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Article

Development of Knowledge Capital in the Field of Nuclear Energy in Poland – Perspective 2035

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Abstract: The article addresses the issue of reducing the carbon footprint in the formula of the European Union's New Green Deal using nuclear energy introduced in place of coal. It contains an analysis of the possibilities offered by currently developed concepts of using nuclear energy in the context of existing energy infrastructure in Poland. It indicates the compatibility of coal and nuclear technologies for generating electricity and heat, considering only those with the highest level of technological readiness. The aim of the article is to identify the possibilities of energy transformation in Poland based on carbon-nuclear transformation. That is, replacing the existing energy infrastructure based on fossil fuels (coal and hydrocarbons) with solutions based on nuclear energy, and acquiring, creating and developing knowledge on this subject. The article pointed out a new approach, which is the transformation of existing power plants based on coal and gas blocks into nuclear power plants - through their transformation. It is assumed that the future of coal-nuclear transformation depends on determining where investment processes could take place in Poland, demonstrating the power that can be replaced through transformation, and indicating appropriate coal CPP (Carbon Power Plant) and nuclear NPP (Nuclear Power Plant) technologies with which a roadmap for the development of Polish nuclear energy can be created. The direction of potential actions is shown, whose coordination and implementation requires cooperation between many entities with appropriate knowledge and experience. For the purposes of this article, preliminary research was conducted on the possibilities offered by currently developed concepts in the context of existing energy infrastructure in Poland, its transformation, and the necessary social capital and its sources. The considerations did not take into account power plants and combined heat and power plants that have been liquidated or the use of their remaining infrastructure.

Keywords nuclear energy; coal energy; Poland; knowledge shaping; knowledge conversion

1. Introduction

The civilization challenges of humanity in the 21st century are related to limiting the negative impact of humans on Earth in the form of the carbon footprint and associated environmental pollution [1]. One of the possible actions to protect the planet is to replace traditional fossil fuels such as coal, oil, and gas with a modified form of energy [2], including nuclear energy based on various nuclear technologies [3]. It has its economic, social, and ideological justification and is associated with improving air and water quality, biodiversity, eco-empathy, and innovations necessary for shaping societies in the European Union [4].

The use of nuclear technologies based on appropriately small, medium and large nuclear reactors tailored to needs creates the possibility of transitioning from the present to “green” capitalism [5]. In it, the current high standard of living of Europeans will be improved to meet vital, ecological individual, group and social needs [6]. It will also allow for maintaining the current functioning of capital markets by separating the increase in GDP of EU member states from the growing consumption of energy that destroys the natural environment [7]. In addition, it will strengthen EU societies as those that are guided by knowledge development [8] and through

providing innovative solutions in the field of nuclear medicine will serve to protect health as our highest value.

The result of this approach should be an increase in the competitiveness of European industry by ensuring the transformation of regions affected by changes in the existing economic order [9]. In addition, it is important to both create and change existing competencies of employees functioning within ecological societies of EU member states aware of their individual and group role played in consumption and production processes within shaping European Green Deal [10]. This involves building new knowledge resources [11]. Primarily in the field of using nuclear technologies both among currently trained staff [12] and development and conversion of knowledge among currently employed workers in conventional industries.

The formula for the development of Polish energy: from coal to atom

The development of Polish energy is closely related to the demand for energy for machines, devices, and people, regardless of its source or method of production. Taking into account the needs and context of climate change, Poland's energy transformation should take place as quickly as possible [13]. This almost obvious statement has, however, a causal - political, economic, social - power that determines the perspective of meeting individual and collective needs, projecting the development of society and its participation in civilizational changes [14].

There are many reasons for Poland's energy transformation, including technological progress, communication and transport, lifestyle and social development [15]. Generalizing them, it is also necessary to indicate future ones related to the 4.0 revolution based on the Internet of Things connecting machines and devices with robotics (including drones), a new formula of economics (using 3D printing), or the use of cybernetics and artificial intelligence to transform matter, information and life in the field of bio-surgery, bioinformatics, nanotechnology, regenerative medicine [16] and nuclear medicine in the form of diagnostics and treatment of diseases (especially oncological) using radioactive isotopes. In documents, not only Polish but also EU ones, the need to build a knowledge-based economy and society with smooth knowledge transfer between nations and the development of own national intellectual capital is constantly emphasized [17].

There is no doubt that it is necessary to increase people's awareness of future challenges, especially energy security. In addition, phenomena related to the situation outside the country and their impact on its economy. Building a sense of security in society also in the context of certainty of constant energy supply to maintain the functioning of the economy as well as independence from supplies from other countries with which conflicts may continue or arise. This is becoming an increasingly important challenge for those in power and making key decisions in the development of Green Deal in Poland [18].

The transition from using coal in Polish energy to using atoms is one of the possible forms of transformation of the energy sector. The simplicity of the solution consisting in placing a nuclear reactor in place of a recently withdrawn coal block and modernizing accompanying infrastructure instead of building it from scratch opens up a new perspective for development. The benefits and challenges associated with transforming liquidated coal-fired power plants into nuclear power plants create new opportunities for the development of Polish energy, its modernization and approach to energy transformation within the framework of European Union's New Green Deal.

Coal-nuclear (C-N) transformation in professional and industrial energy

Currently many different concepts of nuclear reactors for energy purposes are being developed. Along with them various forms of nuclear power plants have been created. Some of them have such a high level of technological readiness that it is possible to propose or plan their use in a relatively short period of time. Among them there are several types of reactors that have a chance to be used in coal-nuclear transformation (Tables 1 and 2).

Table 1. List of built, under construction and implemented large nuclear reactors for the years 2014-2022.

Reactor Type:		Producer	Model - status	Power
BWR – Boiling Water Reactor				MWe
PWR – Pressurized Water Reactor				
PHWR – Pressurized heavy-water reactor				
ABWR	Advanced Boiling Water Reactor (BWR)	GE Hitachi,	ABWR - operating ESBWR - planned	1380 1600
APR	Advanced Power Reactor (PWR)	KHNP Westinghouse Mitsubishi	APR1400 - operating AP1000 - operating APWR- planned	1450 1250 1530
WWER	Water-Water Energetic Reactor (PWR)	OKBM	VVER-1200 - operating VVER-TOI – under construction	1200 1255
EPR	European/Evolutionary Power Reactor (PWR)	EDF	EPR - operating	1750
ACR	Advanced CANDU Reactor (PHWR)	AECL	EC6 - planned	750
ACPR	Advanced China Pressurized Reactor (PWR)	CNNC & CGN SNPTC	HPR1000/Hualong One - operating CAP1400/Guohe One - under construction	1170 1500

Source: Own study based on: <https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx>.

The International Atomic Energy Agency (IAEA) defines “small nuclear reactors” as those that enable the production of electricity at the level of 300 MWe. Medium-sized designs have production capabilities of up to about 700 MWe (above this limit we are talking about so-called large atoms). It is worth noting here that many reactors developed in the 20th century are classified as medium-sized. In the case of large designs, we are mainly dealing with generation III and III+ reactors. These reactors use passive safety systems that rely on natural physical phenomena (gravity, convection, or changes in the physical properties of substances due to temperature). This technological approach enables safe cooling of the reactor even without external power supply. Among the described designs, currently dominant are solutions that are an evolution of existing concepts of light and heavy water reactors.

Small modular reactors (SMRs) are defined as nuclear reactors with a maximum power output of around 300 MWe. They are designed in modular technology. This means that they are produced in such a way as to enable the production of modules in a factory and their subsequent assembly at the place of operation. This approach aims at savings resulting from serial production and shortening construction times. The term “generation IV reactors” does not refer to specific ready-made nuclear reactor projects, but is rather a common name for international research projects dealing with future nuclear reactors. Currently conducted projects of small and medium-sized nuclear reactors focus on such constructions as SMRs and generation IV reactors. The name SMR (Small Modular Reactor) suggests that these are small constructions. However, the name SMR is actually an acronym indicating that a given reactor has been designed for serial construction in the form of modules, with the possibility of combining many modules to build a large nuclear power plant (list of the most advanced models of small nuclear reactors Table 2).

Table 2. 2 List of planned and currently under construction small nuclear reactors.

Reactor type		Producer	Model - status	Power
HTGR – (sometimes HTR) High Temperature Gas-cooled Reactor				MWe
RBMK – Rieaktor Bolszoij Moszcznosti Kanalnyj – High-Power Channel-type Reactor				
FNR – Fast-neutron reactor				
MSR – Molten Salt Reactor				
PWR	Pakistan / China	SNERDI/CNNC	CNP-300 - operating	300
	China	CNNC	ACP100/Linglong One - under construction	125
		CGN	ACPR50S - planned	60
	Russia	OKBM	KLT-40S - operating	35
			RITM-200 - operating	50
			VBER-300 - planned	300
			RITM-200M - planned	50
			RITM-200N - planned	55
	Argentina	CNEA & INVAP	CAREM25 - under construction	27
	USA, Canada	Holtec, SNC-Lavalin	SMR-160 - planned	160
	USA	NuScale	NuScale Power Module - planned	77
	South Korea	KAERI	SMART - planned	100
		Kepeco	BANDI-60S - planned	60
BWR	USA	GE Hitachi	BWRX-300 - planned	300
PHWR	India	NPCIL	PHWR-220 - operating	220
RBMK	Russia		EGP-6 - operating	11
HTGR Gen IV	China	NET, CNNC & Huaneng	HTR-PM operating	210
	USA	X-energy	Xe-100 - planned	80
MSR Gen IV	Canada	Terrestrial Energy	Integral MSR - planned	192
	Denmark	Seaborg	Seaborg CMSR - planned	100
	USA	Kairos	MSR-Triso - planned	35
	UK	Moltex	Moltex SSR-W - planned	300
FNR Gen IV	Russia	RDIPE	BREST-300 - under construction	300
	USA	GE Hitachi	PRISM - planned	311
	USA	TerraPower, GE Hitachi	Natrium - planned	345
	USA	ARC, GE Hitachi	ARC-100 - planned	100

Source: Own study based on: <https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx>.

A separate subcategory of small nuclear reactors are microreactors. Their size should be small enough to allow for their transport, both single modules and many modules ready for connection and operation within a short time after unloading. Reactors of this type are expected to reach a maximum power output of around 15 MWe. Their purpose will be to provide electricity and heat in remote locations (they are dedicated to small communities and advanced military bases for generating electricity, heat and their transformation into other sources of energy) [19].

The current international situation creates the need for decisive steps towards energy safety [20]. The assumptions of Poland's long-term energy policy should be verified. On March 29, 2022, the Council of Ministers adopted assumptions for updating "Poland's Energy Policy until 2040" (PEP2040). These assumptions provide for increased technological diversification, development of renewable energy sources and implementation of nuclear energy, but do not include a comprehensive concept for transforming existing energy generation infrastructure. It is assumed that by 2040 more than half of installed capacity will be zero-emission sources. This will mainly be based on offshore wind energy and by launching new large-scale nuclear power plants. These will be two strategic new areas and branches of industry that will be built in Poland. PEP2040 identifies investments aimed at partially utilizing the country's economic, raw material, technological and personnel potential.

Taking into account the projected demand, it is necessary to point out the coal-nuclear transformation, which, through the development of specialized personnel but also the preservation of existing jobs, significantly increases the chance of development of the domestic energy industry in relation to the transformations identified in PEP2040. Historical and projected primary energy consumption and its final consumption in Poland indicate a steadily increasing trend (Tables 3 and 4). Due to the outbreak of the covid-19 pandemic, the authors decided not to analyze data from the period after 2020 which covers significant changes of chains supplies in world economics and shifts in energy demands by economies. The forecast predicts a decrease in primary energy consumption, which is related to the goal indicated in PEP2040, i.e. a 23% reduction in primary energy consumption compared to earlier forecasts.

Table 3. Historical primary and final total energy consumption in the years 2005-2020 [ktoe].

Years	2005	2010	2015	2020
primary energy consumption	87 952	96 589	90 104	96 423
primary energy consumption (PRIMES 2007)	89 581	95 611	104 804	109 829
final energy consumption	57 472	65 230	60 775	69 720
final energy consumption (PRIMES 2007)	57 169	63 712	71 246	77 448

Source: Poland's Energy Policy until 2040 Annex 2 - Conclusions from prognostic analyses for the energy sector electricity.

Table 4. Forecast of primary and final total energy consumption for the years 2025-2040 [ktoe].

Years	2025	2030	2035	2040
primary energy consumption	93 509	90 682	88 613	87 647
primary energy consumption (PRIMES 2007)	115 057	118 583	119 774	119 826
final energy consumption	67 682	65 509	65 229	65 112
final energy consumption (PRIMES 2007)	82 174	85 467	86 117	86 767

Source: Poland's Energy Policy until 2040 Annex 2 - Conclusions from prognostic analyses for the energy sector electricity.

Data on final energy consumption broken down by fuels and their carriers indicate that since 2020 there has been a noticeable increase in electricity consumption. Taking into account the projected economic growth and electrification of transport, adaptation to the 4.0 economy based on the Internet

of Things and increasing attention paid to building a knowledge-based economy and developing national intellectual capital. In line with the Country Development Strategy and EU documents, this trend will continue over time. It is worth noting the increase in biomass consumption, the increase in the use of earth and solar energy, which indicates an increase in their use in renewable energy sources (Tables 5 and 6).

Table 5. Historical final energy consumption by fuel and carrier in the years 2005-2020 [ktoe].

Years	2005	2010	2015	2020
electricity	9 028	10 206	10 990	12 152
district heat	6 634	6 547	5 462	5 748
coal	12 340	13 733	11 218	9 917
oil products	17 563	20 213	18 646	23 822
natural gas	7 917	8 884	8 487	10 144
biogas	40	48	78	97
solid biomass	3 755	4 306	4 639	5 295
biofuels	46	867	653	1490
municipal and industrial waste	136	378	486	785
solar collectors, heat pumps, geothermal	12	48	116	270
TOTAL	57 472	65 230	60 775	69 720

Source: Poland's Energy Policy until 2040 Annex 2 - Conclusions from prognostic analyses for the energy sector.

Table 6. Forecast of final energy consumption by fuel and carrier for the years 2025-2040 [ktoe].

Years	2025	2030	2035	2040
electricity	13 041	14 202	15 349	16 520
district heat	5 436	5 090	5 080	5 132
coal	7 117	4 899	3 735	2 842
oil products	22 602	20 911	20 063	19 124
natural gas	10 353	10 327	10 277	10 108
biogas	131	165	201	237
solid biomass	5 916	6 439	6 681	7 036
biofuels	1531	1413	1364	1317
municipal and industrial waste	871	891	905	919
solar collectors, heat pumps, geothermal	685	1 172	1 574	1 876
TOTAL	67 682	65 509	65 229	65 112

Source: Poland's Energy Policy until 2040 Annex 2 - Conclusions from prognostic analyses for the energy sector
It should be pointed out that the production of electricity and heat using nuclear energy has been omitted in PEP2040. Did the government realistically not foresee the launch of nuclear power plants during the discussed time?

The future of coal-nuclear transformation depends, however, on the proper identification of various coal technologies CPP (Carbon Power Plant) and nuclear NPP (Nuclear Power Plant), with the help of which a roadmap for the development of energy in Poland could be created. This activity is quite complicated and requires cooperation of many entities with appropriate knowledge and experience. First and foremost, attention should be paid to the possibilities of reusing components from currently operated coal-fired power plants in a future nuclear power plant and nuclear technologies that can be used with them. When discussing implementation possibilities in the field of nuclear blocks, the main focus should be on:

- For large power plants - the most modern PWR or PHWR reactors, these are:
 - American AP1000 reactor with a capacity of 1250 MWe, by Westinghouse Electric (WEC) [21].

- Korean APR1400 reactor with a capacity of 1450 MWe, by Korea Hydro & Nuclear Power (KHNP) [22].
- French EPR reactor with a capacity of 1750 MWe, by Électricité de France (EDF) [23].
- Canadian EC6 reactor with a capacity of 750 MWe, by Atomic Energy of Canada Limited (AECL) [24].
- For medium-sized power plants - the most modern modular PWR or SFR reactors, these are:
 - American NuScale SMR modular reactor with a capacity of 77 MWe (from 4 to 12 modules with a total capacity from 308 to even 924 MWe), by NuScale Power [25].
 - American IV generation reactor with a capacity of 345 MWe (potential possibility up to approx. 500MWe), by TerraPower [26].
- For small power plants - the most modern modular PWR or HGTR reactors, these are:
 - American NuScale SMR modular reactor with a capacity of 77 MWe (from 4 to 12 modules with a total capacity from 308 to even 924 MWe), by NuScale Power.
 - American high-temperature Xe-100 reactor with a capacity of 80 MWe, by X-Energy [27].
- In the case of microreactors, it is necessary to wait for licensing mobile models, in which the following reactors can be considered as the most promising due to their size allowing them to be placed in standard transport containers:
 - American eVinci microreactor, by Westinghouse Electric (WEC) [28].
 - American Xe-Mobile microreactor, by X-energy [29].

In striving for coal-nuclear transformation in Poland, it should be noted that different types of power plants operate in the country's current energy system, using coal or its derivatives as fuel. These are power plants fuelled by hydrocarbons (gas), or lignite and hard coal. Their electrical power varies from 23 to 5102 MWe. Some of them serve as combined heat and power plants where both electricity and heat are generated cogeneratively. Most often these are not contemporary installations; the oldest have been in operation for over 80 years. They were modernized during this time, but the level of these modernizations in the case of professional and industrial active power plants and combined heat and power plants operating in the country's energy system was very different.

In the case of coal-fired power plants fuelled by lignite coal, their transformation towards nuclear energy seems to be the most promising (Table 7). One of those indicated, Pałnow Power Plant, is currently being considered in the concept of C-N transformation using Korean APR1400 reactor with a capacity of 1450 MWe, by Korea Hydro & Nuclear Power (KHNP). In case of this project undertaken in October 2022 there was also a concept for implementing it in public-private partnership formula. The indicated power plants (Table 7) and decommissioned Konin Power Plant are exemplary examples for coal-nuclear transformation using large-scale nuclear reactors.

Table 7. Coal-fired power plants fueled by lignite coal.

Coal-fired power plants - lignite coal Power			
Plant Name	Start-up time	Number of blocks	Total power MWe
Elektrownia Belchatow	1981 - 2011	12	5102
Elektrownia Turow	1962-2021	7	2029
Elektrownia Pałnow	1967-2008	4	1118
TOTAL:			8249

Source. Own study.

Power plants fuelled by hard coal can also be characterized by a high probability of successful transformation towards the transition to nuclear energy (Table 8). In their case, it would be advisable to use medium and small nuclear reactors, such as Canadian CANDU (EC6) reactors with a capacity of 750 MWe, by Atomic Energy of Canada Limited (AECL). When assessing the most promising seems to be the use of American NuScale SMR modular reactors and IV generation reactors by TerraPower. In the case of industrial combined heat and power plants, coal-nuclear transformation

can be carried out using high-temperature reactors, such as the American high-temperature Xe-100 reactor with a capacity of 80 MWe, by X-Energy.

Table 8. Coal-fired power plants and CHP plants fueled by hard coal.

Coal-fired power plants and CHP plants - hard coal			
Plant Name	Start-up time	Number of blocks	Total power MWe
Elektrownia Kozienice	1972-2017	11	4007
Elektrownia Opole	1999-2019	6	3342
Elektrownia Polaniec	1979-2012	8	1882
Elektrownia Dolna Odra	1975-1977	4	903
Elektrociepownia Ostroleka	2009-2018	3	765
Elektrociepownia Bialystok	1967	3	154
Elektrociepownia Siekierki	1961	5	595
Elektrociepownia Lublin-Wrotkow	2002	1	235
Elektrociepownia Zeran	1954	1	299
Zaklady Azotowe „Pulawy” S.A.	2019-2021	1	128
Elektrociepownia Poznan Karolin	1991-1998	2	212
Elektrownia Skawina	1957	3	330
Elektrociepownie w Lodzi	1968-1977	7	404
Elektrociepownia Krakow	1970-1968	4	380
Elektrociepownia Lublin-Megatem	2007-2013	2	23
Elektrownia Pomorzany	1940	2	134
Elektrociepownia Fortum Czestochowa	2010	1	68
Zespol Elektrociepowni Bielsko-Biala	1997-2013	2	106
Zespol Elektrociepowni Bydgoszcz	1971	7	241
Zespol Elektrociepowni Wroclawskich	1961-1976	5	415
Zespol Elektrociepowni Wybrzerze	1970	7	342
Elektrociepownia Elblag	1956	4	74
TOTAL:			15039

Source. Own study.

When considering investment issues in coal-fired power plants and combined heat and power plants, it is impossible to omit those that are located in geologically unstable areas caused by mining damage or resulting from the geological structure of the substrate. Taking into account the ultimate completion of their operation by 2050, there is no possibility of transforming these facilities towards nuclear energy (Table 9)

Table 9. Coal-fired power plants and CHP plants fueled by hard coal on uncertain geological areas.

Coal-fired power plants and CHP plants - on geologically unstable areas			
Plant Name	Start-up time	Number of blocks	Total power MWe
Elektrownia Jaworzno	1977-2020	7	2260
Elektrownia Rybnik	1972-1978	6	1350
Elektrownia Laziska	1960-1990	4	905
Elektrownia Lagisza	2009	1	460
Elektrownia Siersza	1996	2	306
Elektrociepownia Chorzow	1991	2	226
Elektrociepownia Katowice	2000	1	135
Elektrownia Blachownia	1957	3	83
Elektrociepownia Fortum Zabrze	2018	1	75
Elektrociepownia Tychy	1999-2016	2	102
TOTAL:			5902

Source. Own study.

A separate issue is the transformation of power plants and combined heat and power plants fuelled by natural gas (Table 10). Their operating age, compared to the rest of the blocks used in Poland, is relatively small. In this case, there is also a possibility of their transformation and replacement of gas blocks with nuclear ones, especially using Canadian CANDU reactors, American NuScale SMR modular reactors, IV generation reactors by TerraPower. Similarly with power plants on other fuels, i.e. biomass, blast furnace gases, coke oven gases, metallurgical (Table 11)

Table 10. Gas-fired power plants and CHP plants.

Gas-fired power plants and CHP plants			
Plant Name	Start-up time	Number of blocks	Total power MWe
Elektrownia Stalowa Wola	2012	1	450
Elektrociepownia Gorzow	2014-2017	2	208
Elektrociepownia Rzeszow	2003-2014	2	130
Elektrociepownia Wloclawek	2017	1	465
Elektrociepownia Zeran	2021	1	497
Elektrociepownia Zielona Gora	1974	2	190
PKN ORLEN	2018	1	630
PGE Torun	1985	2	107
TOTAL:			2677

Source. Own study.

Table 11. Power plants on other fuels.

Power plants on other fuels			
Plant Name	Start-up time	Number of blocks	Total power MWe
Elektrownia Konin - Biomass	2012-2022	2	100
Elektrociepownia TAMEH - Natural gas, blast furnace gases, coke oven gases	2018	3	75
Zaklad Wytwarzania Nowa - coal, natural gas, metallurgical gases, coke oven gases	2001	5	180
TOTAL:			355

Source. Own study.

The total capacity of the above-mentioned power plants and combined heat and power plants is 32 222 MWe, some of which are located in geologically unstable areas which disqualifies these facilities for C-N transformation. The analysis indicates that facilities preliminarily qualified for coal-nuclear transformation reach a total capacity exceeding 26 GWe. This value represents the potential for coal-nuclear transformation in Poland.

Transfer and conversion of knowledge for the development of nuclear energy and technology

In the context of developing knowledge in society in the field of nuclear technology, it is necessary to emphasize and explain commonly functioning doubts in the information space that it is not an ecological technology. Part of society, not having full knowledge in this area, fears an unspecified threat from nuclear reactors; others are afraid of accidents and nuclear explosions and fear nuclear energy due to ionizing radiation and toxic waste.

The progress of science and the development of methods for using radiation sources or radioactive substances (radiopharmaceuticals) have resulted in their use on a mass scale in medicine. They provides beneficial effects of ionizing radiation, an example being radiotherapy of cancer diseases. Within radiological medical procedures one can mention known and commonly used standard diagnostic and therapeutic medical procedures but also screening tests and new experimental radiological procedures. a Nuclear medicine is *a specialized area of radiology that uses very small amounts of radioactive materials to examine organ function and structure as well as to delivering curative*

radiation doses directly to the targeted tissue making use of radiopharmaceutical products radiolabelled with radionuclides produced in accelerators and nuclear reactors. The field of ionizing radiation related medical procedures is well regulated. There are also certain tools which are addressing the issue of potential risk of novel procedures. Among others, projects such as SINFONIA project aim at the development of novel methodologies and tools that will provide a comprehensive risk appraisal for detrimental effects of radiation exposure on patients, workers, carers and comforters, the public and the environment during the management of patients suspected or diagnosed with lymphoma and brain tumours [42]. This project is not only focused at the patient but also at the dose and risk assessment of staff, comforters, the public and the environment. The threat is only posed by spent nuclear fuel. Nuclear reactors are in line with the assumptions of the EU program on the European Green Deal, which Poland as a member of the European Union must meet and are considered "green". Probably, in time perspective, it will be possible to additionally obtain co-financing from EU funds for such investments [30].

In addition to developing the country's energy and investing in modern technologies, it is crucial to share knowledge about all the advantages of using nuclear technologies, and above all their zero-emission impact on the natural environment [31]. It is also necessary to educate future specialists both in the field of nuclear technology and other fields where ionizing radiation is used. In addition, simultaneous improvement of competences of current staff in the field of designing and building the entire nuclear energy infrastructure, science, industry and nuclear medicine. It is worth using not only special and dedicated courses, trainings and postgraduate studies in the field of staff development and improvement but also human potential that already exists on the market [32]. This applies to current employees of conventional coal and gas power plants, scientists employed in research centers, engineers as well as medical personnel whose task will be both to apply standard and experimental radiological medical procedures and to act in case of negative effects of ionizing radiation on the human body. It is necessary to seriously consider using the experience of specialists in the field of current use of nuclear energy as well as those using more traditional technologies. The intellectual potential of this staff is already built at the base of knowledge. It should therefore be transformed in a slightly different - specialist direction [33].

The development of this staff's knowledge potential, shifting competences and their transfer towards nuclear technologies would be a bridge until a new staff is trained from scratch on specially organized forms and didactic directions. In the European Union, more and more emphasis is placed on developing intellectual capital within individual countries, taking care of converting specialized staff knowledge and using existing knowledge resources in organizations for their expansion, development and transfer in increasingly desirable new directions conducive to noticeable progress - here in the field of energy for creating a knowledge-based economy. It should be emphasized here both the growing need and necessity to prepare an increasingly wide spectrum of study proposals and trainings in the field of nuclear technologies. At the same time it is advisable to update and develop existing study directions in this area as well as expand the program in terms of new ways of using nuclear energy.

Taking into account the nearest perspective it is necessary to expand possibilities for creating own national knowledge in the field of nuclear technologies and searching for innovative solutions. In addition exploring market knowledge resources so that over time it can be obtained from external sources to a lesser extent. In the final result it will be invaluable to work out and create own know-how in the field of broadly understood nuclear energy in order to create and develop own knowledge capital and improve experts with reference to Polish conditions. Internal transfer of knowledge as well as its acquisition from outside the country and adapting acquired solutions to own specificity is important and extremely valuable. Equally important - or perhaps more valuable - is, however, the development of own individual knowledge resources based on acquired experience and knowledge so that they are fully compatible and adapted for use in the existing economic situation and needs of Poland.

Creating and building further teaching programs, study directions or postgraduate studies related to nuclear technology issues in Poland will allow for the education of new specialists. It will

also create an opportunity to create its own intellectual competence base in these fields. Currently, several technical universities and scientific institutes in Poland have already recognized the necessity and importance of developing awareness in the field of nuclear energy. They have created specialized studies and courses. In the field of nuclear energy these are: Gdansk University of Technology, Poznan University of Technology, Silesian University of Technology, Warsaw University of Technology, Wroclaw University of Technology, AGH University of Science and Technology in Krakow [34]. In the field of using ionizing radiation in medicine, the Radioisotope Center of the National Center for Nuclear Research deserves special attention. It should also be added here that Warsaw University, drawing on specialist knowledge and many years of experience from South Korea at the end of 2022 signed a cooperation agreement with the South Korean university KEPCO International Nuclear Graduate School which strengthened the professionalism of trained staff in the field of nuclear energy [35].

Not very often it is said that apart from people creating managing and professionally involved in managing a nuclear power plant it is also important to educate meaning acquiring knowledge in the field of dealing with radioactive waste from these power plants with their storage and disposal. However processing spent nuclear fuel and waste generated in nuclear research centers is another aspect of training specialists in this field. Dealing with radioactive waste in a socially responsible manner is an extremely important technical problem that must be solved in Poland taking into account past experience and new needs if nuclear energy is to be completely safe for people.

The role of green energy obtained from wind water or sunlight is naturally an extremely valuable source of energy. In reality it meets cleanliness and ecology requirements most. However there is a fundamental problem because for pragmatic reasons for maintaining the functioning of the economy smooth functioning of all institutions and comfort of life in the state. Energy obtained from these sources is unstable therefore uncertain i.e. certainty of its delivery - production is at a low level. The guarantee of energy delivery from nuclear power plants exceeds 95% while from onshore and offshore wind farms photovoltaics below 10%. In addition it is worth adding that calculations using average failure rates for conventional power plants and unavailability rates for renewable power plants according to transmission system operators and ENTSO-E are: 5% for nuclear energy 9% for lignite and hard coal 7% for natural gas 72% for run-of-river power plants 35% for biomass 20% for pumped-storage power plants 99% for onshore wind energy 96% for offshore wind energy and 100% for photovoltaics. For other renewable and non-renewable energy sources unavailability at the level of 35% is assumed - similar to biomass [36]. The presented calculation clearly indicates additional advantages of nuclear energy.

Additionally, since nuclear power plants can operate for several decades, they provide jobs for several generations of workers. Emphasizing their ecological operation and the fact that unlike power plants based on burning coal or hydrocarbons nuclear power plants do not emit carbon dioxide during their operation. Small amounts of carbon dioxide are released into the atmosphere during the construction of their power plants. On this basis another argument can be indicated which was mentioned earlier that the production of electricity itself is zero-emission. The above data therefore underline the correctness of the planned actions taken in Poland for energy transformation.

Research shows that in 2021 13 EU member states producing atomic energy generated 731 701 gigawatt hours (GWh) of nuclear energy which is 7 percent more than in 2020. This in turn represents 25% of total electricity production in the European Union [37]. France is still developing its nuclear energy and over half of total nuclear energy production in the EU is energy from French reactors. Finland on the other hand launched the largest nuclear reactor in Europe. Germany on the other hand closed its power plants in April 2023 with the intention of transitioning as much as possible to energy obtained from wind and sunlight. Poland looks favorably at nuclear power plants and constantly acquires knowledge about the development of nuclear energy as well as develops its future investments in this area.

It is worth emphasizing that in April 2023 a company PGE PAK Nuclear Energy was established in the country and thus a project was created to build a nuclear power plant instead of an existing one based on lignite coal. This is one of the first coal-nuclear transformation projects in the world

implemented on a public-private partnership basis by a private company ZE PAK and a state-owned company PGE Polish Energy Group. The whole is to be implemented with the participation of a foreign partner in the form of Korea Hydro & Nuclear Power (KHNP) which is the third largest operator of nuclear power plants in the world [38].

At the same time work is being carried out in Poland on developing energy infrastructure based on SMR reactors. Currently a project for developing BWRX-300 reactors and building new nuclear power plants based on them is being carried out in Poland by Orlen Synthos Green Energy also in public-private partnership with US co-financing about \$4 billion. So far 7 locations have been indicated which are located near Ostroleka Wloclawek Stawy Monowskie near Oswiecim Dąbrowa Gornicza Nowa Huta Special Economic Zone Tarnobrzeg - Stalowa Wola and near Warsaw [39]. By the end of 2023 another 20 such locations are to be proposed. The first small modular nuclear reactor according to announcements is to be launched in 2029.

In Poland several or several dozen nuclear power plants are planned for the coming years. Detailed and final plans have not yet been made as necessary analyses and feasibility studies are still underway. However it is worth emphasizing here that assuming that each nuclear power plant employs an estimated between 500 to 800 workers this is a great opportunity to employ many specialists - both newly educated ones and those mentioned earlier with experience from conventional power plants. The competences and qualifications of the latter will be updated and expanded with knowledge for a new type of energy and intellectual potential will be rebuilt and directed towards green sources of energy.

Thus, staff mainly associated with administration maintenance of energy infrastructure (energy engineers automation engineers electricians IT specialists etc.) can be reused. People in positions responsible for ensuring nuclear safety and radiological protection of the nuclear facility will require improvements and acquisition of new knowledge. It should be emphasized that the authorization to hold a position in an organizational unit performing activities consisting in the construction commissioning operation or liquidation of a nuclear facility entitles to hold a given position only in the unit indicated in the granted authorizations. The condition for obtaining appropriate authorizations is primarily professional practice education appropriate state of health completion of training required by law as well as passing an exam before a competent commission appointed by the President of the National Atomic Energy Agency (PAA). It should be emphasized that in the situation of planning to build a new nuclear facility along with it there is a need to prepare a comprehensive employment plan for staff mainly with highly specific specializations. Earlier naturally there is a cycle of initial trainings and necessary certification. It is worth adding that positions that are extremely important for ensuring nuclear safety and radiological protection include:

- radiological protection inspectors
- nuclear reactor operators
- nuclear reactor dosimetrists
- managers and shift managers of nuclear reactors
- directors for nuclear safety and radiological protection in a unit with a nuclear reactor
- specialists for recording nuclear materials
- operators of spent nuclear fuel storage facilities
- managers of radioactive waste repositories
- managers of radioactive waste disposal plants.

Despite the formal start of the Polish Nuclear Energy Program in Poland so far there are no legal possibilities to issue authorizations related to the construction or operation of power reactors. However this issue is currently a very topical subject of discussion and appropriate initiatives are being taken in this regard which may provide a positive image for the future and give hope for dynamic investments in Poland in nuclear energy as well as development of knowledge capital in this area.

In summary it should be stated that when assessing the existing infrastructure of currently operating energy generation installations based on coal particular attention should be paid to the following categories including reuse:

- reuse of the object: office buildings and electrical components. Coal-nuclear transformation is based on reusing existing infrastructure including land within the old power plant network connections and office buildings.
- use of cooling systems. Both nuclear and combustion power plants require some kind of cooling system to remove excess heat from the energy conversion cycle. This is usually done through access to a source of cool water or chimney coolers. Reusing them may require re-agreements approvals or permits but if approved positively would bring significant benefits. In projects where the planned nuclear power plant would have different energy or thermal efficiency than the current power plant an assessment should be made of the ability of a given location to remove waste heat.
- use of steam cycle elements. Reusing elements of the steam cycle system represents both the biggest challenge and potential opportunity to reduce investment costs for future nuclear power plants. Among them special attention should be paid to turbo generators and steam condensation systems. Their reuse involves serious challenges in terms of compatibility and licensing.
- use of human resources. In order to carry out coal-nuclear transformation it is necessary to retrain the staff. Most employees except for nuclear reactor operators nuclear engineers and technicians radiological protection inspectors or dosimetry services after retraining or job training can continue their work in the new facility. In order to successfully complete the transformation it is necessary to analyse the personal potential of a given unit and the possibility of transferring the workforce from the old power plant to the newly created one depending on their skills education or professional experience.
- increasing social awareness and training specialists in the field of storage and processing of spent nuclear fuel and other radioactive waste generated in nuclear power plants remembering that processing spent nuclear fuel is the least ecological aspect of operating nuclear reactors.
- transfer of knowledge from foreign centres will strengthen the intellectual potential of the built staff base in Poland. At the same time conversion of knowledge of employees of coal-fired power plants with a strong foundation in long-term experience in the energy industry will enrich the created base of knowledge in the field of nuclear energy in Poland. Emerging and developing study directions and specialized courses on nuclear energy will provide staff security for the future and at the same time a strong substantive foundation for creating Polish knowledge capital.

Mentioned above contains, an inexhaustive list of components, objects or items that could theoretically be reused in C-N transformation projects, along with identified limitations. These include: land and land rights, administrative-service buildings, electrical switchgear buildings with their equipment, transport and lifting equipment, air and steam transmission service infrastructure, communication equipment, substations, transmission facilities, generator voltage boosting transformers, roads and auxiliary buildings (e.g. visitor centers, cafes and parking lots).

Conclusions

Coal-nuclear transformation of Poland can bring many benefits. Taking into account challenges in various fields this process requires however careful assessment. In perspective of 2035 it can be assumed that modern nuclear reactors with a capacity less than one gigawatt are suitable for use in most existing power plants and combined heat and power plants located in geologically safe regions. In order to select locations create knowledge and develop it in this area further research should be conducted. Primarily on the impact of coal-nuclear transformation on economy and environment especially in terms of reducing greenhouse gas emissions and in perspective implementing Internet of Things within revolution 4.0 creating energy "hot spots" capable of powering remotely operated machines and devices using artificial intelligence and mentioned developing intellectual capital of individual EU countries. C-N transformation can be an important stimulus not only economic but

also modernization for a given region and development of local communities which with decline of coal energy will find themselves in unfavorable economic and social situation.

Performing activities related to use of ionizing radiation both in industry science and medicine is permissible only after applying appropriate safety measures, which are well covered by the existing regulations. In order for these requirements to be met all units should have reliably prepared programs based on optimization principle ensuring quality. For its proper functioning it is necessary to obtain full knowledge about procedures carried out combined with knowledge about physical chemical phenomena as well as knowledge about technologies and techniques used in devices. When using ionizing radiation in medicine apart from proper training of medical staff it is necessary to educate medical physicists whose duty apart from dosimetry is control over proper functioning of equipment which constitutes most important part of patient exposure optimization process and radiological protection.

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References

1. Powell, D., Krebel, L., van Lerven, F., Five ways to fund A Green New Deal. We can afford it. We can't afford not to, New Economics Foundation, 28 November 2019, <https://neweconomics.org/2019/11/five-ways-to-fund-a-green-new-deal>, accessed 30.04.2023.
2. De Koning, A., Huppel, G., Deetman S. & Tukker A., Scenarios for a 2 °C world: a trade-linked input-output model with high sector detail, *Climate Policy* 2016, 16:3.
3. Gagarinsky, A., Subbotin, S., Small Nuclear Reactors: Forgotten in the Past, Indispensable in the Future, *Security Index: A Russian Journal on International Security* 2008 , 14:2, (pp. 73-80).
4. Ignatov, A., Analysing European economic competitiveness through the prism of economic innovation, *European Competition Journal* 2018, 14:2-3, (pp. 248 277).
5. Curry, I., R., The Green New Deal Must Preserve the Existing Nuclear Fleet, *Environmental Claims Journal* 2020, 32:1, (pp. 77-100).
6. Szulecki, K., European energy governance and decarbonization policy: learning from the 2020 strategy, *Climate Policy* 2016, 16:5, (pp. 543-547).
7. Luke, T., W., Situating knowledges, spatializing communities, sizing contradictions: the politics of globality, locality and green statism, G. Kütting and R. Lipschitz, eds. *Environmental governance: power and knowledge in a local-global world*. New York: Routledge 2009, (pp. 13-37).
8. Aslesen, H., W., Freel, M., Industrial knowledge bases as drivers of open innovation? *Industry and Innovation* 2012 , 19(7), (pp. 563-584).
9. Blažek, J., Kadlec V., Knowledge bases, R&D structure and socio-economic and innovation performance of European regions, *Innovation: The European Journal of Social Science Research* 2019, 32:1, (pp. 26-47).
10. Communication from the Commission EUROPE 2020 A strategy for smart, sustainable and inclusive growth, Brussels, 3.3.2010 COM(2010) 2020, (pp. 3-32).
11. Makrevska Disoska, E., Tevdovski, D., Toshevsk-Trpchevska, K., Stojkoski, V., Evidence of innovation performance in the period of economic recovery in Europe. *Innovation: The European Journal of Social Science Research* 2020, 33:3, (pp. 280-295).
12. Nuclear Engineering Education: A Competence Based Approach to Curricula Development, IAEA NUCLEAR ENERGY SERIES No. NG-T-6.4, Vienna, 2014, (pp. 3-13).
13. Birger Skjærseth, J., Implementing EU climate and energy policies in Poland: policy feedback and reform, *Environmental Politics* 2018, 27:3, (pp. 498-518).
14. von Homeyer, I., Oberthür, S., Jordan, A., J., EU climate and energy governance in times of crisis: towards a new agenda, *Journal of European Public Policy* 2021, 28:7, (pp. 959-979).
15. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A New Circular Economy Action Plan for a cleaner and more competitive Europe, Brussels, 11.3.2020 COM(2020) 98 final.
16. Bergman, N., Foxon, T., J., Drivers and effects of digitalization on energy demand in low-carbon scenarios, *Climate Policy* 2023, 23:3, (pp. 329-342).
17. European Green Deal Striving to be the first climate-neutral continent, European Commission, https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en, accessed 30.04.2023.
18. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Pathway to a Healthy Planet for All EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', Brussels, 12.5.2021 COM(2021) 400 final.

19. Gryz, J., Krol, K., Witkowska, A., Ruszel M., *Mobile Nuclear-Hydrogen Synergy in NATO Operations. Energies* 2021, 14, 7955.
20. Genschel, P., Leek, L., Weyns, J., War and integration. The Russian attack on Ukraine and the institutional development of the EU. *Journal of European Integration* 2023, 45:3, (pp 343-360).
21. Westinghouse Electric Company. <https://www.westinghousenuclear.com/energy-systems/ap1000-pwr>, access 01.11.2022.
22. Nuclear Regulatory Commission. <https://www.nrc.gov/reactors/new-reactors/large-lwr/design-cert/apr1400.html>, access 01.11.2022.
23. EDF Poland. <https://poland.edf.com/en/our-activities/nuclear/edf-a-unique-nuclear-player/our-reactor-portfolio>, access 01.11.2022.
24. Pre-Project Design Review of AECL's Enhanced CANDU 6 Reactor – EC6, The Canadian Nuclear Safety Commission (CNSC), April 01, 2010.
25. NuScale <https://www.nuscalepower.com/projects>, access 01.11.2022.
26. TerraPower. <https://www.terrapower.com/terrapower-and-ge-hitachi-nuclear-energy-launch-sodium-technology>, access 01.11.2022.
27. X-Energy <https://x-energy.com/reactors/xe-100>, access 01.11.2022.
28. Westinghouse Electric Company <https://www.westinghousenuclear.com/canada/evinci-micro-reactor>, access 01.11.2022.
29. Internet source: X-Energy <https://x-energy.com/reactors/xe-mobile>, access 01.11.2022.
30. Szulecki, K., Fischer, F., Gullberg A., T., Sartor, O., Shaping the 'Energy Union': between national positions and governance innovation in EU energy and climate policy, *Climate Policy* 2016, 16:5, (pp. 548-567).
31. Goldthau, A., Sitter, N., Soft power with a hard edge: EU policy tools and energy security, *Review of International Political Economy* 2015, 22:5, (pp. 941-965).
32. Abram, S., Atkins, E., Dietzel, A., Jenkins, K., Kiamba, L., Kirshner, J., Kreienkamp, J., Parkhill, K., Pegram, T., Santos Ayllon, L., M., Just Transition: A whole-systems approach to decarbonisation, *Climate Policy* 2022, 22:8, (pp.1033-1049).
33. Jagger, N., Foxon, T., Gouldson, A., Skills constraints and the low carbon transition, *Climate Policy* 2013, 13:1, (pp. 43-57).
34. Informacyjnie energetyka jądrowa nowym kierunkiem studiów, <https://noizz.pl/informacyjne/energetyka-jadrowa-nowym-kierunkiem-studiow-tylko-30-miejsc-na-roku/5wvj0ew>, , access: 17.04.2023 r.
35. Współpraca dydaktyczna: <https://www.uw.edu.pl/wspolpraca-dydaktyczna-z-kings/>, access: 15.04.2023 r.
36. Ulreich, S., Schiffer, H.-W., Entwicklung der Stromerzeugungskapazität in Deutschland bis zum Jahr 2030, *ENERGY POLICY, ECONOMY AND LAW* 2023, Vol. 68, Ausgabe 2, März, (p. 27).
37. Energia atomowa najwięksi producenci w UE, <https://forsal.pl/biznes/energetyka/artykuly/8616712,energia-atomowa-najwieksi-producenci-w-ue-francja-niemcy.html>, access: 19.04.2023 r.
38. ZE-PAK i PGE powołały nową spółkę, <https://biznes.interia.pl/gospodarka/news-ze-pak-i-pge-powolaly-nowa-spolke-pge-pak-energia-jadrowa-za,nId,6714764>, access: 27.04.2023 r.
39. Projekt SMR ORLENU i SYNTHOSU, <https://www.tvp.info/69226693/projekt-smr-orldenu-i-synthosu-mark-brzezinski-amerykanske-instytucje-deklaruja-4-mld-dolarow-wsparcia>, access: 20.04.2023 r.
40. Home - Sinfonia (sinfonia-appraisal.eu)

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