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CHALLENGES IN THE AREA OF GREEN ECONOMY AND GREEN TRANSFORMATION IN REGARD TO THE DEVELOPMENT OF ENVIRONMENTAL TECHNOLOGIES

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Purpose: The research objective of this paper was to define the lines of the environmental technologies development in the context of the transformation of the economy towards green growth. The discussion focuses on the challenges accompanying the transformation processes and the implementation of sustainable technological changes. The research results allowed identifying the prospective lines of technological development regarding the transformation towards green growth as well as the future research areas.
Design/methodology/approach: The study was based on the analysis of the development trends strictly connected with environmental technologies. The adopted methodology involved a comprehensive literature review and quantitative research using the CAWI technique combined with complementary qualitative research using an expert panel.
Findings: The analyses allowed distinguishing the most important trends and placing them within the process of the Silesia Province green transformation. The dominating importance was attributed to energy generation, storage and decarbonization (CCS and CCU) technologies.
Research limitations/implications: The paper highlights the green transformation issues and the technological changes within the transition process while searching for a model approach enabling to delineate the development determining factors, especially environmental technologies.
Practical implications: The study results can be used to formulate development scenarios and conduct analyses that involve these green economy components which determine the development of chosen technological areas.
Originality/value: In the coming years**,** green economy will constitute a significant area of regional and international development incorporating resource management, RES, energy and material efficiency, clean technologies, CSR, biodiversity protection or the models of sustainable consumption and production. However, there is no research on how green economy is to be implemented in areas undergoing transformation, particularly, which technologies and factors should be considered.
The identification of the challenges concerning the transition towards green economy and environmental technologies may prove critical for the Silesia Province, a region heavily affected by transformation processes, to formulate its 2030 *Green Silesia* Strategy and the development of its regional specialization.

Keywords: green economy, environmental technologies, transformation.
Category of the paper: research paper.

1. Introduction

Green economy constitutes one of the key areas of contemporary development both in the regional and international scale. The notion of green economy is strictly connected with the concept of sustainable development. Introduced in 2008 as an initiative of the UNEP (United Nations Environment Programme – a UN environmental agency), it was considered to be a method to address the economic crisis. Green economy owes its current position to the 2012 United Nations Conference on Sustainable Development (or Rio+20) held in Rio de Janeiro which focused on the idea of the transition towards green economy. The conference debates were centered on the themes of shaping a new model of socio-economic growth and on comparing the brown economy with the green one. It was reiterated that environmental protection constitutes an issue of key importance and that it should prevail in the new paths of growth. The brown model of economy which was still being applied at that time and which relied heavily on the use of fossil fuels and non-renewable resources was to be replaced with a new pro-ecological approach. The differences between the two models are presented in Table 1 below.

Table 1.
Brown Economy vs. Green Economy, a comparison

Brown Economy/Excess Economy	Green Economy/Moderation Economy
Unrestricted economic growth	Decoupling natural resource use from economic growth
Fossil fuels	Renewable Energy Sources
Energy and resource intensity	Energy and resource efficiency
Greenhouse gas emissions	Clean production, curbed emissions
Generation of waste	Protection of biodiversity
Food waste	Sustainable consumption
Biodiversity destruction	Local economy
Global social inequality	Sustainable transportation
Overconsumption	Inter-generational and inter-regional justice
Business as usual	Corporate social responsibility of businesses and investors
Lack of corporate social responsibility	Social trust
Weakened social trust	

Source: Ryszawska, 2013.

In recent years, the European Commission as well as a number of international organizations have started to incorporate green economy in their strategies on a more regular basis. Even though the very term ‘green economy’ falls under numerous definitions, in general, it refers to a low-emission economy which effectively uses natural resources and ensures social growth. According the European Environment Agency (EEA) a *'green economy' is one in which environmental, economic and social policies and innovations enable society to use resources*

efficiently, thereby enhancing human well-being in an inclusive manner, while maintaining the natural systems that sustain us. The EEA also underlines the fact that the majority of green economy definitions inextricably connect the elements of ecosystems, economy, human well-being and the accompanying issue of capital. In the light of the above, this approach poses such challenges as (i) ensuring ecosystem resilience of the natural systems that sustain us, (ii) improving resource efficiency (and reducing the environmental impacts of our actions). The graphic representation of the above mentioned interconnections is demonstrated in Figure 1.

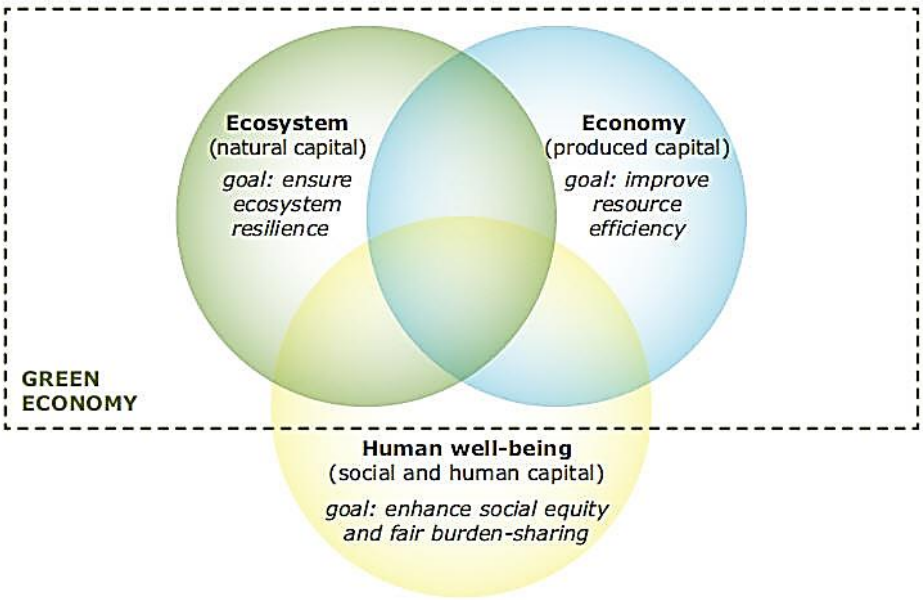

Figure 1. Green Economy processes.

Source: European Environment Agency.

Being a politically oriented concept, green economy is characterized by a broad meaning with sustainable development as a common denominator lying at its foundations. Within this context, one can assume that the basic definition of green economy is the one adopted by the European Commission; namely, it is *the economy which may generate growth and development improving at the same time the human well-being, ensuring jobs, limiting inequalities, eradicating poverty and preserving the natural capital upon which our long-term survival depends.* (Commission Communication "Rio+20: towards the green economy and better governance" COM (2011) 363 adopted on 20 June 2011).

The global trend of accentuating the environmental element was conducive to the introduction of new notions and concepts; for instance, green skills and green jobs, green projects, green growth, or inclusive green growth which favors social inclusiveness (Kasztelan, 2015). What is important, in the case of inclusive green growth, the notion should not be considered as a synonym of the concept of green economy; even though certain relationship between the two exists, they are supposed to be treated as mutually complementing rather than synonymous. Figure 2 presents the result of the European Commission effort to unify the approaches to the concept of inclusive green economy. This model reiterates the key assumption

that a standardized path towards green economy does not exist. As a consequence, the process of green transformation must be adapted to the specific context of each targeted area.

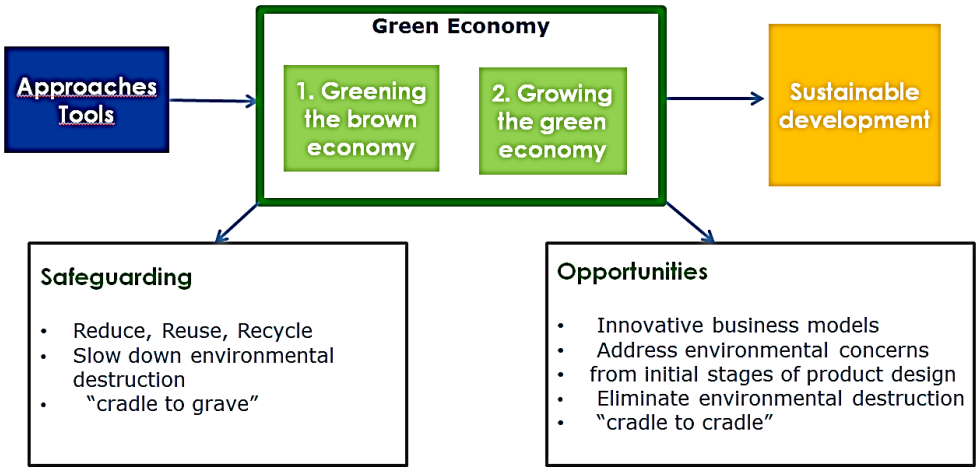

Figure 2. Inclusive Green Economy processes.

Source: The Switch to Green Facility, 2017.

Based on the presented approaches, green economy is predominantly aimed at realizing the principles of sustainable development, not at replacing it but rather constituting its more specialized scope. Quoting the research study by Adamowicz (2021), green economy may be understood as a set of principles, objectives and activities which involve the following:

- adhering to the principles of sustainable development, i.e. the rational use of resources in order to achieve economic and social targets by the present generation without compromising the interests of the future ones,
- using the natural and social capital in a sustainable manner by means of applying different tools such as the internalization of external costs or ecological accounting,
- comprehensive programming of resource use as well as the production and consumption processes, calculating the total and step-by-step costs of product life cycles, optimizing the management of manufacturing and consumption,
- adapting the economic systems to macroeconomic targets and global trends by mans of creating green jobs, eradicating poverty, increasing competitiveness and developing the key sectors of the economy.

Currently, green economy is considered as a political concept and as a growing economic sector which has recently become a priority in the development strategies of states, international organizations or businesses.

The rising interest in the transformation towards green economy results from the critical debate on the decoupling of the economic growth from the ever increasing use of natural resources. The unrestricted rise of production, consumerism as well as lack of moderation in using the non-renewable components of the environment, including the nature's values seriously threatens the existence of our civilization. Therefore, it has become necessary to pursue such solutions which would ensure synergy between the economic activities and the ecosystems.

In his paper, Söderholm (2020) makes a reference to the challenges which emerge during the implementation of sustainable technological changes within the context of green economy; in particular, (i) dealing with the dispersed and increasingly global threats to the natural environment; (ii) the achievement of radical, as opposed to incremental, feasible technological changes; (iii) ecological capitalism and the uncertain scenarios of the business-as-usual; (iv) the role of the state and the appropriate politics combinations; and (v) coping with problems and distribution effects. The author emphasizes the importance of the multi-disciplinary research projects regarding the thorough understanding of the socio-technological transformation as well as the necessity to translate the environmental and technical challenges into actions and social changes.

Another interesting approach to the issue of sustainable technological development with relation to green economy is presented in the paper of R. Tulsiram (2022). While discussing the green economic strategies, the author underlines the need to consider both the development and the application of sustainable technologies as strategic priorities. In a similar manner as in the work by Söderholm, Tulsiram focusses her considerations on the defined challenges which determine the transformation processes and create the future research areas, i.e. (i) the management of the dispersed and increasingly global environmental threats; (ii) the achievement of radical, but not incremental, feasible technological changes; (iii) green capitalism as well as uncertain business scenarios; (iv) the role of the state and the design of relevant political packages; and (v) addressing the problems and sectoral impacts.

2. Theoretical background

The 2030 Development Agenda entitled "Transforming our World: the 2030 Agenda for Sustainable Development" adopted on the 15 of September, 2015 and binding all the 193 UN Member States to undertake efforts to achieve the 17 Sustainable Development Goals (SDGs) constitutes a significant document of international footprint (The United Nations, 2015).

Within the framework of our research, Goal 7 of the Agenda (SDG7) calls for a special attention. The SDG7 is meant to "ensure access to affordable, reliable, sustainable and modern energy for all." In order to achieve the Goal, it is required to undertake comprehensive and orchestrated activities which focus on decarbonization as well as the expansion and upgrade of renewable energy systems. To large extent, it will involve the implementation of modern technologies which are critical for the development of pro-ecological energy sources and which minimize the environmental impact of their production and distribution. The transition to a sustainable energy system is connected with a combination of new challenges and opportunities. IRENA, the International Renewable Energy Agency, is an intergovernmental organization which supports states to promote the widespread adoption of renewable energy systems. It performs research on the technological solutions aiming to overcome the challenges

and recommending the best available practices. The proposed solutions include the following technologies:

- carbon capture, i.e. technologies enabling to capture, transport and store CO_2 which comes from the combustion of fossil fuels before it is released into the atmosphere,
- critical materials, i.e. the resources that are necessary for the production of the energy transformation technologies, including wind turbines, solar panels, electric vehicle batteries and electrolyzers. It is of key importance to ensure that they are available and affordable,
- energy storage, i.e. the energy storage technologies (for example batteries, fly wheels, pumped storage power plants) which offer a significant potential of flexibility for the energy systems in the transition period,
- hydrogen, i.e. ecological hydrogen technologies, production paths and products which create the possibility of limiting transport emissions, the emissions generated by sectors that are difficult to eliminate or of combining sectors,
- technology and infrastructure, i.e. solutions within the scope of renewable energy technology and infrastructure supporting climate change mitigation activities and resilient energy systems, especially in small developing member states as well as the least developed countries.

Sustainability" to Regeneration.

The transformation which is currently taking place in essence constitutes a structural change of the economy encompassing both some radical changes of the production systems and the patterns of consumption. The research studies (Raczewska, 2013, 2016) confirm that the implementation of green economy is increasingly affecting the creation of new sectors, employment, or the competitive advantage of businesses. Being a new trend growing within the pro-climate transformation of global markets, green economy contributes to the creation of new jobs requiring specific competences, which is to compensate the decreasing employment rates in the sectors generating high emissions. Green economy is developing rapidly all over the world, which creates the need for implementing novel technological solutions as well as modernizing the existing industrial infrastructure. As an alternative to the currently dominating economic systems, it should ensure fast and dynamic socio-economic growth and thus delineate the paths of economic development and at the same time minimize the negative impact on the natural environment. In light of the above, the creation of modern environmental technologies which build an innovative ecosystem and adhere to the principles of sustainable development plays a significant role. It will require the remodeling of strategic skills at the stately and regional levels taking into consideration their specific needs. Consequently, the growing importance of green economy as a tool to pursue sustainable development made it necessary to initiate research studies on the prospects concerning the development of environmental technologies within the area of green economy and green transformation.

3. Methods

The research objective was to define the lines of the environmental technologies development in the context of the transformation of the economy towards green growth. For the purpose of this study, we chose the Province of Silesia as a model analytical area due to its active and multivariate participation in the energy transformation processes.

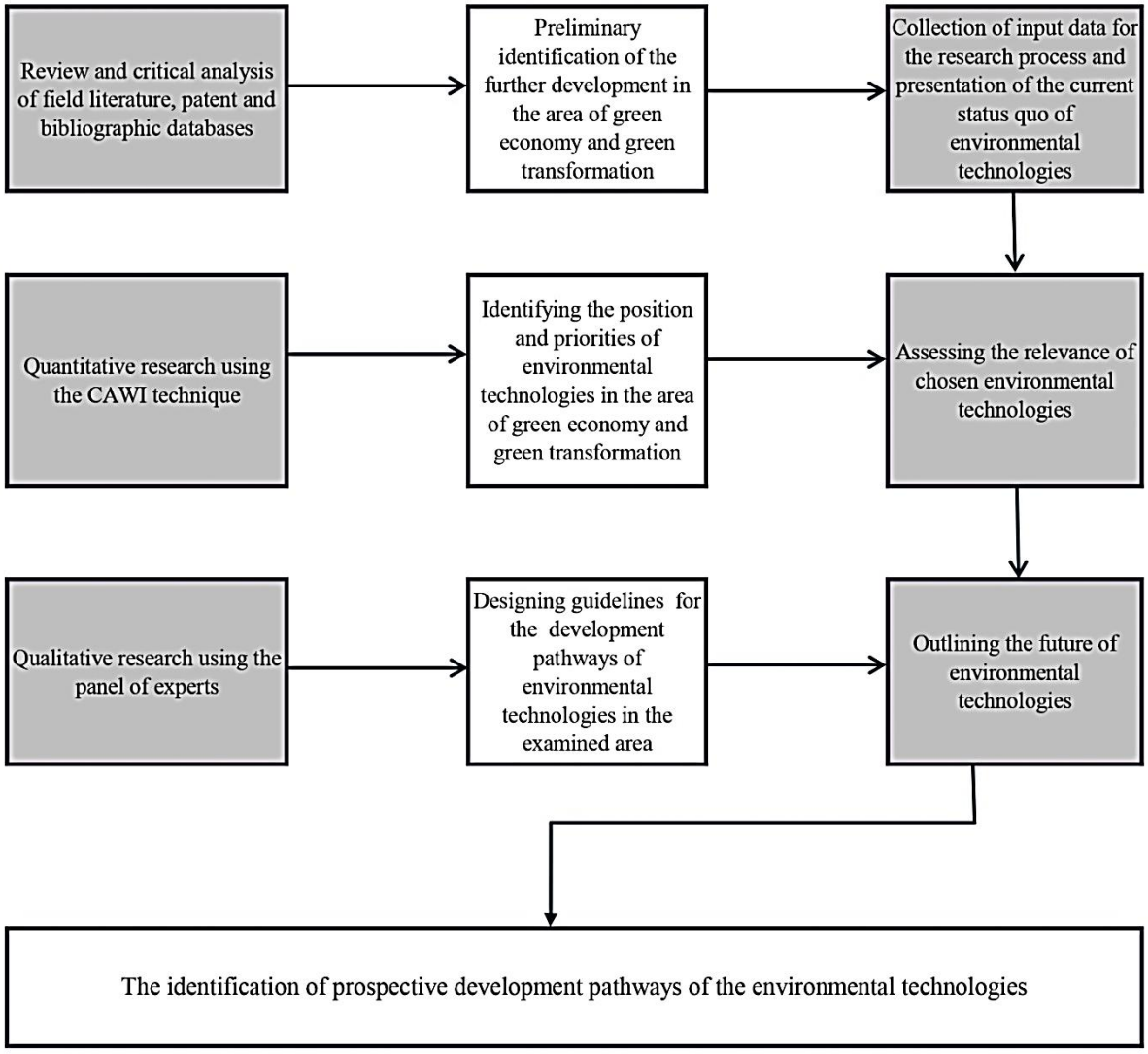

Figure 3. Research process.

Source: own elaboration.

Figure 3 presents the model of the research process which was adopted within the course of the study. The model considers free major research stages including: review and critical analysis of field literature, CAWI research and expert panel. Their selection allowed for a multi-faceted approach to the topic, presenting different views and opinions in the research area.

4. Results and discussion

4.1. Review and critical analysis of field literature, patent and bibliographic data bases

The selection of literature sources for the analyses was justified by the research objective. The following sources were subject of the critical review of the field literature:

- peer review research papers concerning the examined area of research,
- strategic and program documents developed on the state and regional levels, popular science studies, methodological studies, etc.,
- trade magazines,
- public statistics documents, reports, analyses,
- databases of patent data including *inter alia* WIPO statistics database or the European Patent Office (EPO),
- technological projects databases from the International Energy Agency (IEA), regional platforms for technology transfers or academic centers of innovations.

In the initial stage of the research, a comprehensive review of patent databases was performed in order to assess the current status of the development of environmental technologies.

4.1.1. EPO database

European Patent Office (EPO) examines European patent applications enabling to obtain the protection of inventions in up to 44 countries within the framework of a centralized and unified procedure. The organization collects and processes data concerning patent applications. Polish patent applications are presented in Table 2 below.

Table 2.
European patent applications in Poland in 2020 and 2021

Origin	2020	2021	% change 2021 vs. 2020	Share of total applications in 2021
POLAND	478	539	12.8%	0.3%
EPO states: the 38 member states of the European Patent Organization including the 27 EU states	81 531	83 775	2.8%	44%
All countries	180 417	188 600	4.5%	

Source: EPO, 2022.

The analysis of European patent applications indicates only a slight share of Poland accounting for 0.6% compared to the remaining EPO member states and 0.3% in comparison to the rest of the world. In the case of the statistics including the ranking according to the number of applications per 1 million inhabitants, Poland with its 539 applications occupies the 33rd position, while Switzerland which has 8442 application is on the first one. In addition, the platform allows obtaining information about the number of European patent applications according to the technological areas from which they originated (Table 3).

Table 3.
European patent applications including direct European applications and international (PCT) applications that entered the European phase during the reporting period

TECHNOLOGY FIELD	2020	2021	2021/2020
Medical technology	38	65	71.1%
Pharmaceuticals	35	39	11.4%
Transport	21	38	81.0%
Thermal processes and apparatus	49	34	-30.6%
Other special machines	19	33	73.7%
Civil engineering	24	30	25.0%
Measurement	18	23	27.8%
Mechanical elements	8	23	187.5%
Computer technology	22	18	-18.2%
Handling	14	18	28.6%
Chemical engineering	6	16	166.7%
Organic fine chemistry	16	15	-6.3%
Electrical machinery, apparatus, energy	19	14	-26.3%
Other consumer goods	23	14	-39.1%
Digital communication	6	13	116.7%

Source: EPO, 2022.

The analysis takes into account data concerning the key technological areas within the framework of which the patent potential in Poland is built. Medical technology is at the top of the list followed by Pharmaceuticals and Transport. Only the fourth place is occupied by Thermal processes and apparatus, an area connected with environmental technologies.

4.1.2. WIPO statistics database

The World Intellectual Property Organization (WIPO) is a UN agency which coordinates and shapes the rules governing the IP protection systems and creates the PATENTSCOPE data base enabling the access to international applications within the framework of the Patent Cooperation Treaty. The collection of data regarding patents, trademarks and industrial designs includes the applications filed by IP offices from the 190 member states. The analysis of the WIPO data allowed to categorize the number of patents according to technological areas (Table 4).

Table 4.
Patent grants by technology

Field of technology	Patent grants by technology	Field of technology	Patent grants by technology
Total	2283	17 - Macromolecular chemistry, polymers	71
14 - Organic fine chemistry	160	27 - Engines, pumps, turbines	54
35 - Civil engineering	158	18 - Food chemistry	53
23 - Chemical engineering	153	21 - Surface technology, coating	44
29 - Other special machines	136	33 - Furniture, games	44
20 - Materials, metallurgy	135	34 - Other consumer goods	33
19 - Basic materials chemistry	126	11 - Analysis of biological materials	24
10 - Measurement	120	28 - Textile and paper machines	23

Cont. table 4.

32 - Transport	103	22 - Micro-structural and nano-technology	20
16 - Pharmaceuticals	99	9 - Optics	15
26 - Machine tools	96	12 - Control	15
30 - Thermal processes and apparatus	87	6 - Computer technology	12
1 - Electrical machinery, apparatus, energy	82	8 - Semiconductors	9
31 - Mechanical elements	82	2 - Audio-visual technology	7
24 - Environmental technology	81	5 - Basic communication processes	7
15 - Biotechnology	80	3 - Telecommunications	4
13 - Medical technology	73	7 - IT methods for management	3
25 - Handling	72	4 - Digital communication	2

Source: WIPO, 2022.

The data show that environmental technologies are on the 14th place considering the number of the granted patents.

4.1.3. Patent data bases

Within the course of the field literature review, we identified and classified environmental technologies aligned with the principles of green economy and green transformation. The classification of the maturity of environmental technologies constitutes an added value of the study (Table 5).

Table 5.
A list of selected environmental technologies offered in the patent data bases

No.	The name of the technology	TRL	The creator of the technology	Source
1	Cryogenic capture, a refrigeration-based system of CO_2 separation	TRL 4 Early prototype (Prototype proven in test conditions)	Kujawy Cement Plant, Lafarge Poland Holcim Group)	(The International Energy Agency website, 2022)
2	Zero-emission hydrogen technologies	TRL 5	SES Hydrogen S.A.	(Platforma transferu technologii ARP, 2022)
3	3D Photovoltaic panel	TRL 5	Rafał Stajniak	(Platforma transferu technologii ARP, 2022
4	MTT (Microwave Thermal Treatment) + MOS (Microwave Oxidation System)	TRL 9	Jakub Lis	(Platforma transferu technologii ARP, 2022
5	PEM (Polymer Electrolyte Membrane) fuel cell technologies	TRL 7	AVL Software and Functions GmbH Sp. z. o. o., Poland	(Platforma transferu technologii ARP, 2022
6	KLINOTECH RMO, molecular recycling of waste	TRL 6	Klinika Nowych Technologii Energetyki Środowiskowej Sp. z o.o.	(Platforma transferu technologii ARP, 2022
7	KLINOTECH CR – thermo-catalytic cracking of polyphilic waste plastic	TRL 9	Klinika Nowych Technologii Energetyki Środowiskowej Sp. z o.o.	(Platforma transferu technologii ARP, 2022

Cont. table 5.

8	NanoBioCell technology for biodegradable, antibacterial and antiviral filters for innovative protective bionanocellulose masks	TRL 8	The Department of Technology and Chemical Engineering, West Pomeranian University of Technology, Szczecin	(Baza technologii ZUT, 2022)
9	Preparing activated carbon for the absorption of CO_2 using common stinging nettle as a raw material	In the current stage of the research, the technical solution proves to be effective for the production of activated carbon for the CO_2 absorption based on common stinging nettle as a raw material	The Faculty of Technology and Chemical Engineering, West Pomeranian University of Technology, Szczecin	(Baza technologii ZUT, 2022)
10	Innovative biodegradable packaging for different sectors	Mature technology	The Faculty of Food Sciences and Fisheries West Pomeranian University of Technology, Szczecin	(Baza technologii ZUT, 2022)
11	Water purification in a reactor with a replaceable photo-active filter	The stage of research and development	The Faculty of Technology and Chemical Engineering, West Pomeranian University of Technology, Szczecin	(Baza technologii ZUT, 2022)
12	Technology for amber waste management	TRL 4, in transition to TRL 5	Warsaw University of Technology	(CZIITT, 2022)
13	HABITARS, teledetection for the ecology	TRL 6	Warsaw University of Technology	(CZIITT, 2022)
14	REWARD, water purification	TRL 9	Warsaw University of Technology	(CZIITT, 2022)
15	Graphene shield protection against infra-red radiation	TRL 3	Warsaw University of Technology	(CZIITT, 2022)
16	SAFEDAM, advanced technologies for the prevention of flood hazard	TRL 9	Warsaw University of Technology	(CZIITT, 2022)

Source: own elaboration.

4.1.4. Critical review of field literature and trend analysis

The analysis of field literature enabled to distinguish the observations, guidelines and statements connected with the development of environmental technologies in the context of the on-going transformation processes of the Silesia Province. The selected technological trends and market prospects are presented in the compilation below.

- Energy generation, metallurgy, chemical industry, machine industry, mineral industry or transport industry constitute sectors which are characterized by greatest technological challenges; at the same time, they are high-emission and energy-intensive sectors with relation to the just transformation of the region (Województwo Śląskie, 2022a).

- A development of modern technologies will take place within the framework of the SMART-CITY concept with a special emphasis put on the management of urban water, waste and energy infrastructures as well as medical services with the use of robots and virus detecting and neutralizing drones to hamper the development of pandemics in the future.
- The development of distributed generation with RES, especially in terms of an organizational area understood as an integrated ecosystem (small renewable energy producers) is of key importance within the context of mining sub-regions and balanced energy generation based on alternative sources.
- The construction, logistics and transport are rapidly developing sectors which have convergent requirements concerning the qualifications of workers leaving the mining industry (Województwo Śląskie, 2022a).
- The development potential of the creative businesses and the nano-technology sector will be strengthened in order to foster market investments in mining regions (Strategia Rozwoju Miasta Katowice 2030, 2016).
- The closure and restructuring of coal mines as well as phasing out the outdated power units will contribute to the deployment of the existing infrastructure for implementing energy storage technologies including the pumped storage power plants and battery energy storage systems.
- The decarbonization of industries will induce the development of hydrogen technologies, for example electrolyzers for the production of green hydrogen generated in the process of electrolysis using RES electricity to be used in hydrogen filling stations or in the industry (Polskie Stowarzyszenie Energetyki Wiatrowej, 2021).
- The energy storage, the implementation of intelligent energy networks, electromobility, as well as highly efficient and energy saving technologies constitute the priority areas of the development (Ministerstwo Aktywów Państwowych, 2019).
- In order to address the need to deploy the chemical energy of the gas obtained in the process of coal seams de-methanation, the development of innovative methods of production using methane fed co-generation installations will take place (Tauron, 2019).
- Within the framework of the transformation process, projects connected with the so called circular economy will be fostered; in particular, those which involve the prevention of waste generation, the energy and transport infrastructures as well as decarbonization, i.e. energy efficiency or RES.
- The growth of hydrogen economy through the employment of renewable, low-emission hydrogen will take place (Zespół ds. Rozwoju Przemysłu OZE i Korzyści dla Polskiej Gospodarki, 2020).

- The aging high-emission coal based power units will be replaced with nuclear plants as a zero-emission reliable source to guarantee energy security and low costs of electricity generation. The transition will be achieved using large scale Generation II(+) pressurized water reactors (Ministerstwo Klimatu, 2022).
- An effective decrease in the CO_2 concentrations in the atmosphere and the introduction of innovative energy generation technologies including the development of geothermal energy solutions is considered to be a priority (Ministerstwo Środowiska, 2019).
- The natural resource potential of the Silesia Province will be exploited by means of an increased utilization of industrial waste and the development of municipal waste management technologies as well as a more efficient use of waste energy (Ministerstwo Rozwoju, 2017).
- The use of ICT will pose another challenge within the scope of Industry 4.0 (Silesia Province, 2022b).
- The elimination of the broadly understood negative environmental impact of mining activities will require developing new environmental technologies to mitigate the effects of the above mentioned activities including decontamination of post-industrial lands, remediation, rehabilitation or regeneration (Województwo Śląskie, 2022b).
- Due to the negative impact of mining on the aqueous environment, activities supporting water retention will be promoted.
- Special emphasis will be put on the restoration of degraded land (circular management) and its rehabilitation, which will require the development of relevant technologies.
- The use of no-smoke low-emission fuels will be widespread.
- The green economy will gradually encompass new value chains, for example technologies used for exploiting the potential of marginal soils, including the contaminated ones, to create the value chains in terms of biomass or phyto-technology.
- Along with the green transformation, the demand for mineral resources will rapidly increase. The global community must make sure that all the resources are fully exploited; therefore, new technologies as well as research and development activities are needed.

A wide range of environmental technologies, as well as the intensification of changes taking place in the area of transition and the climate and energy policy framework, indicate how strongly these trends are affecting economic practice. This is directly reflected in the implemented solutions spreading a pro-environmental approach and based on innovative engineering solutions/ ideas, reducing environmental impact or achieving a more efficient and responsible use of natural resources, including energy.

4.2. Quantitative research using CAWI technique

In order to perform the CAWI survey and to design the questionnaire we referred to a set of chosen environmental technologies based on the proprietary review of sources including the on-going Entrepreneurial Discovery Process and the National Center for Research and Development Program – New Energy Technologies, 2020. The survey performed by means of the CAWI technique involved a test sample of Silesia Province enterprises from the sector which undergoes the transformation process and the municipalities qualified for receiving financial support from the Just Transition Fund. The objective of the survey was to assess the relevance of the selected environmental technologies. The questionnaire included the following questions:

- Which of the following technologies do you consider as the most relevant for the transformation of the Silesia Province? Please select the rank-order 1-5, where 1– not relevant at all, 5 – very relevant.
- Which technologies, while implemented, do you think may have the greatest impact on the effectiveness of the transformation of the Silesia Province? Please select the five which are most important.
- Which activities should be undertaken to stimulate the development of the environmental technologies within the process of the transformation of the Silesia Province? More than one answer may be selected.

The results of the conducted survey are presented in Tables 6-8 and in Figure 4.

Table 6.
The results of the ranking of the environmental technologies relevant in the context of Silesia Province transformation in the area of Regional Innovation Strategy – Green Economy

Regional Innovation Strategy – Green Economy	Rank
Technologies of ecological, safe and effective waste management	4.00
Technologies limiting the emissions of pollutants into the atmosphere	3.97
Sustainable transport technologies	3.88
Environmental protection and land rehabilitation technologies including energy technologies and bio-geochemical engineering	3.82
Environmental technologies of different sectors of the industry	3.79
Technologies supporting the management of the natural environment	3.76
Bio-technologies for environmental protection	3.71
Water treatment and separation technologies, water retention and purification technologies	3.68
Technologies for the construction sector	3.24

Source: own elaboration.

The technologies compiled in Tables 6 and 7 were taken from the Silesia Province Regional Innovation Strategy 2030, a program document highlighting the commitment of the Province to pursue an intelligent transformation of the region based on the regional ecosystem of innovations. The energy and green economy technologies presented in the tables constitute priority solutions for the sustainable development of the Silesia Province. The scope of the technologies was identified on the basis of a foresighting process and complementary activities

connected with the design of the Technology Development Program for the Province of Silesia 2010-2020.

Table 7.
The results of the ranking of the environmental technologies relevant in the context of Silesia Province transformation in the area of Regional Innovation Strategy – Energy Generation

Regional Innovation Strategy – Energy Generation[2]	Rank
Technologies of energy generation from waste and alternative fuels	4.00
High-efficiency energy generation technologies limiting the emissions of GHGs and other pollutants	3.94
Energy storage technologies	3.94
Energy generation from renewable sources and the improvement of efficiency	3.91
Technologies of intelligent networks and inter-system connections	3.88
Combined Heat and Power generation, cogeneration and polygeneration	3.85
Fuel cells technologies	3.85
Prosumer energy generation	3.82
Intelligent and energy-efficient construction	3.76

Source: own elaboration.

The intelligent regional specializations of the Silesia Province concerning the area of green economy and energy generation were highly ranked in terms of their relevance for the transformation process of the said region. The technologies of energy generation from waste and alternative fuels as well as the technologies of ecological, safe and effective waste management were particularly distinguished. This means that these technological solutions are of key strategic importance for the Province because they are region-specific and address the emerging challenges associated with the transformation process.

Table 8.
Results of the survey concerning the impact of implementing chosen environmental technologies on the effectiveness of the transformation process of the Silesia Province

Region specific environmental technologies with respect to different industry sectors	Share
Energy storage technologies including pumped storage power plants and battery energy storage systems	74%
Hydrogen technologies including electrolyzers for the production of green hydrogen generated in the process of electrolysis using RES electricity to be used in hydrogen filling stations or in different sectors of industry	71%
Technologies for circular economy applications	59%
Energy generation technologies using methane fed co-generation installations	50%
Technologies for mitigating the effects of industrial and mining activities including decontamination, remediation, rehabilitation, etc.	50%
Technologies for the production of no-smoke low-emission fuels	44%
SMART-CITY concept technologies with a special emphasis put on the management of urban water, waste and energy infrastructure as well as medical services	35%
Nuclear energy technologies	29%
Energy storage technologies integrated with RES	29%
Technologies for hydrogen generation and application	12%
Information and communication technologies (ICT) for optimizing the manufacturing processes and logistics, especially with regard to the Internet of Things, Smart Cities and Industry 4.0	9%

Cont. table 8.

Waste to energy conversion technologies	9%
Technologies for mobile thermal energy storage facilitating to use waste heat in remote (up to several dozen kilometers) heating installations	9%
Technologies supporting the system management of post-industrial areas	6%
Forrest and agriculture biomass gasification technologies, biodegradable waste included, for the generation of synthesis gas as a potential source of hydrogen and its derivatives (methane, methanol, ammonia, etc.)	6%
Technologies for heat and electricity generation using hydrogen and its derivatives	6%
Integrated energy micro-grids (territorial integration of the sources for generating electricity, heat or cold including energy storage and balance)	3%
Technologies for utilizing the accessible energy sources including the development of geothermal energy	0%
Power-to-x technologies and e-fuels	0%
Technologies for innovative applications of photovoltaic cells in agriculture, construction, transport and other areas	0%
Technologies for the production of high efficiency new generation photovoltaic cells of technical and economical properties exceeding the currently available ones to be applied in the electromobility and construction sectors	0%
Information technologies for supporting the operation of wind farms (Intelligent Wind Farm)	0%

Source: own elaboration.

The elaborated set of region specific environmental technologies concerning different sectors of the industry constitutes a result of a proprietary review of sources for the selection of technologies which are most relevant for the on-going transformation process of the Silesia Province and which may have the largest impact on its effectiveness. Within this scope, the CAWI survey indicates that the biggest number of the respondents (over 50% of the participants) attribute this feature (the largest impact of the implementation of a given technology on the effectiveness of the transformation process) to the following:

- energy storage technologies including pumped storage power plants and battery energy storage systems,
- hydrogen technologies including electrolyzers enabling to obtain green hydrogen generated in the process of electrolysis using RES electricity to be used in hydrogen filling stations or in various sectors of the industry,
- circular economy technologies,
- energy generation technologies using methane fed co-generation installations,
- technologies for mitigating the negative environmental impact of industrial and mining activities (*inter alia* remediation, rehabilitation, regeneration, renaturalization, decontamination of post-industrial areas, purification of contaminated surface and underground waters, water retention, etc.).

What is important, solutions encompassing power-to-x, e-fuels, photovoltaic cells or wind farms technologies were completely passed over by the respondents.

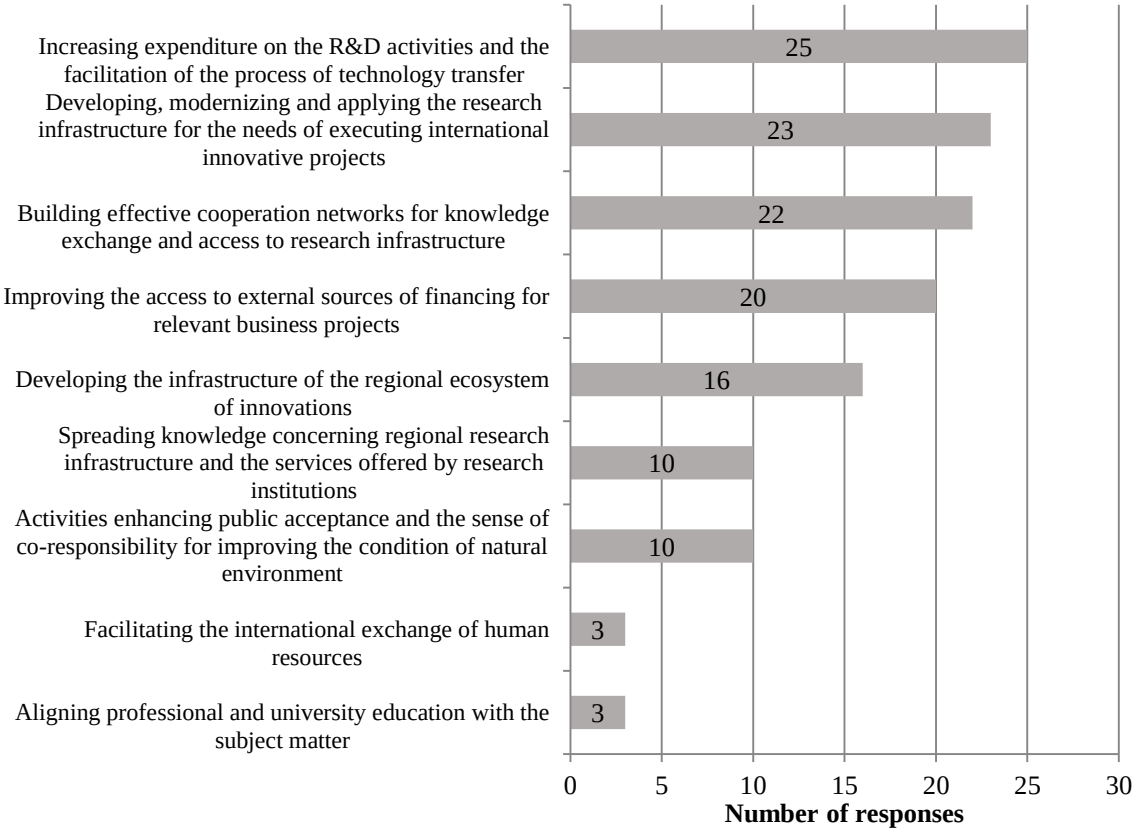

Figure 4. The assessment of activities which should be undertaken to stimulate the development of environmental technologies in the transformation process of the Silesia Province.

Source: own elaboration.

In order to design the scope of activities which should be undertaken within the transformation process of the Silesia Province, the CAWI survey was complemented with a question concerning what should be done to stimulate the development of the environmental technologies (Figure 4). The respondents indicated the need of increasing the expenditure on R&D activities, the development of research infrastructure in the region or the build-up of effective networks for cooperation. The smallest group of respondents signaled the need for international exchange of human resources or the alignment of professional and university education with the chosen subject matter.

4.3. Qualitative research using an expert panel

An expert panel constitutes one of key methods used in foresight research, trend analysis or in building long term visions of the future. In our study, it allowed to systematize the obtained results in relation to the research objectives. Within the course of the discussions on the prospective lines of environmental technologies development, it was agreed that energy, green transformation as well as environmental technologies would become the core pillars of modern economy. This means that the green transformation along with broad implementation and sustainable use of all forms of energy form renewable sources will be economically inevitable as well as environmentally and socially desirable.

In addition, the panel of experts pointed out that plans executed at the EU level, among others, the European Green Deal and EU's Fit for 55 Package, should be taken into consideration because they encompass solutions and ambitious goals which may have a significant impact on different sectors of the economy. The EU green transformation policy initiative may prove conducive to inspire or even necessitate the development of chosen environmental technologies. At this moment, special emphasis should be put to undertake decisive actions to foster a complex just transformation of each of the following sectors: energy generation, transportation, food system. Another critical issue that comes to the forefront is the strong interlinkage of low-emission economy with the construction and cement and concrete industry.

Importantly, the Province of Silesia, the largest mining region in the European Union is facing a tremendous transformational challenge entailing radical changes in the economic, environmental and social areas.

Considering the above mentioned issues as well as the results of the research, the green transformation of the Silesia Province should take place first of all within the area of energy generation technologies including the CCS (*carbon capture and storage*) and CCU (*carbon capture and utilization*). The transformation of local business models along with the regional and national raw material and energy resource base as well as waste management by means of innovative pro-ecological solutions should constitute activities complementary to the process.

5. Summary

The results of the performed analyses enabled to identify the prospective lines of the development of environmental technologies in the framework of the transformation towards green growth as well as to delineate the areas for future research. Within the context of the Silesia Province as the analyzed research area, adjusting the economy of the mining sub-regions to follow the path of green, intelligent as well as digital growth appears as the key challenge to the development. The Province of Silesia which is the most coal-dependent region in the European Union must face not only the urgent energy issues associated with the transformation processes but also the spatial and social challenges. In particular, it means that the system management and the monitoring of economic, technological and social phenomena are necessary within the course of the transition process. Taking into account the enormous scale of the challenges to be addressed, the Silesia Province transition to climate neutral economy will be a demanding multi-dimensional task requiring phased implementation of the changes.

The analyses conducted within the framework of the research enabled to distinguish the most important trends and to place them within the process of the Silesia Province green transformation. The dominating importance was attributed to the energy generation and energy

storage technologies as well as those technologies which are directly connected with decarbonization, i.e. CCS (*Carbon Capture and Storage*) and CCU (*Carbon Capture and Utilization*).

The current challenges induce the necessity to modify the existing local business models as well as the regional and national raw material and energy resource base along a wider application of innovative, pro-ecological solutions in the high-emission and energy intensive sectors. Consequently, the improvement of energy efficiency constitutes a significant area of activities connected with the process of green transformation.

The awareness of the emerging challenges associated with the transition as well as of the future potential enables to make the most of the transformation process and to accentuate all its benefits. In order to be successfully implemented, the current transformation necessitates comprehensive and proven knowledge to build flexible models and the technological know-how which constitute the foundation of sustainable, just and economically efficient low-emission economy.

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References

1. Adamowicz, M. (2021). Zielona gospodarka, zielony wzrost i zazielenienie jako formy realizacji koncepcji zrównoważonego rozwoju. *Wieś i Rolnictwo, 2(191),* pp. 13-33. doi: 10.53098/wir022021/01.
2. *Baza technologii Regionalnego Centrum Innowacji i Transferu Technologii Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie*. Retrieved from: https://innowacje.zut.edu.pl/technologie/, 2.08.2022.
3. Commission Communication (2011). "Rio+20: towards the green economy and better governance" COM (2011) 363 adopted on 20 June 2011.
4. *CZIITT - Centrum Zarządzania Innowacjami i Transferem Technologii Politechniki Warszawskiej – Katalog Badania Innowacje Technologie 2022*. Retrieved from:

https://www.cziitt.pw.edu.pl/DBA/Katalogi_BIT/Badania-Innowacje-Technologie-2022.pdf, 2.08.2022.

5. *EPO - European Patent Office (EPO) database - Espacenet*. Retrieved from: https://worldwide.espacenet.com/, 8.08.2022.
6. Kasztelan, A. (2015). Zielony wzrost jako nowy kierunek rozwoju gospodarki w warunkach zagrożeń ekologicznych. *Studia Ekonomiczne*, *2*, pp. 185-208.
7. Krzymowski, A. (2022). Energy Transformation and the UAE Green Economy: Trade Exchange and Relations with Three Seas Initiative Countries. *Energies*, *15*, 8410. https://doi.org/10.3390/en15228410.
8. Kuáyk, P., Gąsiorek-Kowalewicz, A. (2018). Rozwój zielonej gospodarki w krajach Grupy Wyszehradzkiej. *Problemy Rolnictwa światowego*, *18(2)*, pp. 193-206.
9. Lee, S. (2022). Toward a just green economy transition. *Field Actions Science Reports, Special Iss. 24*. Retrieved from: http://journals.openedition.org/factsreports/6903, 20.12.2022.
10. Ministerstwo Aktywów Państwowych (2019). *Krajowy plan na rzecz energii i klimatu na lata 2021-2030.*
11. Ministerstwo Klimatu (2022). *Program polskiej energetyki jądrowej*. Retrieved from: https://bip.mos.gov.pl/fileadmin/user_upload/bip/prawo/inne_projekty/PPEJ/Program_polskiej_energetyki_jadrowej.pdf, 7.11.2022.
12. Ministerstwo Rozwoju (2017). *Program dla Śląska*. Retrieved from: https://archiwum.miir.gov.pl/media/65008/Program_dla_Slaska.pdf, 13.11.2022.
13. Ministerstwo Środowiska (2019). *Polityka ekologiczna państwa 2030*. Retrieved from: https://bip.mos.gov.pl/fileadmin/user_upload/bip/prawo/projekty/PROJEKT_POLITYKI_EKOLOGICZNEJ_PANSTWA_2030/Projekt_Polityki_ekologicznej_panstwa_2030.pdf, 7.10.2022.
14. PARP (2010). *Przeprowadzenie badań rynku wybranych usług wspierających rozwój przedsiębiorczości i innowacyjności w Polsce „Ochrona środowiska i ekoinnowacje". Raport końcowy.* Warszawa. Retrieved from: https://www.parp.gov.pl/storage/publications/pdf/raport_19_07.pdf, 10.12.2022.
15. *Platforma transferu technologii Agencji Rozwoju Przemysłu S.A*. Retrieved from: https://ptt.arp.pl/bazy/, 15.07.2022.
16. Polskie Stowarzyszenie Energetyki Wiatrowej (2021). *Zielony wodór z OZE w Polsce.* Retrieved from: http://psew.pl/wp-content/uploads/2021/12/Raport-Zielony-Wodor-z-OZE-77MB.pdf, 1.12.2022.
17. Prokopowicz, D. (2020). Implementation of the Principles of Sustainable Economy Development as a Key Element of the Pro-Ecological Transformation of the Economy Towards Green Economy and Circular Economy. *International Journal of New Economics and Social Sciences, 1(11),* pp. 417-480.

18. Ryszawska, B. (2013). *Zielona gospodarka – teoretyczne podstawy koncepcji i pomiar jej wdrażania w Unii Europejskiej*. Wrocław: Wydawnictwo Uniwersytetu Ekonomicznego we Wrocławiu.
19. Ryszawska, B. (2016). Zielona transformacja gospodarki jako droga do gospodarki umiaru. In: J. Pach et al., *Ekonomia umiaru - realna perspektywa?* (pp. 187-204). Warszawa: PWN.
20. Söderholm, P. (2020). The green economy transition: the challenges of technological change for sustainability. *Sustain Earth,* 3,6. https://doi.org/10.1186/s42055-020-00029-y.
21. Tauron (2019). *Metan z kopalni w Brzeszczach źródłem prądu i ciepła*. Retrieved from: https://media.tauron.pl/pr/431391/metan-z-kopalni-w-brzeszczach-zrodlem-pradu-i-ciepla, 7.10.2022.
22. *The European Environment Agency (EEA).* Retrieved from: https://www.eea.europa.eu/publications/environmental-indicator-report-2012/environmental-indicator-report-2012-ecosystem/part1.xhtml, 1.12.2022.
23. *The International Energy Agency website*. Retrieved from: https://www.iea.org/data-and-statistics/data-tools/etp-clean-energy-technology-guide?country=Poland, 1.08.2022.
24. The United Nations (2015). *Transforming our world: the 2030 Agenda for Sustainable Development*.
25. The Switch to Green Facility (2017). Presentation on theme: *Inclusive Green Economy: Seizing new opportunities to generate growth, create jobs and help reduce poverty*. Retrieved from: https://www.switchtogreen.eu/uganda-inclusive-green-economy-workshop-24-28-april-2017/, 7.10.2022.
26. Tulsiram, R. (2022). The challenges of technology transformation for sustainability in the green economic transition. *International Journal of Mechanical Engineering, vol. 7, Special Iss. 2*, pp. 240-245.
27. Uchwała XIX/365/15 Rady Miasta Katowice z dnia 17 grudnia 2015 r. Strategia Rozwoju Miasta Katowice 2030 (2016). Retrieved from: https://www.katowice.eu/Documents/strategia_miasta_sklad.pdf, 10.10.2022.
28. UNDP (2013). *Inclusive Green Economy Contribution to Sustainable Development Chart*, p. 6.
29. UNEP (2011). *Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication, Report*. Retrieved from: http://www.unep.org/greeneconomy/GreenEconomyReport/tabid/29846/Default.aspx, 16.12.2022.
30. *WIPO - The World Intellectual Property Organization*. Retrieved from: https://www.wipo.int/portal/en/index.html, 5.08.2022.
31. Województwo Śląskie (2022a). Terytorialny Plan Sprawiedliwej Transformacji Województwa Śląskiego 2030 – projekt – v. 04. Retrieved from: https://transformacja.slaskie.pl/images/Dokumenty/1646921120_terytorialny_plan_spr.04.pdf, 7.10.2022.

32. Województwo Śląskie (2022b). Załącznik nr 2 do projektu Terytorialnego Planu Sprawiedliwej Transformacji Województwa Śląskiego 2030 - v.04 Potencjały i wyzwania rozwojowe województwa śląskiego w kontekście sprawiedliwej transformacji. Zróżnicowanie obszaru podregionów górniczych. Retrieved from: https://transformacja.slaskie.pl/images/Dokumenty/1646921120_za_C5_82.-2-potencjały-c5-82y-i-wyzwania-rozwojowe.pdf, 13.11.2022.
33. Zespół ds. Rozwoju Przemysłu OZE i Korzyści dla Polskiej Gospodarki (2020). Raport zespołu nr 4 Gospodarka Wodorowa. Retrieved from: https://klasterwodorowy.pl/images/zdjecia/Gospodarka%20Wodorowa.%20Rekomendacje%20grupy%204.pdf, 15.10.2022.
34. Zuzek, D. (2015). Determinanty rozwoju ekoinnowacji w sektorze MSP na przykładzie województwa małopolskiego. *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu, t. 17, z. 1*, pp. 240-244. Retrieved from: https://agro.icm.edu.pl/agro/element/bwmeta1.element.agro-d0842e4e-1226-4311-b7ca-e816f10376fb/c/2.pdf, 15.12.2022.