of the Polish energy sector in accordance with the paradigm in the global energy sector in the existing socio-economic conditions?
2. Are business models an effective tool for seeking the strategic advantage of business entities in the era of energy transformation?
3. Are quantitative and qualitative research effective for building energy management models?
4. What criteria should be taken into account when choosing one of the many available models for energy management?
5. Do the conditions under the influence of the changing environment in which a given enterprise operates in any economic sector affect the selection of the type of model for designing a competitive advantage?
6. Can the mode of conduct of enterprises representing various sectors of the economy in the design process be adopted as the same and at the same time take into account the individual specificity of organizations and their sectors?
7. What are the main barriers and factors stimulating the development of RES in Poland?

8. Does renewable energy have and can have a significant impact on the level and quality of life of residents and meeting social needs?
9. What are the legal conditions for the production of energy from renewable sources?
10. What are the motives and determinants conditioning the production of energy from renewable sources, both in households and in industrial plants?
11. What are the systematics of factors favoring and limiting the development of energy production from renewable sources, taking into account the economic, environmental, social and technical and technological areas?
12. How is the structure of production costs of raw materials and energy and what is theirs competitiveness with fossil fuels?
13. Does the production of energy from renewable sources require support from public sources in the current economic and social conditions?
14. Are quantitative methods good measures in forecasting electricity demand?
15. What are the directions of development of low- and zero-emission sources in the longer term?
16. How great is the potential of renewable energy sources and the possibilities of their use at the local level?
17. What are the directions of development of renewable energy production in Poland compared to the European Union?
18. What is the role of rural and urban farms in production and use renewable energy?
19. Is the production of energy from renewable sources conducive to the development of local areas in accordance with the principles of sustainable development?
20. Which renewable sources in the region have the greatest development potential?
21. Which raw materials and phases of the technological process create the most pollution and how can they be minimized?
22. What is a necessary element of creating a market for renewable energy sources and how does it translate into their development?
23. How does the production of energy and the use of renewable energy sources improve efficiency?
24. How does the use of various types of RES installations in single-family and office buildings affect the saving of final energy consumption?
25. Is simulation modeling a good tool to assess the energy standard of buildings?
26. What are the possibilities of developing and using the potential of agricultural biogas for energy purposes in Poland?

27. Whether the determination of unit values for the allocation of greenhouse gas emissions to production of biofuels in the life cycle will reduce the emission of harmful gases into the atmosphere?
28. Will the introduction of rules in accordance with the Industry 4.0 concept to industrial plants improve their efficiency and reduce the emission of harmful gases and dust into the atmosphere and how?
29. Is it possible to monitor and manage the risk in the conditions of actual implementation of production processes?

The answers to the above questions were aimed at determining the economic, social and environmental effects under the influence of the applied factors of changes shaping development, taking into account contemporary trends in the national and international environment as part of the energy transformation.

Due to the lack of collective, original and current research, especially in the sector of private farms and enterprises on the local market, the presented publications provide the reader with the necessary knowledge on: the legitimacy of using RES, investment and ecological profitability. The research covered renewable sources with the greatest potential for use in Poland in various sectors of the economy. On the basis of the performed analyzes and research, they were compared in terms of various aspects: legal, technical, economic and climatic. The obtained conclusions will help the potential investor to make a rational decision on the right selection of specific RES for his investment and constitute a starting point for a discussion on the direction of development of the Polish energy sector.

The subject and, at the same time, the main area of research undertaken in the research work were the socio-economic, legal and economic conditions and environment related to renewable energy in Poland, which were examined in a measurable and immeasurable way. The analysis of the problem also takes into account international legal conditions related to the implementation of the EU climate and energy policy. The research as part of the scientific work covered entities involved in the energy value chain process, wholesale recipients and consumers of electricity, companies participating in the emission allowance trading system, as well as Polish and EU public administration bodies. The conducted research focused on entities operating in Poland. The time range of the research includes selected secondary data, with particular emphasis on the period 2019-2022. It is worth noting that the data was collected and analyzed from the actual implementation of production processes, which allowed to propose actions remedial and corrective production and service processes within the framework of the "just time" management philosophy. Two types of information sources were used in the research: sources of primary information, which came from production and service facilities, and sources of secondary information, which consisted of, among others: bibliographic items, including domestic and foreign literature on the subject, including in particular documents of a legislative; acts of Polish and EU law, statistical materials, industrial research, industry reports and studies, surveys and numerous internet sources. The following research methods were used in the individual stages of the research:

a) critical analysis of Polish and foreign literature on management and quality sciences and other materials constituting sources of secondary information,

b) direct observation, indirect observation and unstructured and targeted interviews,

c) the method of collecting data from primary sources as part of inspection visits to various production and service facilities and secondary,

d) the method of analyzing statistical data from primary sources (derived from collected empirical data) and secondary sources,

e) the method of logical analysis used in the creation of models and the analysis of the results obtained during the tests,

f) the method of synthesis, enabling the combination of the components separated by analysis,

g) method of mathematical and statistical analysis, enabling qualitative and quantitative presentation of the results of primary and secondary research,

h) scientific reasoning combined with the processes of induction, deduction and modeling, used in the interpretation and synthesis of research results and in the creation of models.

Mainly quantitative and qualitative methods were used to analyze research problems.

In quantitative research, measurements were made both in industrial plants as well as in private households and service premises. Based on the collected results, advanced statistical analyzes were conducted, such as factor analysis, regression analysis and multivariate scaling. The results of these studies allowed to determine the "scale" of the variables, compare them with each other and determine the factors influencing the studied phenomenon. Quantitative research was selected for the research because of its systematic nature and the possibility of its indispensable connection with statistics. The main tools used during the implementation of quantitative research were: questionnaires of direct interviews with production technologists and private physical entities as well as tools for observing the functioning of various implementations of production processes. A graphic form of the scale was used to represent the measured feature, because the measurement made it possible to accurately determine the scale value and to determine the differences in measurement units. In addition, descriptive statistics were defined for the values on the quantitative scale, such as: standard deviation or standard error of measurement. This method made it possible to measure hard-to-observe features in a practical way through mathematical transformations of a combination of many factors describing a given phenomenon, such as technical parameters of the devices used. In order to obtain reliable research results, the following were determined: sample size, population data were defined and a random method (probability, representative) was selected, then the obtained results were analyzed and interpreted using statistics. The results were presented in a tabular and/or graphical manner and interpreted and discussed. The obtained results were confronted with the results contained in other literature, on the basis of which cognitive and application conclusions were formulated.

In qualitative research, the author focused on a deeper analysis of phenomena so that, using special research techniques, e.g. in-depth method of knowledge management, environmental management, desk research to better and more accurately interpret the characteristics of the

analyzed research aspects. Desk research is a research method that consists in compiling, analyzing and processing data and information from existing sources, and then formulating conclusions on the basis of the researched problem. This is secondary research that opposes primary research. The use of these studies allows us to understand why certain features of the analyzed objects function in such a way and why the current construction solutions and mechanisms used are so commonly used. The research was carried out using: in-depth interviews, individual process observations, interpretation of industry documents and standards in order to broaden knowledge, update information and identifying prevailing general trends. The phase of the qualitative research project included: formulation of the research problem and research objectives, selection of research methods and techniques, selection of the sample, data collection, data analysis and interpretation, and presentation of the results. As part of the qualitative research, a research problem was identified using the existing literature on the subject, research gaps were sought, the purpose of the research was defined, research questions were formulated, research methods and procedures were selected, including research design, methods of data collection and analysis, and the results were presented, which were later used to creation of experiments and models of the studied problems. As part of the experiments, the influence of the independent variable on the dependent variable was measured. The obtained results of qualitative research allow to reflect a precisely defined character in a short time and contribute to the emergence of specific problems and methodological discourses. This makes qualitative research varied.

As part of the research, a number of calculations were made and many mathematical models were built regarding the forecast of the economic efficiency of the energy process based on the national energy potential and renewable energy sources. The models were based on historical data, thanks to which it was possible to observe the current trends and make an attempt to project into the future. All data has been obtained in a reliable manner and used in such a way as to reflect the actual parameters occurring in various sectors of the economy in the most objective way. The input data used in the model were divided into the following categories: macroeconomic, prices on energy markets, cost and energy indicators. The models took into account both factors affecting the economic efficiency of individual stages of the energy process, such as: selling prices of raw materials, fuels and energy, costs associated with a given process, but also examined how the competitiveness of energy was shaped from coal sources compared to obtaining energy from alternative sources. The models analyzed:

a) methods of management, organization and forecasting of electricity as part of its demand on the local market in the conditions of professional and prosumer power industry,

b) the possibilities of development economics and the use of the potential of agricultural biogas for energy purposes in Poland.

c) assessment of the value of allocation of greenhouse gas emissions for the production of biofuels in the life cycle using the LCA (Life Cycle Assessment) technique as part of sustainable energy management in the area of agriculture,

d) determinants of the use of knowledge management and environmental management resources to build business models in terms of a holistic approach to sustainable energy balancing in the housing sector in the conditions of energy transformation,

e) methods of managing production resources in a metallurgical enterprise in order to reduce energy consumption and reduce pollutant emissions,

f) methods of ecological and environmental risk management by energy-intensive plants on the local market, in accordance with the Industry 4.0 concept, towards improving the economics of their operation.

4.4. Structure and content of individual articles

✓ ***Key elements of the Polish energy policy strategy - theoretical introduction to the research problem***

The European Commission's vision outlines seven main strategic elements for Member States:

- maximizing energy efficiency, including zero-emission buildings,
- maximizing the use of renewable energy sources (RES) and electricity for the full decarbonisation of energy supplies in Europe,
- adopting the principles of clean, safe and connected mobility,
- competitive EU industry and circular economy as key factors in reducing greenhouse gas emissions,
- development of appropriate smart grid infrastructure and interconnections,
- full use of the advantages of the bioeconomy and the creation of the necessary carbon sinks,
- tackling the remaining CO2 emissions through capture and storage carbon dioxide (CCS).

Poland has been obliged by 2050 to:

- reduction of greenhouse gas emissions by 55%,
- increase in the share of RES in final energy consumption to 32%,
- improve energy efficiency by 32.5%.

Potential outline plan for full decarbonization of Poland in 5 key sectors of the economy was outlined by the Ministry of Climate and Environment. Within each sector, their key frameworks are presented:

- Energy:

- moving away from energy production from fossil fuels to renewable energy sources,
- a larger share in the total energy mix: solar and wind energy,
- necessary investments in new infrastructure,
- the introduction of nuclear energy in place of coal,
- modernization of CCUS in coal-fired power plants,
- use of biomass in the district heating network.

- Buildings:

- thermal modernization of buildings,
- replacement of high-emission energy sources with devices powered by energy from low-emission alternative sources,
- energy-saving and passive construction.

- Agriculture:

- dissemination of low-emission fuels in agricultural machines,
- low-emission land management,
- development of biogas plants,
- preventing the eviction of forest areas and protecting their function related to the reduction of emissions.

- Industry

- electrification of the heat generation process,
- the use of carbon capture, use and storage technologies,
- circular economy closed,
- use of biomass to replace fossil fuels and raw materials.

- Transport

- replacing internal combustion engine vehicles with electric vehicles,
- installation of fuel cells in coaches and trucks,
- sourcing of raw materials, processing and assembly into battery components,
- charging station infrastructure.

The implementation of the energy transformation in Poland must be based on the 3 main pillars of a just transition, a zero-emission energy system and good air quality. The main tool to achieve climate neutrality by 2050 is the energy transformation based primarily on the decarbonisation of the energy sector, as well as its decentralization and digitalisation. It can be achieved if all sectors of the regional economy contribute to the adoption of flagship projects and the setting of specific targets in efforts to reduce greenhouse gas emissions. These goals should be reflected in the national strategy - energy policy, and above all in the energy sector and climate plan to which Poland has committed to the EU. The main objective of the strategy can be achieved through the implementation of operational objectives regarding: improvement of air quality, high energy efficiency and development of renewable energy sources i energy storage technology. As part of the energy transformation, Poland, according to the author, should aim at:

- departure from the use of fossil fuels in the production of electricity and the generation of heat and cold,
- reduction of CO2 emissions to the level of 80-95% compared to the emissions in the 1990s,

- achieving the share of RES at the level of 70% in total energy production and 97% in electricity production,
- continuous improvement of energy efficiency in construction, transport, agriculture and the energy sector,
- promoting electroprosumerism,
- full electromobility of transport,
- use of electricity from RES in all areas of economic activity and life of residents,
- obtaining security of energy supplies based on industrial energy technologies storage,
- the use of innovative technologies, including the share of "green" hydrogen at the level of 13-14%, in accordance with the EU hydrogen strategy.

These assumptions meet the urgent needs to determine the directions of support for the energy sector. It diagnosed well-occurring climate change and its impact on society and the economy. Requirements and obligations towards the European Union regarding climate neutrality will be met if three main operational goals are taken into account in the transformation, i.e.: improvement of air quality, high energy efficiency and development of renewable energy sources and energy storage technologies. In Figure 3, the author proposes a road map that Poland should follow in implementing the climate neutrality desired by the EU, presented in Figures 4 and 5.

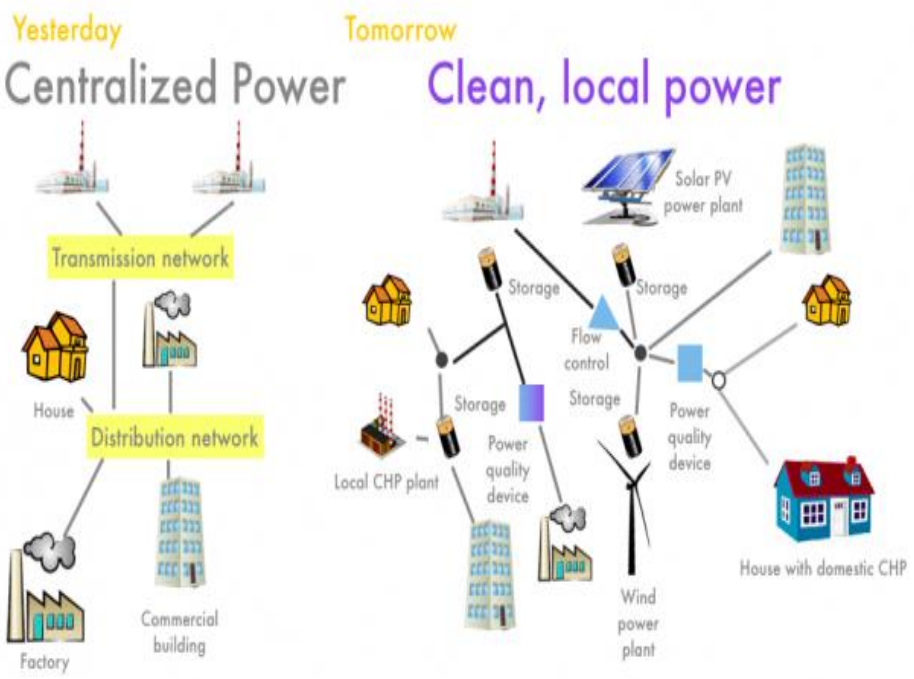

Fig. 3. Road map of the Polish energy transformation strategy.

Energy transformation
taking into account self-sufficiency electricity

Wind Energy at sea
installed capacity will reach:
approx. 5.9 GW in 2030 to approx. 11 GW in 2040

There will be a significant one **power increase** installed in **PV to**: approx. 5-7 GW in 2030 and about 10-16 GW in 2040

Increasing the share of RES in all sectors and technologies. In 2030, the share of RES in gross final energy consumption will be at least **23%**, not less than 32% in the power sector (mainly wind and PV) 28% in district heating (increase by 1.1 pp. y/y) 14% in transport (with a large contribution electromobility)

In 2030, the **share of coal** there will be no electricity generation exceed **56%**

Usage reduction carbon in the economy will be done in a way that ensures **fairness transformation**

Efficiency will increase energy - for 2030 **23% target set reduce consumption primary energy**

Investment programs will be focused on the development of RES and **active consumers** and balancing local

In 2033, the first unit of the **nuclear power plant** will be launched with a capacity of approx. 1-1.6 GW. Subsequent units will be implemented every 2-3 years, and the entire nuclear program assumes the construction of 6 units

By 2040 **heating needs of all households** will be covered by system heat and by zero- or low-emission sources individual

Natural gas will be the fuel bridging in transformation energy

In 2030 achieved will be the ability network transport gaseous mixtures containing about **10% of gases decarbonized**

It will undergo **reconstruction infrastructure** natural gas, crude oil and liquid fuels, and diversification of supply directions will be ensured

A number of activities will be targeted at **improving air quality**, **including**:
– development of district heating (4-fold increase in the number of efficient district heating systems by 2030)
– low-emission direction of transformation of individual sources (heat pumps, electric heating)
– **moving away from burning coal in households** in cities by 2030, in rural areas by 2040; by maintaining the possibility of using smokeless fuel until 2040.
– increasing the energy efficiency of buildings
– development of low-emission transport, in particular the pursuit to **zero-emission public transport by 2030** in cities over 100,000 inhabitants

Reduction of the phenomenon of energy poverty to the level of max. 6% of households

Development of energy technologies:
- storage energy,
- intelligent energy management systems,
- electromobility,
- hydrogen technologies

By 2030, GHG emissions will be **reduced by approx. 30%** compared to 1990

Fig. 4. Key elements of Poland's energy policy strategy.
Source: study based on the Ministry of Climate and Environment.

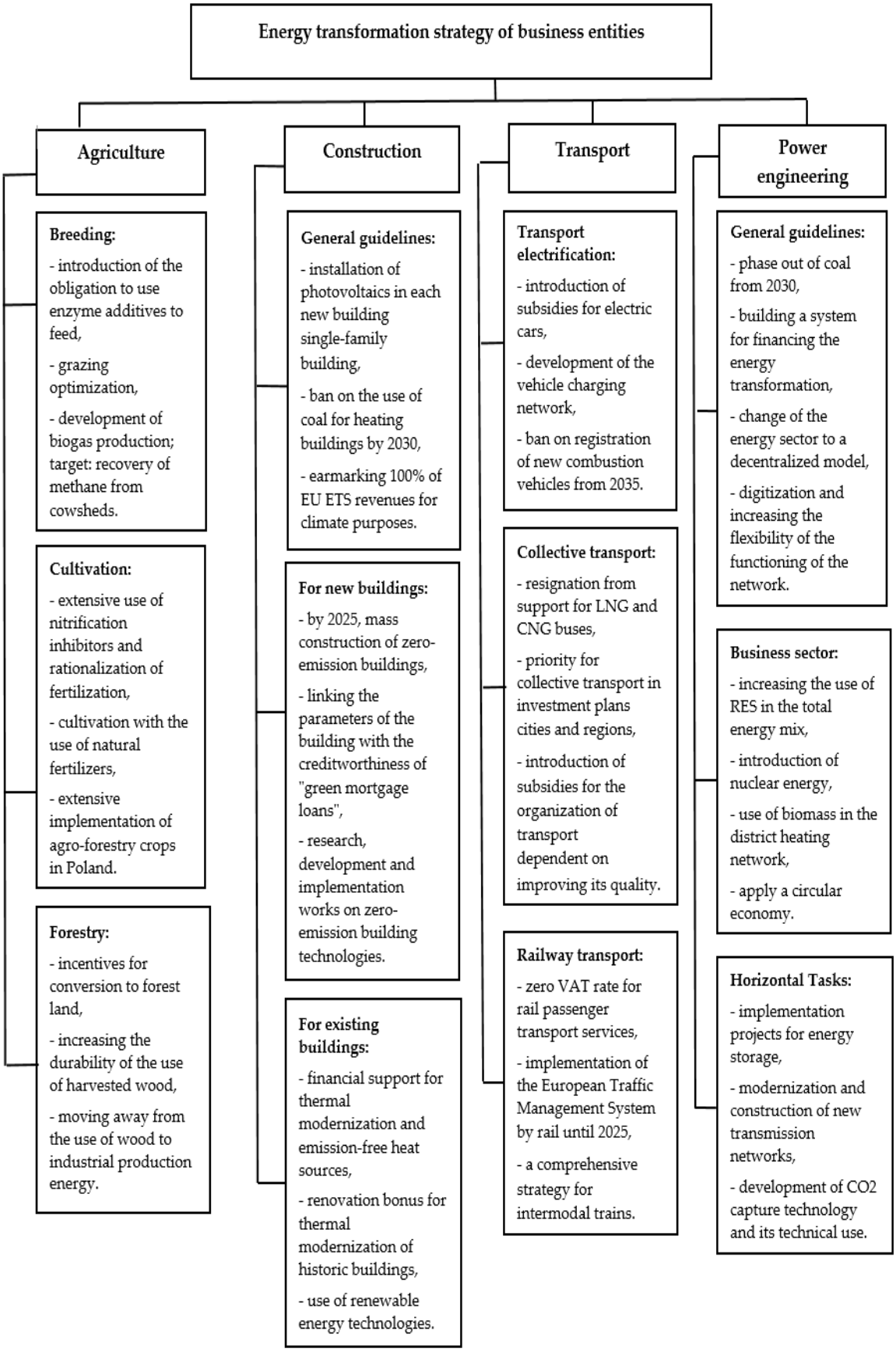

Fig. 5. Significant elements of the energy policy strategy of Polish enterprises in various sectors of the economy.

As part of the implementation of the strategy, Poland has developed 8 specific objectives:

1. Optimal use of own energy resources.
2. Expansion of the generation infrastructure and network electricity.
3. Diversification of supplies and expansion of the network infrastructure of natural gas, crude oil and liquid fuels.
4. Development of energy markets.
5. Implementation of nuclear energy.
6. **Development of renewable energy sources aimed at reducing CO2 emissions in important sectors of the economy: energy, agriculture, construction, transport and industry.**
7. Development of heating and cogeneration.
8. Improvement of energy efficiency.

The thematic scope of the publication, the presented research results and the author's recommendations aimed at implementing the adopted strategy of achieving climate neutrality by Poland, i.e. net zero emissions, are based on a detailed analysis of objective No. 6. The research has been divided into four main thematic areas: energy, agriculture, construction and industry. Transport and the related electrification have been deliberately omitted from the author's considerations due to the wide compendium of knowledge available on this subject in the literature. These sectors of the economy have a significant and real impact on the ongoing energy transformation in Poland, aimed at meeting the emission obligations towards the EU, and give a positive impulse to the national economy, ensuring its energy security. With this in mind, the author presents a collective compendium of cognitive and application knowledge in 4 main sectors of the economy and indicates directions to improve climate neutrality in national and regional terms.

✓ ***Substantive discussion of the content of individual articles submitted as scientific achievements***

▪ ***Main scientific and research achievements within the sector - Energy***

As part of this part of the research, the author:

- analyzed the effects of: economic, social and environmental combinations of three different scenarios for the development of the Polish energy sector, which, according to the author, are of strategic importance in the context of the country's energy security.

  The research was carried out using the scenario method based on intuitive logic. This method allowed to determine the road map of the Polish road transformation.

- developed aggregate results regarding the profitability of using all potential renewable sources in Poland.

The research was carried out using the NPV and IRR economic models, the results of which were used to calculate the costs of reducing greenhouse gas emissions as a result of replacing fossil fuels with renewable energy technologies.

- examined the capacity utilization potential of a wind farm in the national energy mix.

  As part of the research, a model for short-term forecasting of wind power was built using artificial methods intelligence - Pearson's universal kernel and its effectiveness for forecasting in real conditions was confirmed.

- built a model that will make it easier for operators of energy companies to effectively support their decisions in the actual forecasting of demand for electricity, which allows to reduce CO2 emissions due to the production of its surpluses.

  Measures of quantitative methods were used to build the model. On the basis of data from the distribution company, it was verified and an analysis of profits and losses was carried out in the conditions of actual operation.

- defined the determinants of the boundary conditions at which there is investment and economic justification for potential investors to make business decisions in the implementation of the project of electricity production for their own needs.

  To determine the determinants of investment in household photovoltaic PV micro-installations and solar collectors, the following were used: technical specification of devices, national and international, legal regulations. The collected data made it possible to perform technical calculations and propose construction solutions regarding the rules for selecting the optimal type of investment for a private entity in technical and economic terms.

The proposed methodologies go beyond the current assessment tools regulated by the energy policy and included in the available literature on a given subject. The analysis of individual companies allows you to optimize the choices made regarding investments in green energy in terms of: management (knowledge, environment), economic (investment costs, potential savings at the level of general energy costs); environmental (lower energy consumption, thus CO2 emissions, lower environmental fees); social (reduction of negative impact on human health). It can be concluded that the proposed methodology is a comprehensive tool for making rational "energy" decisions accompanying the production processes of the company, which in the context of its functioning in the changing conditions of the 21st century may give it a chance for continuous improvement and survival in a dynamically changing environment.

The energy sector is responsible for approximately 34% of greenhouse gas emissions in Poland. For over a decade, this sector has stood at the crossroads between urgent modernization and decarbonisation and maintaining the status quo in the mining and coal energy sectors. The increase in the prices of allowances in the EU ETS system, the declining competitiveness of domestic hard coal and other areas of climate policy, combined with the growing awareness of citizens and the development of RES, will lead to the "greening" of the energy sector. At the

same time, due to the progressive electrification of the economy, a significant increase in demand for electricity is expected.

The research carried out within the thematic scope "professional and prosumer power industry" was of research and analytical nature [**H1-H5**]. The research began with indicating the directions of development of low- and zero-emission sources in the process of transformation of the energy sector in Poland. This study analyzed the economic, social and environmental impacts of three using a scenario method based on intuitive logic different scenarios for the development of the energy sector in Poland. Each of them assumed a different structure of the combination of generation sources as the basis for the activity of this sector - from the predominance of coal-fired power plants, through a mix of various sources with the participation of nuclear energy, to the dominance of RES. The study provides a broad review of possible scenarios for the development of the Polish energy sector based on the draft national energy policy and determines the potential of using domestic energy carriers until 2050. In the further part of the study, the impact of each of the three scenarios on energy security and the country's economy was compared, taking as a basis strategic document "Energy Policy of Poland". Empirical research was conducted using the most up-to-date macroeconomic data illustrating cross-sector links in the Polish economy. The calculated individual investment and operating multipliers made it possible to estimate the effects macroeconomic for the considered development scenarios. The obtained empirical results allow, in particular, to claim that in the next 20 years it is possible to maintain a stable level of employment in the PV industry - depending on the scenario considered, from 25 to 45 thousand jobs. The results of this study present both positive investment aspects and a critical assessment of the opportunities and risks associated with the possible implementation of individual scenarios. The presented results and considerations are the starting point for understanding Poland's restraint in achieving zero emissions and are the knowledge base for determining the directions of development of the Polish energy sector.

In the further part of the study, the economic efficiency of renewable energy sources (RES) technologies was assessed and the ecological benefits of using these technologies were assessed. The key to deriving credible systemic conclusions in the proposed studies [**H3-H5**] was the microeconomic assessment of RES technologies, the generalized results of which allowed to calculate the marginal costs of reducing greenhouse gas emissions due to the replacement of fossil fuels with energy from renewable sources. The research nature of the work resulted from the need to obtain original, reliable and verified input data for the model of comparative economic assessment of various RES technologies. The most popular RES technologies in Poland were adopted for the analysis. The data was collected by means of a survey using specially prepared forms describing representative operating installations for various technologies and using the database of the European Center for Renewable Energy on completed investments in the RES sector. The collected data was verified by conversations with users, and in justified cases by a visit. The tool for conducting comparative economic and financial studies based on the obtained input data was the methodology of data analysis and results evaluation, consistent and uniform in relation to all sources and technologies. This methodology was based on the concepts of discounted inflows and outflows defined in English-language literature as cash flows. This method typically led to the determination of such

economic parameters of the investment project as: net capital value (NPV), internal rate of return (IRR) and payback period (PBT). The variable parameters considered in the assessment of the conditions for the profitability of investments in renewable energy were: the level of investment subsidies, the preferential interest rate on investment loans, the accelerated depreciation rate, the VAT on equipment, a reduced rate or exemption from income tax, and a possible surcharge to the price of energy sold by an independent supplier of energy from renewable sources to the grid. The economic assessment of the use of renewable energy technologies was supplemented with an assessment of ecological benefits. The ecological assessment criterion adopted in the paper was the assessment of the potential and costs of reducing greenhouse gas emissions as a result of replacing fossil fuels with renewable energy technologies. The developed calculation sheet made it possible to assess the profitability of any investment, assuming specific data on the amount of investment outlays, the method of their financing, operating costs, tax burdens, the method of depreciation and revenues over a period of up to 20 years. The following indicators were used to assess profitability: repayment period, net present value of future cash flows (NPV), internal rate of return (IRR). essential element of the analysis a pro forma profit and loss account and a statement of cash flows. The financial result in a given year took into account: revenues from the sale of electricity, operating costs, which include: annual costs of inspections and repairs; additional service charges, other repair costs expressed as a percentage of investment outlays incurred for commissioning, depreciation of the entire investment, interest on repaid loan, income tax. The net profit obtained was the basis for determining cash surpluses in a given year. The second method of economic evaluation of the investment project that was used in the calculations was the updated value of future net cash flows (NPV). This method is based on the discounted cash flow methodology. The NPV calculations were made according to the following principle: the present value (ie for year "0") of cash flows discounted in each period at the cost of capital (discounting rate) was determined; the sum obtained discounted cash flows were defined as the NPV of the project and if the NPV was positive - the project was accepted, if not, it was rejected. The NPV method was supplemented by the IRR (internal rate of return) method, defined as a discount rate that equates the present value of expected cash flows with the present value of expected costs (investment) and the payback period (PBT). The economic assessment of the use of renewable energy technologies was supplemented with an assessment of ecological benefits. The ecological criterion adopted in the work was the assessment of the potential and costs of reducing greenhouse gas emissions as a result of replacing fossil fuels with renewable energy technologies. In addition, the article [**H3**] presents the results of calculations of the leveled emission reduction costs and additional parameters: the leveled annual cost of GHG emission reduction expressed in PLN CO2 equivalent for the use of a given RES technology, expressed in tonnes of CO2 eq/year, using the GWP conversion factor corresponding to the 100-year period of GHG presence in the atmosphere. Some of the RES technologies are characterized by a negative leveled cost of GHG emission reduction (solar collectors, a small hydro power plant and technologies for the use of landfill gas and slurry biogas), others have positive emission reduction costs. Negative costs meant that reducing emissions practically does not require additional costs, on the contrary, it brings profits in the long run.

Based on the constructed economic model for the assessment of investment profitability with highly correlated data from PV installations, which are very often omitted in the literature, it has been shown that the analyzed projects will start to bring, depending on their type and technical specification, measurable economic benefits in the form of a reduction in the amount of energy purchased in on an annual basis and environmental benefits in the form of reduction of carbon dioxide emissions into the atmosphere. In addition, the calculations indicate a high potential for the use of some renewable sources in Poland, which contributes to the fulfillment of energy and emission obligations towards the EU. The analyzes and research of the Polish energy market with the use of the presented models showed that the project in their implementation is fully economically justified and will allow investors to make a rational decision on the right selection of specific RES for their investment. The presented economic models for assessing the profitability of investments in RES can be successfully used in other countries, and may also be a starting point for discussion on the direction of development of the energy sector.

The article recommends that the use of energy from renewable sources, in addition to measurable market elements of costs and benefits associated with the implementation of these projects, there are also the so-called. external costs and benefits that are not priced in the market. You can mention here, for example:

- on the side of potential external benefits:
  - positive impact on local labor markets by creating additional jobs in the production and operation of small renewable energy equipment,
  - beneficial, synergistic links between the development of renewable energy sources (especially biofuels) and the introduction of structural changes in agriculture, necessary both from the point of view of improving the economic efficiency of agricultural production in Poland and due to the requirements of the process of joining Poland with the European Union,
  - reduction of emissions of local air pollutants (SO2, NOx, dust, heavy metals) and thus reduction of economic losses (currently only partly compensated by emission charges) caused by: degradation of forest, agricultural and water ecosystems, accelerated corrosion of building elements, machinery and equipment, adverse effects of pollution on human health, etc.,
  - increase in political prestige (both at the level of local communities and the whole country) in connection with the care for natural environment and sustainable economic development, and creating the possibility of reducing the civilization gap between rural and peripheral areas and urbanized regions, as well as increasing entrepreneurship by introducing new technologies in the country,
  - easier fulfillment of the country's international obligations regarding the reduction of emissions of local pollutants and greenhouse gases (mainly CO2), and thus reducing the costs of actions that must be taken to achieve the national emission limits required by relevant conventions.
- and on the side of potential external costs:

- land takeover (this applies only to those cases where there are alternative, economically attractive ways of land development),
- problems in the labor markets of traditional energy carriers (e.g. in the coal sector), which may accompany a decrease in demand for these carriers due to the large-scale development of renewable energy.

An individual entrepreneur does not take the above factors into account when making economic decisions. However, these elements should be taken into account by local governments and central state administration, because the company does not currently feel their effects, neither on the side of costs nor on the side of benefits. External costs and benefits can be internalized, i.e. introduced into the market system through appropriate legislative initiatives and executive decisions both at the level of the central state administration and local government authorities. Examples of already existing methods of internalization include: applicable fees for the economic use of the environment, which mainly burden conventional energy technologies; obligation to purchase electricity and heat from renewable sources by energy network operators at a higher price; redistribution of fees for the use of the environment to subsidize ecological investments, etc.

Research results obtained in publications [**H3-H5**] in which, among others, that investments in specific renewable energy sources, depending on their type of application, location and technical specification, will bring measurable economic benefits in the form of a reduction in the amount of purchased energy and environmental benefits in the form of reduction of carbon dioxide emissions into the atmosphere, prompted the author to conduct further research on energy forecasting on the local market [**H1-H2**]. The purpose of these articles was to forecast: the demand for electricity from the commercial power industry on the local market [**H2**] and taking into account the installed selected RES technologies [**H1**]. The development of effective forecasting models gives measurable economic benefits from investments in renewable energy projects. With this in mind, the author used quantitative methods to perform these studies as measures of forecasting demand for electricity. For the development of the local energy market short-term forecasts with a horizon of 1 to 2 hours are needed. These forecasts (especially the one one hour before the delivery) must be subject to the smallest possible error, as it is on the basis of this forecast that decisions on balancing activities on the local electricity market are made. To achieve this goal, forecasting models based on classical methods and artificial intelligence methods were built. Due to the periodic nature of the examined time series, a detailed analysis of seasonality and periodicity of a given signal was carried out using spectral analysis and autocorrelation. After selecting the forecasting model, a number of analyzes were carried out on the possibility of using this model in forecasting the hourly demand for electricity. The purpose of this analysis was to demonstrate the possibility of balancing energy shortages on the local market. The most desirable value of the forecast error is the ±1% range, as the balancing price includes band is the smallest. This is due to the regulations of the balancing market, where there are three different deviation prices, separate for purchase, sale and for the ±1% deviation band. The proposed system for balancing deviations on the hourly market was based on comparing the forecast made an hour before delivery with the forecast made a day earlier for the same hour. The results of the analysis of

the application of the balancing system on the local market using the SARIMA hourly forecasting model showed that the profit of using the system is in the order of 2-9%. Despite the large range, these results are very promising. In order to improve this result, as part of corrective actions, an expert system based on the principles of fuzzy logic was developed to support decision-making on including or excluding a given hour in the balancing system. This system analyzes the forecast error from the previous hour and the differences between the forecast and the actual value in the previous day. Based on this information the risk of balancing the selected hour is assessed. The creation of a local hourly electricity market, taking into account the author's forecasting model, has become possible and profitable, and the mutual cooperation of electricity producers and distribution companies brings measurable financial benefits to each party of this market.

As part of examining the effectiveness of using energy forecasting methods for various RES installations, the author in paper [**H1**] presented the results of research for one of the wind energy installations. Since wind energy is characterized by high variability of output power and low availability, it is therefore necessary to predict their future energy production for economic purposes. The aim of the work was to develop and test forecasting methods to increase the accuracy of wind power prediction using artificial intelligence methods. The study investigated the potential of various Gaussian process regression (GPR) models based on kernel functions. In particular, the proposed models were dedicated to short-term prediction. The analysis was based on the operation of 6 wind farms located in Poland. A total of 120 sets of input data were selected for training and testing the proposed models, and then their impact on changing the accuracy of the forecasts made. As a result of the conducted research, various structures of forecasting models were proposed and tested in order to select the most advantageous variant. The developed models based on the GPR method were compared and the Pearson Universal Kernel (PUK) model was indicated for the possibility of effective forecasting. The prediction results of this model turned out to be the most accurate and are consistent with real values, which allowed to verify the feasibility and effectiveness of using this model for forecasting. In a sea of data, machine learning methods effectively create forecasting models without the need for the analyst's tedious interference in data preparation and multi-stage analysis. The proposed models allow for any frequent updating of the form of forecasting models, even after each completion of the data set, and enable making forecasts comparable or often better than the models, which confirms their effectiveness.

As part of this part of the research, a wind energy forecasting system based on multiple machine learning methods was proposed. It was shown that all analyzed models generated forecasts with similar, high accuracy. The GPR-PUK model, with a MAPE of 18.5%, was the most accurate of all analyzed. This method of forecasting has not been studied too often in the literature so far, so it is difficult to compare the obtained results with studies by other authors. The results presented in the form of error rates, scatterplots, tables and Taylor diagrams confirmed that all presented methods can predict energy production in advance and with high accuracy, although there are some differences in the results. Within this research, efforts were made to create various regression models based on kernel functions, i.e. GPR-RBF, GPR-Poly and GPR-PUK, which can be used to predict the power output of wind turbines. The feature-based GPR-PUK model was found to be Pearson VII kernel makes predictions accurate and

outperforms other models for this dataset. Moreover, the PUK kernel model showed a better agreement with the observed data based on scatterplots of actual and predicted values, indicating that it has the potential for wider applications in the analyzed forecasting. Specific cases have been studied with both very accurate energy production forecasts and large errors. In stable weather conditions with moderate wind speeds, all models predicted wind energy production with high accuracy, but when meteorological conditions are very unstable or wind speeds are extremely high, we can expect an increase in prediction errors. In the case of the proposed method, the accuracy of the numerical weather prediction forecasts and a sufficiently long database with wind energy production and a similar level of wind turbines installed on the tested area have a large impact on the results. area. For extreme weather conditions that were not present in the training dataset, the results of this method may have unexpected errors. As part of future work, I plan to develop a larger sample size that will not only give the best possible prediction, but also produce probabilistic information to aid in the decision-making process. In addition, future research will focus on testing and using other algorithms such as XGBoost, evolutionary polynomial regression and gene expression programming to predict wind farm energy production.

- ***Main scientific and research achievements within the sector - Agriculture***

As part of this part of the research, the author:

- analyzed the raw material base for obtaining biogas from bio-waste and made calculations on the basis of which he determined the efficiency of agricultural biogas for energy purposes, taking into account the general mass balance,
- determined the amount of biogas production, including: the amount of energy required for the aggregate with the assumed power, the amount of clean electricity and heat produced without CO2 emissions, the daily production of biogas required to obtain the required amount of energy,
- determined dry organic matter from cattle breeding,
- determined the daily production of biogas from slurry from cattle breeding,
- calculated the daily production of biogas from organic waste and maize silage,
- determined the total mass of the raw material feed directed to the digesters, including dry and wet organic mass,
- calculated the heat demand for heating the fermentation chamber batch by the production of thermal energy that can be used in the cogeneration process,
- author estimated daily demand for maize silage and on this basis he determined the requirements of the cultivation area,

The result of these studies was the construction of a diagram of the mass balance of raw materials and products for the installation processing into biogas: maize silage, organic waste and slurry from cattle waste. Data for the research were taken from sample households.

- analyzed the biodiesel production process and determined all the components during the cultivation of the raw material affecting the emission level of the biodiesel production process to power agricultural machines and more,
- performed calculations based on different allocation methods and determined the overall mass balance of the entire production process based on shares in mass, energy and finance.

In order to achieve the emission targets set by the EU for Poland, it is necessary to prioritize the development of renewable energy technologies within the energy sector. Reducing the emission of harmful substances into the air requires a number of actions to be taken at the same time. Agriculture plays an important role in this respect as part of the country's sustainable development. In recent years, it has become, through the acquisition and use of biogas, an important sector of the economy towards the development of renewable energy sources. The existing sources of biogas (landfills, sewage treatment plants, agricultural biogas plants) are only a small part of its production capacity. Currently, biogas can be produced in energy biogas plants only from biomass, e.g. silage, corn or cereals. Large-scale production of biogas can increase the energy security of the country, reduce the state's gas deficit, become independent of gas imports and meet EU obligations regarding the production biofuels and renewable energy. The aim of the article [**H6**] from the series of thematically related publications was to present the current state and prospects for the development of the market of agricultural biogas producers in Poland. As part of the research, raw material bases for obtaining biogas from bio-waste were analyzed and the efficiency of agricultural biogas for energy purposes was determined. Based on the collected data and assumptions, calculations were made to estimate the energy potential of biogas produced from agricultural raw materials, taking into account the general mass balance. The conducted research shows that in the case of farms dealing with plant breeding and production, there are premises to obtain the appropriate amount of waste for the production of biogas, and consequently for the production of electricity and heat. Biogas production can be based on waste material of agricultural origin, both animal and plant. The use of a substrate in the form of a mixture of slurry with silage from corn yields about 6,968,000 m3 of biogas, the possibility of utilizing slurry, and the production of about 16,000 MWh of "green electricity" in cogeneration systems. Corn silage co-ferment used for biogas production has a high energy potential and stable quality, thanks to which it is possible to plan stocks for the supply of biogas plants. In addition, the use of biofuels has a positive effect on the environment, as it reduces the use of natural resources of fossil fuels and contributes to reducing the greenhouse effect. The production of agricultural biogas also allows the use of waste from the agricultural and food industry as well as manure and plant waste produced by farms for the production of both ecological fuel and natural fertilizers. Thanks to this, it is possible to prevent the risk of biogas leaking into the atmosphere, which contributes to reducing the greenhouse effect and reduces the risk of uncontrolled fires caused by farmers burning waste. In the agricultural biogas production process, using a smaller amount of substrates (manure and plant waste), it is possible to produce about 50% more of the final product than during the production of landfill biogas, due to the biochemical composition of the substrates, and thus - a simpler and more cost-effective way their fermentation, which fits perfectly into the trend of Poland's energy transformation.

An important element of research in this field was the detailed analysis in [**H7**] of the potential for reducing greenhouse gas emissions using the LCA (Life Cycle Assessment) technique in the production of biofuels. Thanks to the allocation methods, i.e. the distribution of the total GHG emission between each of the products resulting from the production of biofuel, it is possible to reduce the emission of these gases by up to 35% compared to the production and combustion of fuels derived from crude oil. As part of this work, the biodiesel production process was analyzed in terms of greenhouse gas (GHG) emissions. Based on the obtained results, key factors affecting the level of emissivity of the biodiesel production process were identified. In addition, all components of GHG emissions generated during the cultivation of the raw material used to produce the final biocomponent were determined and their validity was determined. Rapeseed - an agricultural raw material most often used in Poland for production of vegetable oil, from which fatty acid methyl esters are produced at a later stage. The calculations made as part of the research were based on real data obtained from various entities. The obtained data were averaged and used as input data for calculations of greenhouse gas emissions. To assess the sensitivity of the results of the adopted allocation method, calculations of GHG emissions were made using the allocation method based on mass, energy and financial shares. Due to the fact that for the purposes of meeting the requirements of Directive 2009/28/EC, the GHG emission for the cultivation stage is given in g CO2eq per 1 MJ of the obtained biofuel, the obtained emission per ton of agricultural raw material was calculated taking into account all subsequent processing processes. In the case of rapeseed, these are most often processes leading to the production of fatty acid methyl esters (FAME). For this purpose, calculations were carried out using conversion factors for a given process processing and emission allocation coefficients were applied, taking into account the type of obtained products: main and by-products. As part of the research, the allocation was carried out:

- based on physical quantities (mass, energy content),

  This method is based on assigning GHG emissions to each of the resulting products and by-products in direct proportion to their achievement (based on a mass or energy balance). If the allocation method was adopted on the basis of a mass balance, the mass of the main products and by-products was initially calculated. Then, on the basis of their percentage shares in the total mass of production (the sum of the masses of the main product and the by-product), they were assigned a percentage emission volume.

- based on economic size,

  Allocation based on economic size gives the least stable and hardly comparable results. The allocation may be made on the basis of market prices of raw materials and final products, incurred costs of production, storage, transport of the final product and by-products. Analyzes carried out in different regions of the world may differ from each other, because the prices of raw materials and by-products, as well as production costs may vary significantly depending on the economic policy of the country and the location of the region.

- based on an extensive system,

Allocation carried out by the extended system method is used especially by scientists from the USA. According to the concept of this method, the boundaries of the system are extended to include alternative products. Activities not related to the life cycle of a given product are also included in the calculation. At the beginning, it is necessary to define the amount of biofuel and by-products produced and the products that are on the market and can be replaced by by-products resulting from the production of biofuel. Then the ratio to which the products can be replaced by by-products of the biofuel production process is calculated, and then the environmental impact of the products we want to replace is determined. It may turn out that the replacement of existing products on the market with by-products of the biofuel production process will reduce the negative environmental impact in the life cycle of the biofuel.

Summing up this part of the research, the article discusses recent advances that potentially enable a sustainable energy transition, green economy and carbon neutrality in the biofuels sector. The work showed that the technology used for the production of biodiesel is of great importance for sustainable development. The possibility of using renewable raw materials for the production of fuels leads to a reduction in the consumption of minerals and lower emission of pollutants. It has been shown that during the combustion of biodiesel, the amount of gases released, with the exception of nitrogen oxides, which is an increase by 13%, of other components is significantly lower: CO2 - 78%, CO - 43%, SO2 100%, PM10 - 32% and volatile hydrocarbons - 63%. In addition, biodiesel was found to biodegrade 5 times faster in the environment than diesel. Additional highlights from these studies include:

1. Pollutant allocation reduces total GHG emissions in the life cycle of the main product (biodiesel) by about 31%, as the emissions are split between it and the by-product (glycerine).
2. The least favorable method of GHG emission distribution is financial allocation, because its result depends on the prices of raw materials used for production and the prices of final products and by-products, which may vary in individual countries of the world. The high price of biodiesel in relation to the price of glycerine makes the total GHG emission for the main product the highest.
3. The allocation of pollutants based on mass shares is the most advantageous method of GHG emission allocation, because the allocation of its percentage shares is calculated on the basis of the actually produced quantities of the main product and by-product during the year. The total amount of greenhouse gas emissions attributed to the main product is the smallest.
4. Carry out allocation of GHG emissions for one stage of the biofuel life cycle - transesterification - does not significantly affect the total value of the generated greenhouse gases, because this cycle does not consist only of the production process, but also the cultivation and storage of raw materials, transport of raw materials to the plant and transport of final products to recipients.

- ***Main scientific and research achievements within the sector - Construction***

As part of this part of the research, the author:

- based on a multi-criteria analysis, it assessed the development of smart buildings, taking into account the changing socio-economic conditions,
- using computer simulations and using knowledge and environmental management tools, he developed a business model on the example of a photovoltaic installation of a building and supplying it with heat with almost zero energy consumption, indicating the significant importance of heat losses and gains in heating installations,
- on the basis of the standards, he assessed the energy standard of office buildings and the possibility of their design in the framework of sustainable construction technology,
- based on the requirements of energy-saving construction, he presented the assumptions and results of the analysis of calculations of the use of energy installations in residential buildings using RES resources to balance energy consumption in various areas of its use,
- made calculations regarding the impact of the use of installations using renewable energy sources on the energy performance of a building of different size the quality of partitions and improvement of the energy and ecological efficiency of used fuels from non-renewable sources,
- validated the calculation model of heat loads in buildings using simulation tools based on the PN-EN ISO 52016-1:2017-09 standard and proposed load conditions for new generation buildings and recommended specific heat sources for these buildings.

Electrification of heating systems in construction is becoming a necessity and an obligation. This is the best way to reduce greenhouse gas emissions. One of the basic challenges of the modern world is to reduce energy consumption in residential construction. This is due to economic and ecological reasons. The higher the consumption, the higher the emission of pollutants into the atmosphere. Reducing consumption also has an impact on increasing the energy security of the world. Taking into account the entire life cycle, buildings consume about 41% of primary energy in Poland and are responsible for 38% of carbon dioxide emissions. The problem of poor air quality in our country is related to CO2 emissions from the construction sector, which is largely caused by the emission of dust pollutants from solid fuel boilers (the so-called low emission). Most existing buildings have an energy standard that is far from the 2021 energy standard for all new and refurbished buildings. On the other hand, the target, from the point of view of Poland achieving climate neutrality in 2050, should be the zero-emission standard of the building, understood as the zero value of the CO2 emission factor included in the building's energy performance certificate. As a result of reducing the energy demand of buildings, it will be possible to reduce over 46 million tons of CO2 and almost 90,000. tons of dust per year. The introduction of "deep" thermal modernization of existing buildings will reduce energy consumption by approximately 35-85%. Optimization of energy consumption, with particular emphasis on reducing primary energy consumption, and at the same time also emissions of pollutants into the environment, is one of the most important activities of the European Commission as part of the climate goals and strategies. There are at least two ways to achieve the zero-emission building standard defined in this way. The first is to achieve the

maximum technically possible energy efficiency of the building i generation of the rest of the required energy from RES within its balance limit. The second - on achieving an economically effective standard of energy efficiency of the building and covering the demand for energy from zero-emission heating or power networks.

With this in mind, articles [**H8**] present various variants of thermal modernization of both private and service buildings, taking into account research on the quality parameters of external partitions and the selection of an appropriate source of RES heating installation. The results presented in this part of the research will allow future investors to make an informed decision in the selection of the appropriate thermal modernization variant to meet the legal requirements for their building. The presented variants take into account various degrees of energy efficiency achieved and aspects of economic assessment of the incurred expenditures.

The single-family house and office building used for the research were designed for the needs of the Engineering Project on the basis of a study on an energy house. The object was spatially modeled in the Termocadia program by Intersoft, and then thermal calculations were carried out on it in the compatible ArCADia TERMOCAD 7.1 program in accordance with the PN-EN 12831 standard. In accordance with the requirements of energy construction, the building partitions were selected: windows, doors, flat roofs, internal partitions, floor, three variants of external walls were subjected to a detailed analysis. Subsequently, the RES equipment necessary to determine the facility's demand for primary and final energy was selected and the energy performance of the building was made. As part of the research, the impact of the use of selected RES resources (i.e. heat pump, photovoltaic installation, induction boiler, mini wind farm) on the energy performance of the building was analyzed by performing variant calculations of the demand for non-renewable primary energy for various options of equipping the building with heating installations using RES resources . The obtained test results allow in most cases to significantly reduce their EP indicators of demand for non-renewable primary energy. The following variants were analyzed for the considered building use of RES installations for energy supply for central heating needs and hot water preparation In the calculations of energy characteristics, the values of heat transfer coefficients were assumed for external partitions and separating heated and unheated spaces, equal to the maximum values in force in the standards. Calculations were carried out for different values of heat transfer coefficients for external partitions, applicable in a given period of their construction.

The use of renewable energy sources to supply buildings with heat can significantly reduce their EP indicators of the demand for non-renewable primary energy. The presented case studies also show that obtaining a favorable EP index does not mean a favorable value of the EK index of final energy demand, and vice versa. Each time, the decision to use a given building energy supply solution should not result from the analysis of only one of these indicators, but should take into account the mutual correlations between these individual indicators of the building's energy demand. Greater savings effects are obtained for older buildings due to their originally higher energy consumption. In most cases, the mere replacement of a conventional source with a RES-based source is sufficient for the value of the EP indicator for a building after reconstruction to be lower than the reference value. The exception may be heat pumps whose drives use electricity from the national power system, powered by electricity generated in conventional sources. In these cases, the high non-renewable primary energy input factor set

for the driving electricity is of decisive importance. Improving the energy performance of a building means saving resources of non-renewable primary energy. For existing buildings, replacing conventional sources with renewable energy sources may be the most effective method of their thermal modernization. In order to encourage building owners to use renewable energy sources, it is necessary for the state to create a wider support system and to modify the existing regulations, enabling them to operate prosumer on the market.

The current state of the energy quality of newly built buildings in Poland results from national standards specifying the permissible thermal insulation of building partitions or the maximum value of the reference indicator of the annual unit demand for non-renewable primary energy. The analyzes carried out in the articles show that in each type of buildings (including public buildings) where installations using RES will be used, it is possible to reduce the demand for conventional final energy in their energy characteristics and thus, in most cases, increase their energy efficiency . Such undertakings are eligible means of improving energy efficiency in this sector of the economy. If the use of installations using RES resources is also implemented in public utility buildings and farm buildings to cover their energy needs, then for the entire stock of newly commissioned or thermomodernized buildings, we will achieve a significant improvement in the energy efficiency of using conventional carriers. This trend will greatly enable the implementation of the national ones tasks in the field of final energy savings, resulting from the provisions of the European Union Directives. The most important results of this part of the research that should be emphasized include:

1. Using a heat pump instead of a solid fuel boiler, the amount of CO2 emitted to the atmosphere is reduced by almost 90% per year and amounts to 2,935.83 kg CO2/year with an air-source heat pump and 3,196.79 kg CO2/year with a ground-source heat pump .
2. "Zero emission" occurs in the case of solutions in which the consumer himself produces the electricity needed to power the heat pump or induction boiler. Variants with the generation of electricity using a turbine with a vertical and horizontal axis of rotation, as well as using a photovoltaic installation, are presented.
3. The fusion of a heat pump with a system of photovoltaic panels is a solution that can be profitable for both ecological and economic reasons. The use of such a hybrid system makes it possible to make the cost of heating independent of external prices, which may be beneficial in view of many changes on the markets.

   Investing in a heat pump is profitable. This is shown by the break-even point that appears in the 9th year of the analysis - in other words, in the 9th year the sum of the costs incurred for the investment is less than the amount obtained as a result of investing cash and operating the pump. If we use the self-consumption of the heat pump with PV, we fully use the electricity produced by the investor's panels and the payback period is significantly shortened. In addition, using the current government subsidy programs, this investment is fully justified economically and ecologically.

   The direction of development of such a hybrid solution is certainly storage systems (both heat and electricity). Such devices, if their operation was economically justified, could further increase the self-sufficiency of a household in the context of energy purchase.

4. Using a solution with renewable energy sources from a highly energy-intensive building with energy class F house can become a passive house with energy class A+ with little effort. The household is then energy self-sufficient and is not affected by possible increases in energy prices or power outages.

Renewable energy installations, as an alternative to conventional systems, should become a standard in the design of low-energy buildings. In the near future, a regime of almost zero energy consumption standard will be imposed for newly commissioned buildings. Achieving these standards in the demand for final energy requires the inclusion of local RES resources to cover these needs by designing mono- or bivalent installations in buildings, powered by energy obtained from renewable sources. The main energy needs in residential buildings relate to heating and ventilation of rooms, which results from the statistical structure of energy consumption in individual areas of its use. If the main activity rationalizing the demand for final energy for the building is focused on improving the energy efficiency of the heating and ventilation system and the installation for the preparation of domestic hot water, then we can achieve the maximum effect energy and ecological. These activities should include thermal modernization of building partitions and implementation of central heating installations to the maximum extent. and hot water, using RES resources to cover the required energy needs of the building. Targeted and well-thought-out actions to rationalize the consumption of final energy for buildings should no longer be a challenge, but should be a necessary task in a sustainable economy.

The summary of research in the field of the construction sector is the work [**H9**], in which the author, taking into account the importance of implementing sustainable development of enterprises in the conditions of energy transformation, presents the methodology of the essence of how to effectively manage a company in a changing environment. The article presents the essence of the phenomena, the necessary changes in the enterprise management strategy and their scope, which are a key factor in their adaptation to the environment and the challenges of the green transformation. As part of the own research, an algorithm was built on the basis of which the essential elements of the energy policy strategy of Polish enterprises in various sectors of the economy were determined. In a holistic approach, a business model for the functioning of knowledge-based enterprises was built and tested for an example energy company, i.e. a prosumer/customer of a photovoltaic installation. In the case of a photovoltaic installation, an important advantage of the presented one of the business model is the creation of high social value and the possibility of obtaining effective environmental protection. Analogous models can be built for: a local biogas plant, construction, transport and industry, taking into account legal, environmental, social, technical and management conditions. The proposed business model in the knowledge-based economy makes it possible to respond to flexible adaptation to frequent changes on the energy market and to the changing needs of customers. In addition, this model fully corresponds to the pillars of the knowledge-based economy, creating innovative solutions and giving opportunities for the development of technology and entrepreneurship at the regional level in Poland. The conducted research on the use of the knowledge and environment management method in innovative processes allowed the formulation of the following conclusions:

- Increasingly, knowledge management is used by enterprises as an effective tool to change the way they operate and adapt to changes in the environment in the conditions of the ongoing energy transformation. These resources, which are inexhaustible, enable: quick and flexible response to the needs of the dynamically changing market and making the right strategic decisions.
- The use of a photovoltaic installation in an enterprise based on a business model is justified in practice and allows to reduce electricity costs incurred by the enterprise, in this case by about 60%.
- Thanks to knowledge management aspects, it is possible to analyze the distribution of energy, broken down into energy consumed and sent to the grid, as well as taking into account the amount of energy produced by the photovoltaic installation, depending on weather conditions.
- Based on the analysis of the measurement results, the annual energy consumption oscillates around 850 MWh, and the installed photovoltaic installation covers over 60% of the total demand. These data give a positive assessment of the functioning of business models and their effective use for various investments in RES.
- The savings generated in a relatively short period of time from the analyzed pro-consumer installation prove that this installation allows to significantly reduce electricity costs. Taking into account the result for the calculated payback period of 3 years, it proves that such an investment is very profitable for the company.

Summing up, the conclusions resulting from all the research allow us to conclude that the use of a photovoltaic installation in an enterprise based on the business model of knowledge and environmental management has its practical justification. Taking into account both the work efficiency and the economic background, high energy yields can be seen, and as a consequence, a significant reduction in the costs incurred by the company for electricity consumption.

- ***Main scientific and research achievements within the sector - Local industry***

As part of this part of the research, the author:

- made a logistic system model using simulation tools on the example of a hot-rolled steel strip rolling mill, taking into account material flow and storage subsystems, on which experiments were carried out to obtain results on how the implementation of the Industry 4.0 solution will improve the effectiveness and efficiency of the analyzed production line aimed at reduction of CO2 emissions,
- based on the collected real empirical data from the rolling process, the author built a model of electricity and natural gas consumption in the walking furnace, on which research experiments were conducted to reduce the cost of manufacturing the final product, depending on the rolled rolling program,

- made calculations of energy costs based on the heating curve and recommended ways to prevent and reduce the plant's environmental impact by 56.7 thousand tons of CO2 per year, which allowed to reduce the prices for the purchase of emission permits,
- examined using analytical tools ecological risk and methods of its minimization on the example of a steelworks and municipal waste incineration plant,
- built an ecological risk management algorithm, taking into account the procedure for its implementation and monitoring in real conditions on the example of a municipal waste incineration plant,
- developed a technology for comprehensive recycling of depleted and used photovoltaic (PV) cells made of crystalline silicon,
- proposed a recycling line with the selection of machines for which he calculated the total energy demand and presented a holistic approach to project profitability based on a SWOT analysis.

In order to avoid catastrophic climate change, the world must achieve zero carbon emissions in all sectors of the economy by 2050. To this end, in accordance with Directive 2009/28/EC, EU Member States should gradually increase the share of energy from their renewable sources, both in total energy consumption and in the transport sector. In Poland, despite the fact that the production of energy from RES is increasing year by year, its main use is still conventional energy sources, which emit a large amount of pollution into the atmosphere. The overriding EU goal is to achieve 32% of energy from renewable sources by the end of 2030 and to reduce greenhouse gas emissions from 40% to 55%. These are very ambitious goals imposed on the EU Member States, which will be unachievable without a complete energy transformation into RES and into the sectors of the already operating conventional economy. In addition, electricity prices are rising rapidly across Europe. In August 2022, the average MWh price in Poland reached PLN 1,217.39 on the commodity energy exchange. In Spain, it already costs over 150 euros - three times more than in 2020. In Germany, energy prices have increased by more than 60% this year. According to experts, this trend may continue in the coming months. This is the effect of more expensive European allowances for carbon dioxide emissions, or low energy production from RES. Energy companies pay record prices for the purchase of CO2 emission allowances - already over EUR 65 per tonne, over 18% more than in mid-July 2021. There is a large number of studies in the literature on the potential of using renewable energy technologies in the global energy mix, but there is no studies on how to reduce CO2 emissions to the atmosphere by plants with a diversification method of production, i.e. the metallurgy. In Poland, the steel industry is responsible for 14% of total CO2 emissions into the atmosphere. It is a branch of the economy that is still in the intensive phase production and, due to the high energy demand for steel production, conventional energy, i.e. natural gas and electricity, cannot be replaced with energy from RES. Therefore, it is necessary to look for solutions optimizing the existing technologies that will allow to reduce CO2 emissions into the atmosphere, and thus pay production plants less for emission permits.

The authors of their study [**H10-H11**] fill this research gap and the aim of the work was to build a model of energy consumption divided into electricity and natural gas in a walking

furnace depending on the length of the rolling campaign and the established rolling program. The final result of the work is a model enabling calculation of energy costs of material processing depending on: steel grade and ingot mass, heating time in the furnace, thickness and band width. The results of the work can be widely used in the implementation of projects optimizing energy consumption on the hot rolling mill. The presented algorithms make it possible to significantly reduce the emission of harmful compounds into the atmosphere, which will contribute to the fulfillment of Poland's emission obligations towards the EU.

The work [**H11**] presents the built algorithm of the electricity and natural gas consumption model in the walking furnace with the use of artificial intelligence and simulation methods depending on the the length of the rolling campaign and the agreed rolling program. This algorithm was built on the basis of the results presented in publication [H10]. The aim of the research [**H10**] was to present the concept of applying the hitherto unpopular idea of the fourth industrial revolution - the concept of Industry 4.0 in steel enterprises. The full implementation of the Industry 4.0 concept allows you to achieve an unprecedented level of operational efficiency and accelerate productivity growth, which should be considered a great advantage. As part of this part of the research, a model of the logistics system was made on the example of a hot-rolled steel strip rolling mill, taking into account the subsystems of material flow and storage, on which experiments were carried out to obtain results on how the implementation of the Industry 4.0 solution will improve the effectiveness and efficiency of the analyzed production line. In addition, the article presents the areas of implementation of the concept in question, the potential advantages of implementation in the analyzed enterprise were discussed. Work related to the Industry 4.0 concept also focused on the operational aspects of production system components and monitoring their effectiveness in all characteristic areas, such as: production agility, cooperation of executive systems, modularity, ease of programming and safety of use. The completed implementation of the decision support model, although it concerned only certain aspects of the logistics production planning system, its results showed that the use of simulation modeling techniques allows to effectively rationalize the flow of materials in the process of logistics production planning. As a result, the time of the technological process was significantly shortened, the production costs of the finished product were reduced, and the qualitative and technological conditions of the produced tape did not change. In addition, the results of this work were used to build algorithm, the extensive description of which is included in the work [H11] in a given metallurgical plant for the consumption of electricity and natural gas. This algorithm is the basis for developing a proposal of a set of minimum requirements characterizing the best available techniques (BAT) for walking furnaces placed in hot rolling, taking into account the requirements set out in national legal regulations and the recommendations described in BREF reference documents. This information should be taken into account when preparing an application for an integrated permit, as well as when determining the level of permissible emissions. Based on the constructed algorithm, it was shown that the analyzed projects, depending on their type and technical specification, will bring measurable economic benefits in the form of a reduction in the amount of energy consumed on an annual basis and environmental benefits in the form of reduction of carbon dioxide emissions into the atmosphere. Constructed algorithm verified in conditions of actual rolling mills contributes to the fulfillment of energy and emission

obligations towards the EU. The effectiveness of the electricity consumption model compared to the actual electricity measurements for the period of two months was 99.97%. On the other hand, the correctness of the natural gas consumption model, compared to the actual measurements for the period of six months, amounted to 99.76%. High compliance allows the model to be used in real conditions of the rolling mill, taking into account its extension by the amount of energy consumption depending on the profile and grade of hot-rolled sheets and strips. Based on the analysis of hot rolling methods, the techniques, achievable emissions and consumption levels corresponding to the use of BAT are presented. The purpose of this part of the study is to provide information to industry, environmental authorities and the public on achievable emission and consumption levels using specific techniques. The right techniques BAT for the walking beam kiln and limit values have been established taking into account local conditions, costs and the degree of environmental pollution. In addition, research was carried out on how to prevent or reduce the impact of metallurgy on the environment. As part of the recommendation, it was proposed:

- reduction of emissions of harmful compounds: NOx, SOx and dust should be limited by using high-methane natural gas, low-emission burners and recuperators for heat recovery from flue gases,
- the process of loading the furnace should be carried out with the minimum opening and minimum dimensions of the batch window. The opening time of batch windows should also be kept to a minimum. oven. The above actions affect the optimization of gas consumption, the reduction of excess air and thermal losses in the furnace,
- constant control of the quality of the gas used, the temperature of the combustion process and the content of H2S in the coke oven gas and excess air should be carried out,
- gases from fire treatment should be discharged into the air through an electrostatic precipitator with a dust removal efficiency of 95%,
- to reduce energy consumption in furnaces, the heat of rolled materials obtained in the previous process should be used,
- low-emission swirl or flat-flame burners should be used be characterized by the emission level: NOx 380-100 g/Mg (reference data 80-360 g/Mg)/ 260 mg/Nm^3,
- the rolling mill should limit the temperature of air heating by automatic control of the furnace operation,
- thermal losses of the process should be limited by minimizing the storage time of hot charge and maximizing its rolling share,
- it is also important to complete the charge in batches with a similar technological regime of heating in order to maximize the use of the working space of the furnace. In both old and new plants, there should be a change of charge from rolled ingots to slabs of continuous casting of COS steel.

The benefits of this work include: determination of cost-energy dependencies between individual profiles and steel grades in active production; the ability to track energy consumption and processing costs depending on the currently produced assortment; verification of market

prices for individual steel grades and profiles. The application of the BAT recommendations for the rolling mill in the examined rolling mill will reduce CO2 emissions by 56.7 thousand tonnes per year, which will reduce the prices for the purchase of emission permits.

The topic related to ecological risk in thermal waste processing plants is another very important aspect of my research. Risk is an inherent element of business activity. Achieving success, making a profit, or taking a position on the market means the need to delimit the risk. The concept of risk is therefore somehow inscribed in the functioning of every enterprise, and the risk itself is determined by a number of factors internal and external, including global aspects. When analyzing the determinants of the operation of a waste incineration plant, the role of energy and ecology is often underestimated - treating its cost as insignificant, and the security of its supply as obvious. Recent years have shown, however, that sustainable energy production is becoming a global challenge, and Polish enterprises must take into account a new risk factor - energy and environmental risk, which not only reduces their competitiveness on the international arena, but also begins to threaten their existence. It is necessary not only to define and estimate the scale of environmental risk in enterprises, but also to propose methods of its mitigation, which was examined on the example of a thermal waste processing plant in article [**H12**]. Waste incineration plants as a large plant dealing with thermal waste treatment are exposed to various types of risks that can lead to significant damage and precipitate. With this in mind, paper present the results of reducing the ecological risk associated with reducing the amount of harmful emissions of compounds into the atmosphere from the thermal incineration of waste in an eco-incineration plant in Krakow. The articles present theoretical issues related to environmental risk, including ecological risk. They describe the procedure for implementing environmental risk management in the enterprise. The main objective of the conducted research was to present a model of ecological risk management and to define the methods of its monitoring. Considering the importance of this issue, the papers describe the risk research methodology together with empirical results. Thanks to the use of the matrix method, the most significant threats to the waste incineration plant related to ecological risk and the best prospective possibilities of counteracting their effects were identified. It was built on the basis of identified hazards related to ecological risk using the FTA method, a failure tree was identified, in which the basic events affecting the intermediate events were separated. The environmental risk management process aims to closely monitor and prevent primary events to prevent intermediate events from occurring. However, when such an event occurs, it is necessary to try to limit its negative effects, which affect the formation of further undesirable phenomena affecting intermediate events. Types of risk and recommendations for counteracting ecological risk for waste incineration plants are described in detail in the article [**H12**]. In addition, as part of this work, an algorithm for monitoring environmental risk management was built on the basis of the obtained results. It is particularly important that the creation of this type of tool can fill the gap consisting in the lack of sufficient environmental risk management tools for waste incineration plants. However, the implementation of this tool may involve financial constraints. The costs can be offset in the future by the elimination of significant risks, which can bring benefits to both the company and society. In order to implement the described tool in incineration plants on a larger scale, it would be important to carry out a pilot action as part of a scientific project in order to test and possibly improve the already targeted tool.

4.5. Conclusions and recommendations for activities supporting the increase of energy production from renewable sources

The research carried out allowed for the implementation of the main objective and specific objectives, verification of the adopted hypothesis and formulation of conclusions and recommendations for actions ensuring the development of energy production from renewable sources.

Detailed conclusions regarding the performed tests are presented in section 4.4. In this part of the considerations, only a few of the most important application conclusions are presented, which are significant for the adopted strategy to reduce greenhouse gas emissions and confirm the implementation of the objectives and the adopted research hypothesis:

1. Predicting wind power production with high accuracy is not necessarily possible by using a standard physical or statistical model for each wind farm, but by using a machine learning model with wind speed predictions. It was found that the GPR-PUK model based on Pearson kernel functions with a prediction error of 18.5% showed the highest prediction accuracy, which indicates that it has the potential for wider applications in the analyzed forecasting.
2. The developed method of forecasting the demand for electricity in a commercial power plant, taking into account the quantitative methods of the SARIMA model at the error rate of 1.34%, showed that it is possible to obtain, based on historical data of the Polish power system, model qualifying it for forecasting the hourly demand for electricity and assessing the risk of balancing the energy shortage at any time on the local market.
3. Diversification of the energy mix will improve Poland's energy security. The determined total costs of the analyzed scenarios until 2050 were set at a similar level. This is due to the falling costs of RES generation and the advantage of those sources for which investment costs are falling and which have low or no variable costs. The proposed diversification will allow to reduce CO2 emissions from the energy sector by 18% compared to 2005, and in the case of the renewable scenario by 27%. In the coal scenario, CO2 emissions in 2005 and 2030 will be at the same level. By 2050, the coal scenario will provide a 7% reduction, the diversified scenario from 65-68% (with nuclear), and the investment in RES - 84% reduction.
4. With the current costs of construction of photovoltaic installations, their electricity generation capacity and the method of selling surplus energy produced on favorable terms, the investment will also be profitable from the economic point of view. The proposed support system will be an appropriate instrument to support the development of the RES (photovoltaic) micro-installation market.

   The conducted analyzes show that the higher the installation capacity (up to 3 kW), the lower the investment price per PLN per WP of the capacity of photovoltaic modules, and thus the faster the cost of return on investment. With the assumed energy use profiles, the payback period may be 9.5 years for a small installation (capacity 585 WP and a production

profile of 50%) and 7 years for a larger installation (capacity of 2000 WP and a production profile of 25-75%).

For the tested micro-installation, with a total capacity of photovoltaic modules equal to 585 WP, the amount of energy that can be generated by the inverter is at the level of 0.93 kWh/WP year for the first year of production. In the fifteenth year of operation, as a result of the decrease in the efficiency of photovoltaic cells, the amount of energy produced will be only 0.83 kWh/WP year.

5. The power of solar collectors should be selected so that the production of electricity fully balances the energy consumed from the grid. The more energy is used at the time of its production, the less energy goes to the grid for free.

   For the analyzed installation, the investment consisting in extending the collector area in accordance with the NPV is economically effective for the absorber area in the range of 5.6-7.6 m^2 and reaches the maximum value for the absorber area of 6.6 m^2. On the other hand, the absorber area exceeding 7 m^2 contributes to the reduction of the economic return on investment. The analyzed installation produced 6756 kWh per year, which allows to reduce CO2 emissions at the level of 2.4-3.6 Mg per year.

6. The use of a photovoltaic installation in an enterprise based on a business model is justified in practice and allows to reduce electricity costs incurred by the enterprise, in this case by about 60%.

   Thanks to the knowledge management aspects, it is possible to analyze the distribution of energy, broken down into energy consumed and sent to the grid, as well as taking into account the amount of energy produced by the photovoltaic installation, depending on weather conditions.

7. One of the activities promoting electrification heating systems in Poland could be to reduce the primary energy input factor for electricity taken from the Polish electricity grid from wi = 3.0 to wi = 2.5. This action would ensure effective promotion of heat pumps and hybrid systems, such as biomass boilers with air-source heat pumps. It would also make it possible to unify analyzes in the field of energy certificates and audits, both in terms of new and existing residential buildings.

   According to the authors, it is necessary to recommend the design of low-temperature installations with a design flow temperature not higher than 55°C (applies to central heating installations in new buildings). Such a solution would ensure better efficiency of modern heating devices, e.g. gas condensing boilers, and would make new buildings ready for the use of heat pumps in the future.

   Optimization of operation (so-called balancing) of heating installations would reduce heat consumption by about 10%, and at the same time to a similar extent, would significantly reduce the emission of air pollutants and would contribute to the effective promotion of the use of zero-emission solutions.

8. The use of a substrate in the form of a mixture of liquid manure with maize silage provides about 6,968,000 m^3 of biogas, the possibility of utilizing the liquid manure and the production of about 16,000 MWh of "green electricity" in cogeneration systems.

   Meanwhile, taking into account the potential of processing agricultural waste, Poland could produce 13.5 billion m^3 of biogas annually. If maize for energy purposes was started on a similar scale as in Germany, the estimated potential for electricity production from biogas could be up to 8 GW. Comparing this value with the average monthly national power demand (22-25.5 GW), it can be concluded that biogas could meet up to 30% of the daily power demand in Poland.

9. The use of biofuels has a better environmental impact than the use of petroleum products, because their combustion emits on average 35% less greenhouse gases compared to the combustion of diesel oil. Using methods by determining the distribution of the allocation value, the total life-cycle greenhouse gas emissions of the product (biodiesel) can be reduced by approximately 31%, as these emissions are split between the main product and the by-product (glycerin).

10. The constructed algorithm for calculating energy costs based on the heating curve in metallurgical plants is an effective tool to reduce energy consumption and reduce the cost of purchasing emission permits. The model's high compliance with the actual measurements of energy consumption for the period of 6 months was 99.76%, which allows for the effective use of the model in the actual conditions of the rolling mill, taking into account its extension by the amount of energy consumption depending on the profile and grade of hot-rolled sheets and strips. These actions will help reduce the plant's environmental impact by 56.7 thousand tons of CO2 per year.

11. The design of the efficiency of the PV panel recycling process line should at taking into account the current PV development in Poland, it should be at the level of 45 t/h. This will enable the processing of 1 ton of photovoltaic laminates at the level of energy consumption of 16.49 kWh, which will result in meeting the integrated permits regarding pollutant emissions at the level of the requirements of environmental standards.

12. Ecological risk analysis performed in the eco-incineration plant using the following methods: matrix, weight, FTA and HIRA, allowed for a very precise identification of hazards related to the analyzed risk at every stage of the plant's operation. The research made it possible to identify all 15 potential risk groups on the basis of which an algorithm for their monitoring was built, which contributed in 96% to proposing preventive measures for each occurring threat.

To sum up, the European Union has adopted an increase in energy efficiency and an increase in the share of RES in order to reduce pollutant emissions as a long-term goal. Sustainable energy plays an important role in this. A comparison of the long-term potential of RES and domestic coal mining confirms that both economic and technological trends will profoundly change the structure of available domestic energy sources on the Polish market. Even with the most optimistic assumptions, Polish mines will not be able to meet the growing demand of the energy sector. Even in the optimistic scenario - support for the development of

coal mining will cover less than 60% of the demand of the energy sector in 2050. In the middle of the century, domestic hard coal will satisfy only 20% of the demand of the energy sector. On the other hand, the share of RES may reach 3/4 by 2050, and without significant breakthroughs – the combination of different technologies is key. The significant role of variable sources (wind and sun) means that achieving a high share of RES requires flexibility at the system level. Maintaining significant energy independence requires a shift towards a new paradigm: large-scale investments in low-carbon technologies, gradual shifting of coal power plants to the reserve, development of cross-border connections and the search for effective energy storage options. The most important conclusions of this part of the analysis include:

1. To achieve climate neutrality in the EU and Poland by 2050, it will not be enough reducing the use of fossil fuels and developing renewable energy sources. In addition, the economy as a whole will need e.g. large-scale implementation technologies: Carbon Capture and Utilisation, Carbon Capture and Storage, electrification of industry, use of hydrogen, expansion of electromobility and reduction of livestock production in the agricultural sector.
2. Transition to a low-emission and ultimately climate-neutral economy, require there will be coordinated actions in many areas. A strategy should be developed to steer industries in transition and develop a financing framework to ensure that sufficient capital is available for the required investments. The European Union's decarbonisation goals are ambitious but achievable assuming a fast pace of development of innovative low- and zero-emission technologies and access to financial resources.
3. Most of the emission reductions in Poland occur in the energy sector, but the role of this of the sector in the reduction effort decreases over time. This sector is responsible for approx. 80% of the total reduction by 2030 and for 55% of the total reduction by 2050 (relative to 2015). This means that a large part of the reduction potential in the energy sector it is used in the initial period, while in later years the low-emission transition must rely more on more expensive ones activities, including in industry, construction, transport and agriculture.
4. Climate neutrality in 2050 is achieved at high marginal costs emission reduction - over EUR 400/tCO2 eq. in the EU ETS and over EUR 1,300/tCO2 eq. in non-ETS for Poland.
5. It is necessary to introduce the necessary technological processes into the market purpose reducing emissions in hard-to-mitigate sectors (i.e. transport, agriculture and energy intensive industry), which will require consistent public investment and private. It will also require more attention from entrepreneurs and policy makers to introduce new technologies.

In order to promote investments in renewables, a combination of transparent, stable regulations and financial support is necessary to take full advantage of the already expressed acceptance of green energy. The development of renewable energy technologies is of key importance for the transformation of the economy towards zero-emissions. It is important for ensuring the country's energy security and diversification of energy sources. The use of the domestic RES potential may contribute not only to the construction of new, innovative branches

of the economy, but also to strengthening the competitiveness of Polish entrepreneurs on foreign markets.

Recommendations resulting from the conducted research include: the need to stabilize the legislative situation in the area of energy; necessity ensuring attractive forms of financing investments in RES; increasing availability credible analyses, scientific studies, forecasts and scenarios that would allow entrepreneurs to assess energy risk and take remedial action in advance; education and expanding knowledge among entrepreneurs on the subject risk factors that have an increasing impact on economic activity; necessity government assessment of the overall impact of energy risk on competitiveness the Polish economy, which may shrink sharply in the coming years; increase availability of data necessary to conduct analyzes - including, for example, information about profiles energy consumption in Polish enterprises. The pool of recommendations resulting from the number of studies carried out is therefore extremely wide and it should be expected that in nearby. In the future, the issue will become not only the subject of scientific discussion, but also discussion public and political.

4.6. Contribution to the development of social sciences in the discipline of management and quality science

The submitted series of thematically related publications contributes to existing research, concerning the determinants of pollutant emissions into the air on a regional scale. This effect was obtained by taking a series of related threads with a differentiated one research methods. It should be emphasized that the indicated cycle of publications is not only complementary empirical study, but also sets directions for future research. Findings presented in the series of publications complement the existing achievements in this field. Effect conducted considerations in a series of thematically related publications, which I indicate as scientific achievement is the contribution to the development of science in the field of management and quality sciences. As a significant contribution to my research should be considered:

- in cognitive terms:

1. Indication of the theoretical basis for sustainable development through the selection and synthesis of domestic and foreign literature on the subject as a determinant of the development of renewable energy production.
2. Recognition of the status, structure and volume of energy production from renewable sources in Poland, taking into account the international context.
3. Getting to know the motives of investment decisions in RES and making a systematics of factors favoring and limiting the development of energy production from renewable sources, taking into account the economic, environmental, social, technical and technological areas.
4. Assessment of RES development prospects in the context of sustainable development.

- in the utilitarian approach:

1. Application of the IRR method (and the NPV indicator) to identify and assess the effectiveness of investments aimed at using various renewable energy sources.
2. Determination of barriers and possibilities of energy production from renewable sources from the point of view of household owners.
3. Indication of the advantages and weaknesses of individual types of RES in order to facilitate their selection by potential investors.
4. Deepening scientific knowledge on how to make economic choices by entrepreneurs and residents in the field of energy generation methods electricity and heat, which to a lesser extent contribute to the emission of pollutants into the air.
5. Systematizing and updating knowledge in the field of environmental protection, taking into account the impact of harmful substances that are emitted into the air from energy sources for solid fuels.
6. Providing the potential investor with theoretical knowledge and empirical evidence to make a rational decision about proper selection of a specific source of renewable energy for the implementation of your investment in the era of energy transformation.
7. Adaptation of the cost and environmental efficiency model for the purposes of allocation and distribution of GHG emissions for the production of biofuels.
8. Development of forecasting methods for Gaussian regression models based on kernel functions to increase the accuracy of predicting the use of various renewable energy sources.
9. Providing an effective analytical tool verified in real conditions for forecasting demand for electricity in the time horizon "an hour before delivery".
10. Development of an original model of an algorithm for electricity and natural gas consumption in a metallurgical enterprise.
11. Identification of the economic, social and environmental effects of the implementation of RES development in Poland from the point of view of various possible scenarios.
12. Providing empirical evidence and environmental knowledge and information on the impact of selected energy generation methods on air quality.
13. Critical evaluation and identification of potential economic policy instruments environment in terms of reducing emissions of pollutants into the air on a scale regional.
14. Application of modeling techniques in the estimation of equations combining the features of controlling heat gains and losses from installations inside and outside the building insulation jacket.
15. Indication of further research directions in the field of Poland's energy transformation.

The contribution of the presented series of publications to the development of management and quality sciences applies not only to the cognitive sphere, related to the rationality of behavior, optimization of the selection of methods energy production, energy efficiency,

contributing to the reduction of emissions pollutants into the air, but also research methodology and application aspects. Research carried out in real conditions is a reliable compendium of cognitive and empirical knowledge on the subject of problem analysis. The results of the conducted research can be used as a starting point for further analyses, especially of an empirical nature. The research confirms the desirability of conducting further research on the importance of energy production from renewable sources as a factor in the sustainable development of regions aimed at minimizing the level of pollution in the environmental sphere.

5. Information about demonstrating significant scientific activity

5.1. The area of scientific research and discussion of other scientific and research achievements

My interests and research activity after obtaining the doctoral degree focused mainly on the practical management trend related to quality management, environmental protection and broadly understood aspects of production management. All of my scientific work falls into three conventional thematic areas:

1. Energy - economic and financial, ecological and social aspects of reducing air pollution emissions in terms of the use of energy resources, energy security, conditions and development trends in the era of energy transformation in Poland and regions.
2. Commodity science - research and evaluation of the functional properties of food and non-food products as well as factors affecting their quality in the pre-production, production and post-production spheres.
3. Logistics - the study of the processes of planning, implementing and controlling the efficient and economically effective flow of raw materials, materials, finished products and the appropriate information from the point of origin to the point of consumption to meet customer requirements.

Research in each of these areas of management (especially the first one) influenced the choice of the subject of my habilitation thesis. The other two research streams allowed me to gain a solid scientific background to tackle difficult and complex issues related to the energy transformation and directions of development of the Polish energy sector. Below, the characteristics of the indicated three research areas are presented, together with the most important publications and monographs that were not included in the series of single-subject publications.

Research area 1:

Ecological aspects related to the reduction of pollutant emissions in the region as part of the energy transformation

Research within the first area concerned both individual instruments of environmental policy, e.g. air pollutant emission allowances, ecological taxes, integrated permits, etc., as well as aspects of the overall environmental policy in terms of national and European Union

regulations. The first area of my scientific and research activity is closely related to the series of single-subject publications presented for evaluation. As part of this scientific and research activity, which is extensively described in the first part of the self-report, I additionally defined the economic, financial and environmental aspects as well as the dimension of energy security for the entire country and regions. In addition, I studied the possibilities of using various sources of renewable energy in both private households, transport and regional industry. As part of this research, I carried out:

- identification of factors affecting the market in various national and regional sectors economy aimed at reducing pollutant emissions,
- determining the impact of economic and environmental aspects of electricity generation from RES in the context of energy security of regions in accordance with sustainable development,
- identifying the perception of risk and the state of energy security among various sectors of the regional economy,
- assessment of the environmental impact of electricity generation depending on the energy carrier used,
- assessment of conditions, barriers and directions of development of renewable energy sources in the aspects of energy transformation.

Scientific publications supplementing the series of single-subject achievements in this area, apart from technical and cognitive aspects, are the result of research conducted during visits to various industrial centers, with particular emphasis on the most energy-intensive enterprise in the region, the ArcelorMittal SSC Hot Rolling Mill Branch in Krakow. Scientific publications consisting of achievements in this area include:

1. Mikulik J., Niekurzak M. (2023). Impact of a photovoltaic installation on economic efficiency on the example of a company with high energy consumption. *Scientific Papers of Silesian University of Technology*. *Organization and Management*. ISSN 1641-3466. (punctation MEiN: 70)
2. Niekurzak M., Lewicki W., Coban H.H., Brelik A. (2023). Conceptual design of a semi-automatic process line for recycling photovoltaic panels as a way to ecological sustainable production. *Sustainability*, 15, 2822. (**indexing in the database Web of Science, 2022, Impact Factor 3,889**; punctation MEiN: 100)
3. Niekurzak M., Lewicki W., Drożdż W., Miązek P. (2022). Measures for assessing the effectiveness of investments for electricity and heat generation from the hybrid cooperation of a photovoltaic installation with a heat pump on the example of a household. *Energies*, 16,6089. (**indexing in the database Web of Science, 2022, Impact Factor 3.252**; punctation MEiN: 140)
4. Niekurzak M., Kubińska-Jabcoń E. (2022). Assessment of the impact of wear of the working surface of rolls on the reduction of energy and environmental demand for the production of flat products: methodological approach. *Materials*, vol. 15 iss. 6

art. no. 2334, s. 1-18. (**indexing in the database Web of Science, 2022, Impact Factor 3.748**; punctation MEiN:140).

5. Niekurzak M. (2022). Development directions of low and zero emission sources in the transformation of the energy sector in Poland based on the scenario method based on intuitive logic. *Energetyka*, no. 4, pp.181-192.
6. Niekurzak M., Lewicki W., Brelik A. (2022). An innovative approach to sustainable development on the example of assessing the energy standard of office buildings using simulation modeling. *Business Success and Innovation Management: A 2025 Vision to Sustain Economic Development During Global Crisis*. International Business Information Management Association, Seville, ISBN: 979-8-9867719-0-8, pp. 2364-2374.
7. Kubińska-Jabcoń E., Niekurzak M., Paliś B. (2022). Możliwość zastosowania algorytmu do monitorowania i zarządzania ryzykiem ekologicznym na przykładzie spalarni odpadów komunalnych. *Przedsiębiorczość i ryzyko w działalności gospodarczej*. Wydawnictwa AGH, Kraków, s. 75-95. ISBN: 978-83-67427-02-9.
8. Niekurzak M., Kubińska-Jabcoń E. (2019). The evaluation of the selected risk types in external transport with the use of the matrix method. *Logistics and Transport*, vol. 42 no. 2, pp. 65-74.
9. Niekurzak M., Kubińska-Jabcoń E. (2019). The use of biogas as biofuel to power motor vehicles. *Buses: technology, operation, transport systems*, vol. 20, no. 6, pp. 218-222.
10. Niekurzak M., Kubińska-Jabcoń E. (2019). The impact of the production process on the quality of PCBs for the automotive industry. *Buses: technology, operation, transport systems*, vol. 20, no. 10-11, pp. 89-94.
11. Niekurzak M. Kubińska-Jabcoń E., Bazior A. (2018). Analysis of intelligent transport systems on the example of the city of Krakow. *Buses: technology, operation, transport systems*, no. 5, pp. 30-35.
12. Niekurzak M. Kubińska-Jabcoń E., (2018). Influence of supply logistics on the process of modeling complex transport systems in metallurgy. *Buses: technology, operation, transport systems*, vol. 19, no. 6, pp. 1087-1091.
13. Kubińska-Jabcoń E., Niekurzak M. (2017). Analysis of a selected type of risk with the modified FMEA method in a steel company. *Hutnik Wiadomości Hutnicze: a scientific and technical journal devoted to the issues of metallurgy*, vol. 84 no. 6, pp. 250-254.
14. Kubińska-Jabcoń E., Kubiński W., Niekurzak M. (2015). Analysis of the economical, ecological and quality advantages consequent resulting from initiation of technology integrated in metallurgy. *Journal of Mechanics Engineering and Automation*, vol. 5 no. 10, pp. 549-553.
15. Kubiński W., Kubińska-Jabcoń E., Niekurzak M. (2014). Rational use of energy in housing construction. *Enterprise management: theory and practice*, science editor. Piotr Łebkowski. Publishers AGH, Krakow, pp. 440-465. 978-83-7464-732-8.

16. Kubiński W., Kubińska-Jabcoń E., Niekurzak M. (2014). Economic aspects of using solar collectors in single-family housing. *Enterprise management: theory and practice*, science editor. Piotr Łebkowski. Publishers AGH, Krakow, pp. 420-443. e-ISBN: 978-83-7464-732-8.
17. Kubiński W., Kubińska-Kaleta E., Niekurzak M. (2010). Production of synthetic engine fuels from coal. *Aspects of production engineering*, science editor. Piotr Łebkowski. Publishers AGH, Krakow, pp. 251-265. ISBN: 978-83-7464-371-9.

Research area 2:

Testing and evaluation of functional properties of materials and goods: food and non-food

An important trend of my scientific interests is also the research on the quality of materials and goods, their functional properties and the assessment of significant qualitative and quantitative parameters. The motivation to undertake this field of research are the subjects I teach, including material science and commodity science for engineers at a technical university. As part of my research in this area, I was involved in the assessment of performance properties and testing the quality of various groups of goods: industrial, i.e. lubricants, fuels, adhesives, construction materials, textiles, paper, medical, leather, furniture, household appliances and food products. The scope of this research includes 4 co-authored monographs, which I completed in the years of scientific activity 2015-2022, and numerous publications. The scientific monographs that make up the achievements in this area are:

1. Kubiński W., Niekurzak M., Kubińska-Jabcoń E. (2023). *Examination of food products. Volume 2.* Publishing PWN Warsaw. pp.>400 – the monograph will be submitted to the publishing house in September 2023.
2. Kubiński W., Niekurzak M., Kubińska-Jabcoń E. (2018). *Examination of food products. Volume 1.* Publishing PWN Warsaw. ISBN: 978-83-01-20047-3. pp.413.
3. Kubiński W., Niekurzak M., Kubińska-Jabcoń E. (2017) *Industrial goods testing.* Publishing PWN Warsaw. ISBN: 978-83-01-19417-8. pp. 373.
4. Kubiński W., Niekurzak M., Kubińska-Jabcoń. (2015). *Basic tests of fuels, lubricants, varnish coatings and adhesives.* Publishing AGH Krakow. ISBN: 978-83-7464-769-4.

The most important scientific publications that make up the achievements in this area include:

1. Wróblewski P., Niekurzak M., Kachel S. (2023). Experimental studies of welded joints in structures subject to high impact vibrations using destructive and non-destructive methods. *Materials,* 16(5):1886. (**indexing in the database Web of Science, 2022, Impact Factor 3.748**; punctation MEiN: 140)
2. Khan B., Niekurzak M., et.al. (2022). Experimental and numerical evaluation of mechanically stabilized earth wall with deformed steel bars embedded in tire shred-sand mixture. *Buildings*, vol. 12 iss. 5 art. no. 548, pp. 1-17. (**indexing in the database Web of Science, 2022, Impact Factor 3.324**; punctation MEiN:70).

3. Kubińska-Jabcoń E., Niekurzak M., Sroka B. (2022). Evaluation of service quality measurement using the modified servqual method - case study on the basis of motorol company. *International Journal for Quality Research*, vol. 16 no. 4, pp. 1179-1196. (**indexing in the database Web of Science, 2022, CiteScore 2.5**; punctation MEiN:100).
4. Niekurzak M., Kubiński W., Kubińska-Jabcoń E. (2015). Making use of the eddy currents effect in the examination of the tribological characteristics of strip rolling mill rolls. *Journal of Mechanics Engineering and Automation*, no. 9, pp. 481-486.
5. Niekurzak M. (2014). Modeling automated distribution center of goods. *Logistyka*, no. 6, pp. 13595-13604.
6. Niekurzak M. (2014). Modeling the impact of roller operation on their wear. *Tribology: theory and practice*, Polish Tribological Society, vol. 45 no. 1, pp. 75-84.

Research area 3:

Logistical aspects of the flow of raw materials, materials and goods, taking into account the conditions: ecological, economic and social

The third research area in the field of management science is the economic flow of raw materials, goods and materials within the framework of broadly understood logistics, with an indication of the conditions, barriers and directions of its development. The research included the construction of logistic models and algorithms, taking into account its typical subsystems related to production and transport equipment, inter-operational warehouses and finished products, which were implemented as part of industrial research. The built models became the basis for the formulation of the logistic system both in terms of technological and economic aspects. In addition, research in this part was conducted towards the search for and selection of the most advantageous concept and model for organizing production systems and effectively managed tool management. Widely in this research area I used the simulation modeling tool to design, evaluate and verify the created and existing production systems.

The use of this tool made it possible to simulate advanced manufacturing processes carried out in various enterprises, reducing the possible cost of experimenting on a "living organism" and thus contributing to the effective introduction of corrective changes and implementation recommendations. An important part of the research in this research area are the following publications:

1. Niekurzak M. Lewicki W., Coban H.H., Bera M. (2023). Proposal of an innovative model to shorten machine changeover times and improve production efficiency in the automotive industry as way to a circular economy. *Sustainability*, 15(8). (**indexing in the database Web of Science, 2022, Impact Factor 3.889**; punctation MEiN: 100)
2. Niekurzak M. (2021). Assessment of the possibility of implementing the product identification algorithm on the example of a production and service company. *Science - technology - technology: publishing series AGH, T.1*. Publishers AGH, Krakow, p.147-166. ISBN: 978-83-66727-65-6.

3. Niekurzak M., Kubińska-Jabcoń E. (2019). The use of innovative IT tools to improve logistic production processes. *Buses: technology, operation, transport systems*, vol. 20 no. 6, pp. 315-320.
4. Kubińska-Jabcoń E., Niekurzak M. (2018). Logistical conditions in planning the production and storage of aluminum profiles using the ABC and XYZ methods. *Buses: technology, operation, transport systems*, vol. 19, no 6, pp. 1063-1067.
5. Niekurzak M. Kubińska-Jabcoń E. (2017). The use of ABC and XYZ methods to optimize spare parts management in a cold strip mill. *Metallurgical News: a scientific and technical journal devoted to the issues of metallurgy*, vol. 84, no. 3, pp. 131-136.
6. Niekurzak M. (2015). Integrated logistics information systems to support the management as well as resources planning of the metallurgical enterprises. *Logistics*, no. 2, pp. 2-5.
7. Niekurzak M. (2014). Computer support as a tool to study logistic processes of the storage service. *Logistics*, no. 6, pp. 13586-13594.
8. Niekurzak M., Kubiński W. (2014). Roller management in terms of the logistic system of technological transport. *Metallurgical News: a scientific and technical journal devoted to the issues of metallurgy*, vol. 81, no. 2, pp. 105-110.
9. Niekurzak M., Kubińska-Jabcoń E. (2014). A logistic system approach in modeling and managing a steel company. *Logistics*, no. 3, pp. 4630-4637.
10. Kubiński W., Niekurzak M. (2014). Forecasting the rebuilding times of rolls in the rolling unit for the needs of operational production planning. *Metallurgical News: a scientific and technical journal devoted to the issues of metallurgy*, vol. 81 no. 6, pp. 379-384.
11. Kubińska-Jabcoń E., Niekurzak M. (2014). The use of logistics in management on the example of a tourist enterprise. *Logistics*, no. 3, pp. 3482-3489.
12. Niekurzak M. (2014). The use of simulation methods to improve planning processes and flows of material streams in a steel strip hot rolling mill. *Logistics*, no. 6, pp. 13605-13611.
13. Kubińska-Jabcoń E., Niekurzak M. (2014). The use of IT tools in supporting logistics processes in the management of a catering enterprise. *Logistics*, no. 3, pp. 46-48.
14. Kubiński W., Niekurzak M., Kubińska-Jabcoń E. (2013). Computer-aided production system for a hot-rolling steel strip mill. *Metallurgical News: a scientific and technical journal devoted to the issues of metallurgy*, vol. 80, no. 12, pp. 839-846.
15. Kubiński W., Kubińska-Jabcoń E., Niekurzak M. (2012). Simulation of a logistic production system using the Dosimi-3 package, Part. 2. *Logistics*, no. 2, pp. 7-9.
16. Kubiński W., Kubińska-Jabcoń E., Niekurzak M. (2012). Simulation of a logistic production system using the Dosimi-3 package, Part. 1. *Logistics*, no.1, pp. 5-6.

To sum up, my scientific work after obtaining the doctoral degree proceeded in parallel in all defined research areas, complementing each other. A summary of scientific and research achievements since obtaining a doctoral degree is presented in Table 1.

5.2. Scientific achievements in quantitative terms

My scientific achievements after obtaining the doctoral degree include 67 peer-reviewed scientific papers, which include:

- 3 scientific monographs,
- 50 articles in scientific journals,
- 7 chapters in scientific monographs,
- 10 chapters in conference materials.

I was the author or co-author of 38 papers written in Polish and 32 papers written in English. I disseminated the results of some of the research (conducted independently or jointly with other scientists) in 15 publications distinguished on the Scopus and 14 Web of Science list with Impact Factor. The total **Impact Factor** of my publications according to the year of publication is **43.782**. After obtaining my doctoral degree, I published 32 papers in English, which in total accounts for almost 46% of all publications.

A detailed list of achievements, together with the number of points of the Ministry of Science and Higher Education and specifying the contribution of co-authors in relation to co-author publications is included in Annex 4 to the application.

Table 1 summarizes the synthetic breakdown of published scientific papers by basic categories.

Table 1. Quantitative list of publications after obtaining the doctoral degree.

Itemization	**Number of publications**		
	in Polish language (independent/co-authored)	**in English language (independent/co-authored)**	**together (independent/co-authored)**
Scientific monographs	3 (0/3)	0(0/0)	3(0/3)
Chapters in scientific monographs	6 (1/5)	1(1/0)	7(2/5)
Chapters in conference materials	6(0/6)	4(0/4)	10(0/10)
Articles in journals included in the JCR database and having an Impact Factor	0(0/0)	15(2/13)	15(2/13)
Articles in other journals	22(3/19)	13(7/6)	35(10/25)
Together	**38(4/34)**	**32(10/22)**	**70(14/56)**

Before obtaining a doctoral degree in the years October 2010-February 2012, I published:

- 2 articles in scientific journals,
- 3 chapters in scientific monographs,
- 5 chapters in conference materials.

The total score of the Ministry of Science and Higher Education for works published after obtaining a doctoral degree is **2874**, while before obtaining a doctoral degree it is **21**.

My Hirsch index after obtaining a doctoral degree in the database: Web of Science is 5, Scopus is 5 (with the number of citations: Scopus - 58; Web of Science - 51) and with 620 recommendations, while the Hirsch index according to Google Scholar is 7 (with 111 citations).

5.3. Participation in scientific conferences and research projects

After obtaining my doctoral degree, I presented the results of my research at 5 international and 5 national conferences. Details on participation in conferences and presented papers are included in Annex 4 to the application for the degree of habilitated doctor.

In addition, I chaired the thematic session on the economy of sustainable development and energy transformation at the XXI International Scientific Conference Enterprise Management - Theory and Practice in Krakow 2021. In addition, since 2018, I have been the Chairman of the Barbórka Conferences of AGH Student Scientific Circles - 11th Section of Management Engineering and Quality.

In addition, I participated in 6 conferences (seminars, workshops) without a paper, participating in their sessions, including 1 foreign and 5 domestic, on topics related to the energy transformation of Europe and the world. As well as on-line, I participate in many events and congresses on energy topics as a listener.

After obtaining my doctoral degree, I participated in the work: of two grants financed by the Ministry of Science and Higher Education, one international project financed by the European Commission - Erasmus + Partnership Cooperation and two grants as part of the activity of the scientific circle. I was the manager in all grants. Information on participation in research projects after obtaining a doctoral degree, including my research tasks and funding conditions, is presented in Annex 4.

In addition, I was a co-executor in a team of 4 scientists of the expertise (made to order of Swiss Krono sp. z o.o.). Details are provided in Annex 4.

5.4. Scientific awards

For my scientific activity, I received a total of 4 awards from the Rector of the AGH University of Science and Technology in Krakow, including 2 individual award and 2 team awards:

1. Award of the Rector of the AGH University of Science and Technology in Krakow - individual first degree award for scientific achievements, awarded in 2022.
2. Award of the Rector of the AGH University of Science and Technology in Krakow - individual first degree award for scientific achievements, awarded in 2021.
3. The Rector's Award of the AGH University of Science and Technology in Kraków - third degree team award for teaching achievements, awarded in 2019.
4. The Rector's Award of the AGH University of Science and Technology in Krakow - third degree team award for teaching achievements, awarded in 2017.

5.5. Significant scientific activity carried out at more than one university

1. Scientific and industrial internship - Innovation and Design Enterprise INMET in Mikołow in days July 30 to September 9, 2012.

   The internship was scientific in nature. Its purpose was to conduct scientific research in cooperation with scientists and production technologists and to exchange experiences related to conducting scientific research. In addition, the acquisition of practical knowledge in the field of designing and manufacturing machines and devices for a wide base of the machine and metallurgical industry, and the optimization of energy consumption by these machines and cooperating tools.

2. Scientific and didactic internship - University of Economics and Information Technology in Krakow from October 1, 2017 – November 30, 2017.

   The internship had a scientific and didactic character. As part of the internship, I actively participated in the international scientific project BESPOKE - BusinESs PresentatiOn sKills for Employability In The European Labor Market. I developed research methodology in a research project entitled Entrepreneurship Mentoring for Young Graduate Women. I actively participated in the University's program councils and meetings of the Scientific Committee of the series of scientific conferences entitled "Smart city and Smart Velagges". In addition, since 2022, I have been a member of the Program Council at Wydawnictwo Zeszytów Naukowych WSEI in Krakow.

3. Scientific and research internship - Military University of Technology in Warsaw on May 4, 2022 - June 30, 2022.

   The internship was aimed at enabling interdisciplinary cooperation between research centers and improving professional competences in the field of conducting scientific research using the latest research equipment. As part of the internship, I gave a plenary lecture at the cathedral meeting on the habilitation achievements entitled "Determinants of the development of the quality of life of the society in the energy transformation of local sectors of the low-emission economy". Mutual cooperation has brought measurable mutual benefits and has been confirmed by scientific publications.

- **Scientific cooperation with the Military University of Technology in Warsaw**

The cooperation was scientific in nature. Its purpose was to conduct scientific research in cooperation with the University's academic staff and mutual exchange of experience related to conducting scientific research. As part of this cooperation, a joint publication was created:

1. Wróblewski P., Niekurzak M., Kachel S. (2023). Experimental studies of welded joints in structures subject to high impact vibrations using destructive and non-destructive methods. *Materials*, 16(5):1886. (**indexation in the Web of Science database, 2023 Impact Factor 3.748**; punctation MEiN: 140)
2. Wróblewski P., Niekurzak M. (2022). Assessment of the possibility of using various types of renewable energy sources installations in single-family buildings as part of saving final energy consumption in Polish conditions. *Energies*,15,1329. (**indexation in the Web of Science database, 2022, Impact Factor 3.252**; punctation MEiN: 140)

- **Scientific cooperation with the West Pomeranian University of Technology in Szczecin**

The cooperation was scientific in nature. Its aim was to improve the research workshop, exchange scientific experience, transfer knowledge and identify potential areas of cooperation. As part of this cooperation, joint publications were created in which the research results were presented:

1. Niekurzak M. Lewicki W., Coban H.H., Bera M. (2023). Proposal of an innovative model to shorten machine changeover times and improve production efficiency in the automotive industry as way to a circular economy. *Sustainability*, 15(8). (**indexing in the database Web of Science, 2022, Impact Factor 3.889**; punctation MEiN: 100)
2. Niekurzak M., Lewicki W., Brelik A. (2022). The challenges for social and economic policy related to the energy transformation - analysis of profitability and minimizing the risk of deciding to invest in a home micro-installation. *European Research Studies Journal*, vol. XXV, 4, pp. 144-159. (**indexation in the Web of Science database, 2021, Impact Factor 1.57** punctation MEiN:100)
3. Niekurzak M., Lewicki W., Brelik A. (2022). An innovative approach to sustainable development on the example of assessing the energy standard of office buildings using simulation modeling. *Business Success and Innovation Management: A 2025 Vision to Sustain Economic Development During Global Crisis*. International Business Information Management Association, Seville, ISBN: 979-8-9867719-0-8, pp. 2364-2374. (**indexation in the Web of Science database, 2021**, punctation MEiN:70)
4. Niekurzak M. Lewicki W., Coban H.H., Brelik A. (2023). Conceptual design of a semi-automatic process line for recycling photovoltaic panels as a way to ecological sustainable production in Poland. *Sustainability*, 15, 2822. (**indexation in the Web of Science database, 2022, Impact Factor 3.889**; punctation MEiN: 100)

5. Niekurzak M., Lewicki W., Drożdż W., Miązek P. (2022). Measures for assessing the effectiveness of investments for electricity and heat generation from the hybrid cooperation of a photovoltaic installation with a heat pump on the example of a household. *Energies,* 16, 6089. (**indexation in the Web of Science database, 2022, Impact Factor 3.252**; punctation MEiN: 140)

- **Scientific cooperation with the University of Szczecin in Szczecin**

The cooperation was scientific in nature. Its aim was to improve the research workshop, exchange scientific experience, transfer knowledge and identify potential areas of cooperation. As part of this cooperation, a joint publication was created in which the research results were presented:

1. Niekurzak M., Lewicki W., Drożdż W., Miązek P. (2022). Measures for assessing the effectiveness of investments for electricity and heat generation from the hybrid cooperation of a photovoltaic installation with a heat pump on the example of a household. *Energies,* 16, 6089. (**indexation in the Web of Science database, 2022, Impact Factor 3.252**; punctation MEiN: 140)

- **Scientific and didactic cooperation with the University of Economics and Information Technology in Krakow**

The cooperation had a scientific and didactic character. Its purpose, apart from conducting didactic classes, was to exchange scientific experiences with academic teachers of the University of Economics and Information Technology and Capitol Technology University South Laurel, Maryland United States as part of research and discussion on them. A publication was created as part of the advisory team.

1. Niekurzak M. (2022). Forecasting wind capacity using gauss regression models based on nuclear functions. *Energy market,* no. 4, pp. 61-71.

- **Scientific cooperation with the University of Technology and Commerce in Warsaw**

The cooperation was scientific in nature. Its purpose was to conduct scientific research in cooperation with the University's academic staff and mutual exchange of experience related to conducting scientific research. As part of this cooperation, joint publications were created:

1. Wróblewski P., Niekurzak M., Kachel S. (2023). Experimental studies of welded joints in structures subject to high impact vibrations using destructive and non-destructive methods. *Materials,*16(5):1886. (**indexation in the Web of Science database, 2022, Impact Factor 3.748**; punctation MEiN: 140)
2. Wróblewski P., Niekurzak M. (2022). Assessment of the possibility of using various types of renewable energy sources installations in single-family buildings as part of saving final energy consumption in Polish conditions. *Energies,*15,1329. (**indexation in the Web of Science database, 2022, Impact Factor 3.252**; punctation MEiN: 140)

- **Scientific cooperation with the Jagiellonian University in Krakow**

The cooperation was scientific in nature. Its aim was to improve the research workshop, exchange scientific experience, transfer knowledge and identify potential areas of cooperation. As part of this cooperation, a joint publication was created:

1. Kubińska-Jabcoń E., Niekurzak M., Paliś B. (2022). The possibility of using an algorithm to monitor and manage ecological risk on the example of a municipal waste incineration plant. *Entrepreneurship and risk in economic activity*. Publishers AGH, Krakow, pp. 75-95. ISBN: 978-83-67427-02-9. (punctation MEiN: 120)
2. Paliś B., Kubińska-Jabcoń E., Niekurzak M. (2022). Analysis of contemporary trends in the meetings industry in the world. *Marketing and Market*, t. 29 no 7, pp. 23-38. ISSN 1231-7853. (punctation MEiN: 40)
3. Paliś B., Kubińska-Jabcoń E., Niekurzak M. (2023). Change in the management of the meetings industry in the world in the face of the SARS-CoV-2 virus in the opinion of experts. *Marketing i Rynek*, t. 30 no 2, pp. 9-23. ISSN 1231-7853. (punctation MEiN: 40)

- **Scientific cooperation with the Cracow University of Technology in Cracow**

The cooperation was scientific in nature. Its aim was to improve the research workshop, exchange scientific experience, transfer knowledge and identify potential areas of cooperation. As part of this cooperation, a joint publication and conference presentation were created in which the research results were presented:

1. Niekurzak M., Kubińska-Jabcoń E., Gajewska T. (2014). Development directions of the integrated production processes of flat products. *METAL 2014: 23rd International Conference on Metallurgy and Materials*, Brno, Czech Republic, 2928.pdf. ISBN 978-80-87294-52-9. (punctation MEiN: 5)

- **Scientific cooperation with the Silesian University of Technology in Katowice**

The cooperation was scientific in nature. Its purpose was to conduct scientific research in cooperation with the University's academic staff and mutual exchange of experience related to conducting scientific research. As part of this cooperation, a joint publication and conference presentation were created:

1. Kubińska-Jabcoń E., Łukowski J., Niekurzak M. T. (2014). Risk control techniques in the enterprise on example of steel mill *METAL 2014: 23rd International Conference on Metallurgy and Materials*, Brno, Czech Republic, 2928.pdf. ISBN 978-80-87294-52-9. (punctation MEiN: 5)

- **Scientific cooperation with employees of foreign universities:**

  - ✓ Department of Electrical Engineering University of Ardahan, 75002, Turkey

My scientific cooperation with employees of foreign research centers was informal and consisted in the preparation of joint publications:

1. Niekurzak M. Lewicki W., Coban H.H., Brelik A. (2023). Conceptual design of a semi-automatic process line for recycling photovoltaic panels as a way to ecological sustainable production in Poland. *Sustainability*, 15, 2822. (**indexation in the Web of Science database, 2022, Impact Factor 3.889**; punctation MEiN: 100)

2. Niekurzak M. Lewicki W., Coban H.H., Bera M. (2023). Proposal of an innovative model to shorten machine changeover times and improve production efficiency in the automotive industry as way to a circular economy. *Sustainability*, 15(8). (**indexing in the database Web of Science, 2022, Impact Factor 3.889**; punctation MEiN: 100)

- **Scientific cooperation with employees of foreign universities:**

  - ✓ Department of Civil Engineering, CECOS University of IT and Emerging Sciences, Peshawar 25000, Pakistan,
  - ✓ Department of Civil Engineering, Faculty of Engineering, International Islamic University Malaysia, Jalan Gombak, Selangor 50728, Malaysia,
  - ✓ Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia.

The cooperation was scientific as well as informal and consisted in conducting scientific discussions on common research interests and developing publications as a result of these discussions.

1. Khan, B.J.; Ahmad, M.; Sabri, M.M.S.; Ahmad, I.; Zamin, B.; Niekurzak, M. (2022). Experimental and Numerical Evaluation of Mechanically Stabilized Earth Wall with Deformed Steel Bars Embedded in Tire Shred-Sand Mixture. *Buildings*, 12, 548. doi: 10.3390/buildings12050548. (**indexation in the Web of Science database, 2022, Impact Factor 3.324**; punctation MEiN:70).

6. Information on didactic, organizational and science popularizing achievements

6.1. Teaching and organizational achievements

- As part of my didactic work, I conduct classes within my three research areas in the first and second degree studies in the field of Management and Production Engineering, Management and Management and IT, among others. in the following subjects: Machine Science, Materials Science, Engineering Design, Ecological Sources of Energy, Ecology and Ecologistics, Commodity Science, Transport and Forwarding Management.
- I am a co-author of 4 commodity science textbooks for university students and employees of quality control and sales departments.

- I took an active part in preparing the program of engineering studies in the field of Management and Production Engineering at the Faculty of Management of the AGH University of Science and Technology. I was also one of the people who developed the curricula and syllabuses of the subjects that were to be implemented at these studies. As part of this activity, I developed a curriculum and syllabuses, e.g. from the following subjects: Commodity Science, Ecological Sources energy acquisition, Ecology and ecologist.

- Striving to raise professional qualifications in the field of didactics, I took part in didactic conferences and trainings aimed at improving the quality of teaching, as well as introducing new teaching methods.

  I have completed a certification training in the field of conducting classes using distance learning methods and techniques, organized by the AGH e-Learning Center. I started using e-learning in practice and improving my qualifications in this area even before the coronavirus pandemic, when the use of distance learning became a mandatory practice in higher education in Poland.

  In addition, I participated in additional training offered by the AGH e-learning Center: creative group work, tests on the Moodle platform, the use of materials to conduct classes, pedagogical training for university employees.

  In addition, I have a certificate of a management representative for the quality management system. TUVPOL TUV Thuringen Group. No. 1614/ISO/2005.

- In the years 2012-2017 I was a member of the Student Evaluation Committee Session of Scientific Circles of the Metallurgical Division at the Faculty of Management of the AGH University of Science and Technology.

- Since 2018, I have been the supervisor of the "Production Manager" scientific club and the Chairman of the committee evaluating Student Sessions of Scientific Circles of the Mining Division at the Faculty of Management of the AGH University of Science and Technology.

- My activity at the AGH Faculty of Management was not limited to teaching and research:
  - ✓ In the years 2015-2018 I was a member of the Faculty Recruitment Committee.
  - ✓ In 2018-2020, I was a member of the Education Quality Committee at the Faculty of Management of the AGH University of Science and Technology.
  - ✓ I am a member of the Council for Management and Production Engineering at the Faculty of Management for the term 2020-2024.

- Since the beginning of my work at the AGH University of Science and Technology, I have actively participated in the scientific supervision of students, acting as a diploma theses supervisor. So far, I have been a promoter of 33 master's theses and 97 engineering theses and a reviewer of a total of over 100 engineering and master’s theses.

6.2. Organizational and popularizing science achievements

As part of activities popularizing science:

- Together with the Production Manager scientific circle, of which I am the supervisor, we organize annual meetings in the series "Training with Industry" and scientific trips to production plants throughout Poland.

  This activity is to familiarize students with practical knowledge implemented as part of didactic classes and to facilitate future graduates of the university to effectively navigate the labor market.

- As part of the activities of the scientific club, students under my supervision take part in annual conferences and deliver papers at plenary sessions both at their home university and in other research centers.

  In the years 2018-2022, students from my circle became winners of annual conferences as part of the management and quality session. The result of this cooperation are the publications of my students in: 60, 61 and 62 AGH scientific journals.

  In addition, the scientific club Production Manager, of which I am the supervisor:

- Obtains scientific grants for the implementation of research and disseminates its results to a wide audience, e.g. at conferences, in the AGH bulletin, conference materials and scientific notebooks.
- We actively participate in scientific conferences outside the walls of the University.
- Actively participates in the promotional activities of the faculty as part of the "Scientific Circles Symposium" and "Young Scientists Night".
- Engages regionally in socio-cultural issues, e.g. in the organization of the "Noble Box" event.

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(the applicant's signature)