ENERGY TRANSITION IN SLOVAKIA – DESTINY IN/AND CHANGE

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Abstract

The aim of this contribution is to discuss the Slovak position in energy transition processes. The need to understand what is particularly visualized under this term and how it is connected to domestic and international policies that primarily drove this change, as well as public support. This article analyzes the main attributes contributing to Slovakia's energy transition in order to achieve the energy and climate targets. The focus on renewable energy sources aims to bring a sustainability into this transition, thus we describe the challenges such transformation brings.

Key words: *EU Energy and Climate Policy, Slovakia, Energy Transition, National Energy and Climate Plan*

INTRODUCTION

The "Man on the Moon" moment occurred when Ursula von der Leyen introduced the 2019 European Green Deal, marking a significant step in the energy transition processes in the European Union. These processes vary enormously within the EU countries, covering different drivers, motivation, objectives and then governance politics. Intervening variables such as the Covid 19 crisis and the War in Ukraine have unexpectedly affected the decarbonization process. Even though EU's pathway towards energy transition has been present for several years in various documents and policies (e.g. Green paper 2000, 2006, 2013, Paris agreement 2015, European Green Deal 2019, etc.). Slovakia has remained deeply dependent on fossil fuel imports and has been passive in advancing a low-carbon transition, on that account. For instance, in 2004 the share of energy from RES was only 0,06%. [Eurostat 2023b] In addition, the adoption of climate change laws does not usually happen voluntarily. The full embrace of energy transition based on zero-carbon energy sources is often hindered by various barriers such as technological, economical, and regulatory causes. However, when compared to other Visegrad 4 member states [e.g. Kochanek 2021, 2022; Mrozowska 2021], Slovakia has a stronger pro-EU attitude and has experienced growth in green energy production. Hence, this article aims to describe the Slovak energy transition path and evaluate its main pillars. Therefore, we ask: What are the main attributes that contribute to the energy transition in Slovakia and the fulfilment of the energy & climate targets? Furthermore, this article aims to analyze the prospects while taking into account the current geopolitical situation, highlighting the potential, challenges and obstacles of energy transition in Slovakia. Lastly, this data-oriented scientific work provides a basis for further research on the described challenges and a deeper understanding of the obstacles regarding the energy transition.

The connotation of energy transition represents the driver and opportunity that is bringing various interpretations not only among academics [e.g. Sovacool and Geels 2016; Smil 2016; Turnheim and Sovacool 2020] but also politicians and the public. Rotmans et al. [2001] highlights hwo energy transition is a social transformation process in which systems change structurally over an extended period of time. According to Smil [2016], it is a fundamental process behind the evolution of human societies, that drives and is driven by technical, economic and social changes. Carley and Konisky [2020] straightforwardly explained that energy transition indicates transformation from one prevailing source to a different one. In its current context, it is moved towards a "low carbon energy resources such as wind, solar and natural gas" (p.569). The current energy geopolitical turmoil (2022 -23) and former policy decisions (e.g. European Green Deal, Repower EU) bring about new perspectives. As Gatto [2022] points out, energy transition shall be understood as a social determinant with an impact on all forthcoming changes in connection to transformation. Szulecki et al [2023] delves into the details, noting how the energy transition goal is to reach a carbon neutral energy system with low emissions, that also addresses a questions

about who determines and finances it. Siddi [2023] reinforces the view that (this) energy transition redesigns energy geopolitics in "more decentralised forms of energy production and a new competition to secure critical raw material" (p.76).Westphal [2020] similarly argues based on IRENA´s 2019 report, that it is driven by "renewable expansion" (p. 407). In Brendler´s [2022] contribution to this topic, she is concerned more with societal parts of the energy transition in a comparative manner and its implementation, considering various types of actors. Thus, her understanding of energy transition is connected to regulation and policy involvement. A similar argument that "the energy transition is driven by policies rather than by technology improvements" (p.5) or cost competitiveness is by Blazquez et al. [2019]. This is where the authors of the article find mutual agreement on this issue. However, the aim of this article is not to provide the reader with an overwhelming literature review, but rather a sample overview of the current state of rapidly growing body of work dedicated to both energy transition and connected topics such as energy justice or energy democracy. We focus on and explain the case study of Slovakia in a long-term perspective on energy transition with a focus on "storytelling" of renewable energy sources that can be concluded by explaining obstacles and challenges that could be the subject of further research in the three described domains.

1. ENERGY TRANSITION IN SLOVAKIA

Generally, Slovakia is more open to discussion and adopts a stronger pro-EU attitude than Poland or Hungary, although it frequently sides with other Visegrad Group countries in attenuating EU energy and climate policy [Kochanek 2021]. Therefore, the adoption of climate change laws typically does not occur voluntarily. Despite this, Slovakia also rarely refuses to comply with EU commitments [Esser et al. 2018]. When compared with countries that belong to the V4 group, Slovakia has the most dynamic growth of energy generation from RES. [Kochanek 2021]

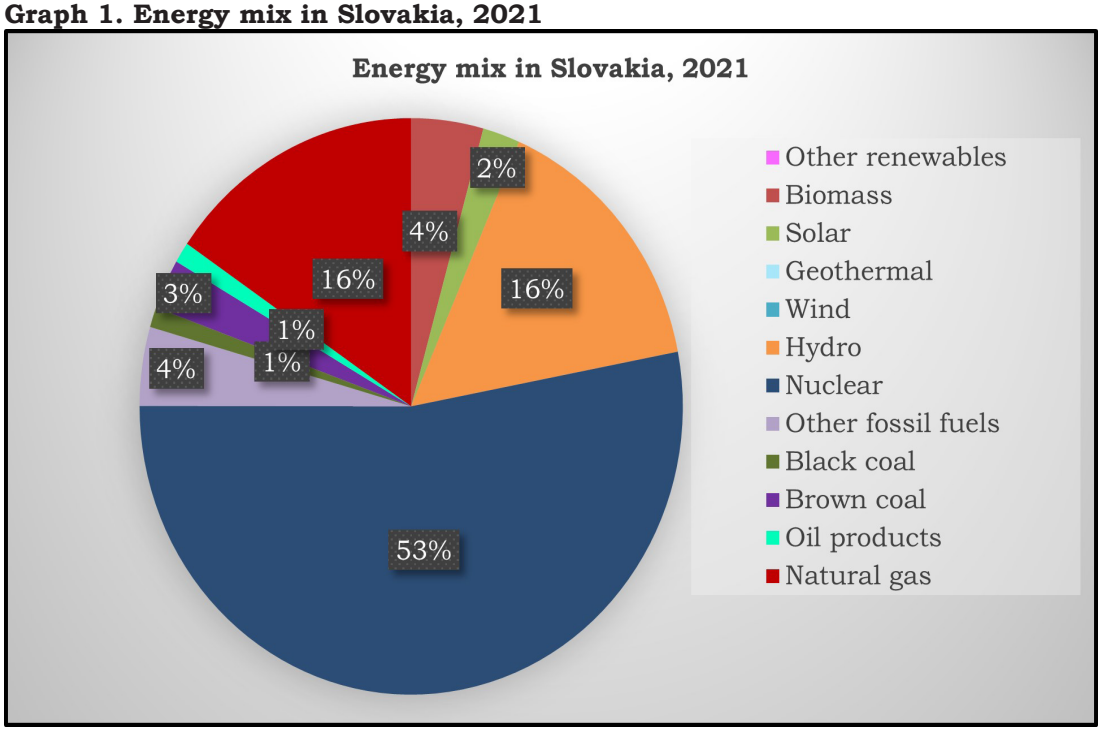
Taking into account the energy mix in Slovakia (see Graph 1) it is evident, that the most dominant position within the mix belongs to nuclear energy (53%). Subsequently, with a share of 16%, there are two renewable sources, namely hydropower and biomass. The other RES have a marginal position within the mix, such as solar (2%), other renewables (0,34%), and wind (0,02%). [OKTE 2021]. From the high carbon footprint sources, the biggest share of 4% belongs to other fossil fuels (e.g., natural gas, oil) followed by brown coal 3%, black coal 1% and oil products 1%

Slovakia has embarked upon the path of energy transition over the past few decades, as a result of the EU's binding climate and energy legislation[1] towards an economy with net zero greenhouse gas emissions. This is undoubtedly a positive sign, considering energy intensity in 2021 was 57% higher greater than the EU average, thus placing Slovakia at the top of the energy-intensive economies in the EU. [Eurostat

[1] The climate and energy legislation is recorded in documents such as Climate & energy package 2020, climate & energy framework 2030 and net zero energy policy 2050.

2023a] Slovakia's energy transition is centred on maximizing the energy mix from the perspective of energy safety to achieve the highest possible energy efficiency and secure comprehensive environmental protection [Furmanczuk 2018]. These national goals are outlined in the "Greener Slovakia: Strategy of the Environmental Policy of the Slovak Republic until 2030" [Ministry of Environment SR 2019a] and "Low-Carbon Development Strategy of the Slovak Republic until 2030 with a View to 2050" [Ministry of Environment SR 2019b], which set the legal framework for Slovakia's energy transition. Similarly, the Energy Policy of the Slovak Republic evaluates the key pillars of Slovak energy policy, namely energy security, energy efficiency, competitiveness and sustainable energy being in accordance with the European Union Energy Policy. [Ministry of Economy SR 2014]

Graph 1. Energy mix in Slovakia, 2021



Source: OKTE, 2021.

In order to achieve the objectives and actions for the transition to a sustainable energy system, each member state was obliged to adopt national energy and climate plans (NECPs), covering the period of energy transition between 2021 and 2030. The long-term objectives of Slovakia's energy transition (see Figure 1) include a reduction of net greenhouse gas emissions by at least 55% compared to 1990 levels by 2030[2], an increase in the share of RES in gross energy consumption to 24% by 2030, and a 32,5% reduction of primary energy consumption in 2030 to increase energy efficiency. [Ministry of Economy SR 2019] The Slovak NECP[3] includes a variety of measures to

[2] The reduction of net greenhouse gas emissions by at least 55% is a part of "Fit for 55 package". (European Council, n.d.)

[3] Slovakia's final NECP was approved on 11 December 2019 by the Slovak Government and submitted to the European Commission on 20th December 2019. [IEA 2022]

achieve "a competitive low-carbon energy industry sector ensuring the secure and efficient supply of all forms of energy at affordable prices and taking customer protection and sustainable development into account" [Ministry of Economy SR 2019: Executive summary, para. 1].

Below we examine the energy transition in Slovakia based on its three main objectives, namely an enhancement of green energy sources, reduction of GHG emissions and improvement of energy efficiency.

Figure 1. Slovak national climate & energy targets.

	National targets and contributions	Latest available data	2020	2030	Assessment of 2030 ambition level
	Binding target for greenhouse gas emissions compared to 2005 under the Effort Sharing Regulation (ESR) (%)	-5	13	-12	Ambitious (national target of -20%)
	National target/contribution for renewable energy: Share of energy from renewable sources in gross final consumption of energy (%)	11.9	14	19.2	Unambitious (24% is the result of the RES formula)
	National contribution for energy efficiency:				
	Primary energy consumption (Mtoe)	15.8	16.4	15.7	Low ambition
	Final energy consumption (Mtoe)	11.1	9.0	10.3	Low ambition
	Level of electricity interconnectivity (%)	43	59	52	N.A.

Source: European Commission [2020].

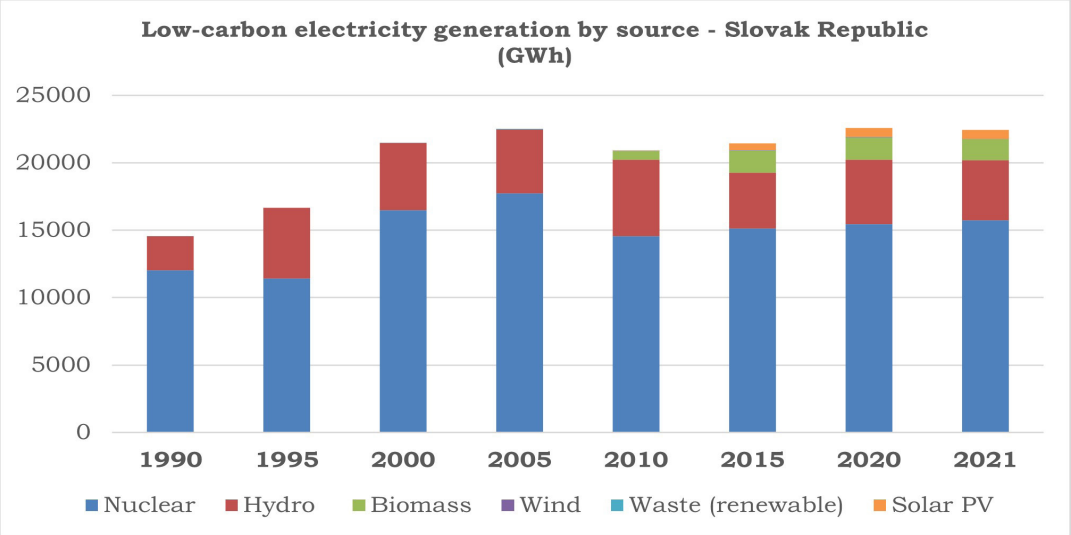
1.1. Low-carbon energy sources in Slovakia

The share of energy derived from renewable energy sources in Slovakia has been steadily growing, reaching a value of 17,35% in 2020, a contrast to 6% announced in 2004. Similarly, Slovakia has successfully fulfilled its 2020 target of a 14% increase in the share of RES, by remarkably exceeding the target, achieving 16,9%. [Eurostat 2023b] Since 2005 onwards, both, renewable energy generation and renewable energy consumption experienced extensive growth tendencies, reaching 8,3% and 7,2% respectively. [BP 2022]

As of 2021, the largest share of low-carbon energy production comes from nuclear power, followed by hydroelectricity, biomass, solar power and wind power. (See Graph 1) Nuclear energy has been the most dominant source of electricity generation over the past three decades. Similarly, hydro power has remained a substantial source of electricity generation, reaching its peak in 2010, followed by a subsequent downward trend. As Graph 1 indicates, wind power as well as power generation from waste are

marginal. However, there is potential for a gradual increase in electricity generation from biomass and solar energy. In both cases, the tendency over the past decade has been for rising production, from 640 GWh in 2010 to 1563 GHW increase in biomass, and from 17 GWh to 667 GWh for solar photovoltaics.

Graph 2. Low-carbon electricity generation by source - Slovak Republic



Source: IEA [2022]

In the following section, we analyze each low-carbon source of energy in Slovakia with an emphasis on providing a more comprehensive understanding of how the individual sources contribute to Slovakia's energy transition and its future potential application.

1.2. Nuclear energy

Since 2022, nuclear energy activities are labelled as "low carbon activities" [European Commission 2022a] as well as "transitional activities" aimed to "facilitate the transition away from more harmful energy sources e.g., coal and towards a mostly renewables-based future" [European Commission 2022b: What have we adopted today? section]. Undoubtedly, the most convincing argument is that the energy generating phase of nuclear energy emits almost no greenhouse gases, making it a significant contributor to the goals of climate change mitigation. Several EU member states' individuals NECP plans rely on nuclear energy together with renewable energy to achieve the 2050 decarbonization goal outlined in Regulation (EU) 2021/1119. This is also the case of Slovak energy policy. Taking into account the Slovak energy mix, nuclear energy has the leading position as almost 60% of the country's electricity is generated in nuclear power plants. [Eurostat 2022] Similarly, Slovakia has the second highest share of nuclear energy in its electricity generation within the EU and has the largest low-carbon source of electricity. [IEA 2019] The four operating nuclear power plants[4]

[4] There are four units of WWER-440/213 type in operation, including two units at the Jaslovské Bo-

produced more electricity than ever before in their history, thanks to investments in increasing their unit efficiency, the installed capacity of Slovak nuclear power plants exceeded 2,000 megawatts last year. Slovakia's largest electricity producer, primarily based on energy from nuclear power plants, supplied up to 94% of electricity to the grid without carbon dioxide emissions. [Slovenské elektrárne 2022] Furthermore, the new Mochovce 3 power plant, that was recently connected to the grid, will be cabale of covering up to 13% of the demand in the country, increasing the production of green electricity from 52% to 65% [Ministry of Economy SR 2022]. As a result, Slovakia will become the leader in the production of electricity from nuclear power at the EU wide level. In addition, Mochovce 4 block is planned for commissioning in the second half of 2024, further increasing the generation of green electricity even more. [SME, 9.9.2022] Therefore, nuclear energy is perceived as a stabilizing pillar of the Slovak energy system, allowing for a possibility to reach zero emissions and become self-sufficient in electricity supply as early as 2023. The significant growth of nuclear energy will further compensate for the shift away from coal [Kochanek 2022], and natural gas, taking into account the REPower EU as a new policy focused on energy independence from Russian oil and gas supplies well before 2030, in light of Russia's invasion of Ukraine.

The long history of nuclear energy in Slovakia[5] has resulted in an experienced workforce and highly developed expertise in nuclear engineering. This is the key reason why the government is more inclined to keep nuclear power as part of the energy mix, as the region has both human capital and an industrial base. [IEA 2019] However, in the long term, the EU isn't inclined to be too dependent on nuclear energy. [European Commission 2023] It's important to not overlook the negative aspects of nuclear energy, such as the high cost of radioactive waste management, the problematic search for sites for permanent storage of radioactive waste, the risk of nuclear accidents, etc. Similarly, while the generation of electricity from nuclear power is considered by the EU taxonomy as "green" we should not mistakenly approach nuclear energy as free of greenhouse gas emissions. Even though direct emissions of carbon dioxide are not produced by nuclear power reactors [EIA n.d.], it is estimated that the entire life cycle of nuclear power plants produces a range of 3.7 to 110 grams of CO2 equivalent per kilowatt-hour (kWh). [IPCC 2014]

1.3. Hydropower

Hydropower is the most widely used renewable energy source, whose history dates into 1912[6]. [Krištof et al. 2010] The success of hydropower in Slovakia is attributed

hunice site and two units at the Mochovce site. There are also two units with WWER-440/V213 type reactors that were under constructions in the Mochovce site - Mochovce 3 is in operation since February 2023, and Mochovce 4 is planned to start operating 23 months after the Mochovce 3. [SME, 9.9. 2022]

[5] The era of nuclear energy in Slovakia started in 1958 in the former Czechoslovakia with the construction of the research and development nuclear power plant A1 in Jaslovské Bohunice. The power plant was in operation for 5 years. (1972-1977).

[6] In 1912, the first hydro power plant called Rakovec located on the river Hnilec was commissioned.

to its rivers, namely Dunaj, Váh, Orava, Hron, Hnilec, and other smaller rivers. In Slovakia, almost a fifth of all electricity is produced using water energy. (See Graph 1) This is primarily due to the two most powerful hydropower plants, namely pumping station Čierny Váh and waterworks Gabčíkovo. These hydropower plant, offer operational flexibility and potential for quick power changes, allowing them to meet the daily load's fluctuating energy needs and are well-equipped to handle power system emergencies. [Zbojkovský et al. 2012] The document "The Concept of using hydropower potential in Slovakia till 2030" clearly defines Slovakia's space in the field of hydropower, namely "to ensure the increase in the use of hydropower potential of watercourses of the Slovak Republic for electricity generation from RES in accordance with the objectives set out in the Energy Security Strategy and other relevant strategic documents of the EU and Slovakia." [Ministry of Environment SR 2017: Úvod, para.1]

In line with the requirements of environmental sustainability and the principles of sustainable development, hydropower and subsequently its electricity generation significantly contributed to the reduction of greenhouse gas emissions in Slovakia. Furthermore, it reinforced the aims of reducing the dependence on fossil fuel imports, which is particularly relevant in the case of Slovakia being almost fully dependent on fossil fuel imports from the Russian Federation. However, since its peak in 2015, when hydropower generation reached nearly 5700 GWh per year, there has been a downfall tendency, with production falling to 4450 GWh in 2021. [BP 2022]

According to Gejuš et al. [2017] hydropower is the most promising renewable energy source and further contributed the most towards the Slovak target to achieve a 14% share of energy from RES. Considering that the actual utilized hydropower potential of the Slovak Republic is at 57.5% [Slovenské Elektrárne n.d.], there is still significant space to increase the potential, which will further contribute to the increase of RES and help reach 2030 and 2050 targets, respectively.

1.4. Biomass

In 2020, 40,1% of Slovak land area was covered by forests (World Bank, n.d.) underscoring the importance of biomass as a low-carbon energy source. While in 2005, the electricity generation from biofuels equalled 9 GWh, it reached the value of 1563 GWh in 2021. [BP 2022] According to Slovakia's low-carbon strategy: "biomass has the largest energy potential among RES in Slovakia, with the theoretical potential of 120 PJ." [Ministry of Environment SR 2019b: 23] The government's renewable energy strategy has been centered on the use of biomass, as a low-carbon alternative to fossil fuels, primarily in the heating sector where it has largely replaced coal, the previously main source of power. In contrast to wind and photovoltaic (solar) power plants, biomass is a predictable and controllable energy source. As a result, it not only contributes to decarbonization but diversification too, increasing Slovakia's energy self-sufficiency [Ministry of environment SR 2019b]

Even though, the expansion of biofuel as a renewable source contributes significantly to the lowering of emissions and decarbonization, the growth of bioenergy projects in Slovakia has driven the demand for wood biomass, leading to widespread logging and a loss of biodiversity among other negative effects [Zámkovský et al. 2018]. Until 2017, there were no sustainability requirements for the majority of bioenergy sources. hence it was difficult to ensure that biomass consumption stayed within bounds that did not harm the environment. However, as of 2017 "The wood biomass sustainability criteria in Slovakia" guide biomass use in order to eliminate deforestation and protection of biodiversity" [Seferova 2020]. Th biomass consumption increased green energy consumption at households, placing Slovakia at the top among EU countries. Biomass consumption for heating and cooling increased from 37,000 terajoules (TJ) to 56,000 TJ between 2018 and 2019. [Statistical Office of Slovak Republic 2020] Significant state support enables the efficient use of biomass, making it likely to remain the most important source for green energy consumption at Slovak households in the future.

1.5. Solar energy

The most common source of green energy generation in Slovakia for private use is solar energy, specifically solar panels and collectors. The expansion of solar energy was low for many years leading up to 2010[7], with PV installations referenced only marginally as part of a wider energy strategy. State obstacles stemmed from technological, financial, and regulatory sources. However, the introduction of state subsidies in 2010, marked a sizeable increase in electricity generation and consumption from solar energy, along with a surge in the amount of installed photovoltaic (PV) power. Both generation and consumption of electricity from solar energy together with installed PV power showed an uninterrupted upward trajectory from 2010. [BP 2022] While biomass has the highest technical potential due to environmental factors, solar energy boasts the largest overall potential among Slovakia's RES. [SAPI 2018] Supported by the "Green for homes II" subsidies, financial assistance for solar panels, heat pumps, and solar collectors in 2023, solar energy's potential can significantly grow in following years. The demands for the installation of solar panels on rooftops and the supply of PV power plants is constantly rising. However, solar energy currently, accounts for just about 1.8% of the electricity used in Slovakia. [Rynska 2022] Significant development of solar energy is hindered by the high payment by the network access cost in addition to expensive connection fees. The instability of power systems caused by the properties of solar energy was a problem for technical advancement. Thus, solar panel installation on rooftops was limited to off-grid systems for a period.

Concerning the 2030 targets, solar energy is destined to expand further as a solar park near the active nuclear power plant Jaslovské Bohunice is under construction,

[7] Up to 2010, the electricity generation and consumption from solar energy was at 0. (BP,2022)

scheduled for completion in 2025. [SME, 30.11.2021] This 105-hectare plant will produce more than a tenth of Slovakia's current solar power plant output, or 48 MGW. Similarly, The Renewable Energy Sources Act (Zákon č. 309/2009 Z. z.) had a significant revision on January 1, 2021, aimed at promoting renewable energy sources and high-efficiency cogeneration options. The introduced guidelines include a new feed-in premium tariff that provides a premium tariff and auctions for solar projects above 100 kW. [Rynska 2022]

1.6. Wind energy

In general, wind energy is underdeveloped in a large part of the Central and Easter European region. [IEA 2019] Consequently, the production of low-carbon electricity from wind power remains rather low, contributing marginally to the share of energy generated from RES. Even though, both the generation and consumption of electricity from wind power experienced gradual growth between 2003 and 2006-2007[8]. Since then both displayed a decreasing tendency, resulting in a 50% reduction[9]. Hence, the growth rate per annum from 2011-2021 was negative, signifying an overall decrease of -2,2% in the share of electricity generation from wind power and -2,7% in the share of consumption of electricity from wind power. [BP 2022]

However, the potential of wind power in Slovakia is high. The theoretical technical potential of wind energy in Slovakia was calculated at the level of approximately 168,000 MW, which represents 420,000 GWh. [SAPI 2022]. Furthermore, approximately 20% of Slovakia's territory contains the naturally suitable conditions for wind power. In contrast, the first and second modernized units of AE Mochovce collectively generate only 2% of the aforementioned electricity. However, the development of wind energy is hindered by several barriers. Among these the most significant are legislative, administrative, regulation and technical barriers. [SAPI 2022] Taking into account the abovementioned considerations, wind energy can play a significant role in ensuring Slovakia's energy security in future and further contribute to the development of clean energy and achievement of the goals set for 2030.

1.7. Hydrogen

In Slovakia, interest in hydrogen as a source of green energy started to grow primarily after the implementation of the National Hydrogen Strategy in 2021. [Sinay et al. 2021] The focus is on the production of clean hydrogen, primarily using electricity produced by nuclear power and hydropower plants maintaining a low carbon footprint. Furthermore, the aim is to transition from the currently produced grey

[8] The peak recorded in 2006 referred to value of 0,008 TWh for wind generation and in 2007 to 0,00008 EJ for wind consumption which are still values very close to zero.

[9] Wind generation in 2006 (the peak) was 0,008 TWh while the wind generation in 2021was 0,004 TWh. Wind consumption in 2007 (the peak) was 0,00008 EJ while the wind consumption in 2021 was 0,00005 EJ.

hydrogen, to blue, green and pink[10]. Implementation of hydrogen into the energy system will further contribute to the decarbonization of numerous sectors in Slovakia, including the transport, industry, heating and others. [NVAS n.d.] The outlook for hydrogen is set to be promising. According to the Action Plan for the Implementation of the National Hydrogen Strategy, Slovakia should generate 45 thousand tons of hydrogen yearly, from low-carbon energy sources such as the surplus energy generated by nuclear power plants and biomass [NVAS, 9.9.2022]. Moreover, in 2022, Slovakia carried out a pilot project aimed at implementing hydrogen in the existing natural gas pipeline, with a positive result claiming that the mixture of the hydrogen with natural gas distributed via the existing pipeline infrastructure is safe and effective, further widening the future potential of hydrogen. [TREND 12.08. 2022]

Currently, the two main producers of hydrogen in Slovakia are Duslo Šala and Fortischem Nováky. However, the hydrogen they produce is solely consumed by their own needs. The future role of hydrogen in Slovakia could significantly contribute to the decarbonization of numerous sectors such as industry, heating, cooling and feedstock for industry processes, with the biggest potential in the transport industry. [NVAS n.d.] Long-distance transport could benefit highly from the usage of hydrogen. On that account, already two hydrogen refueling stations are operating in Slovakia.

1.8. Geothermal

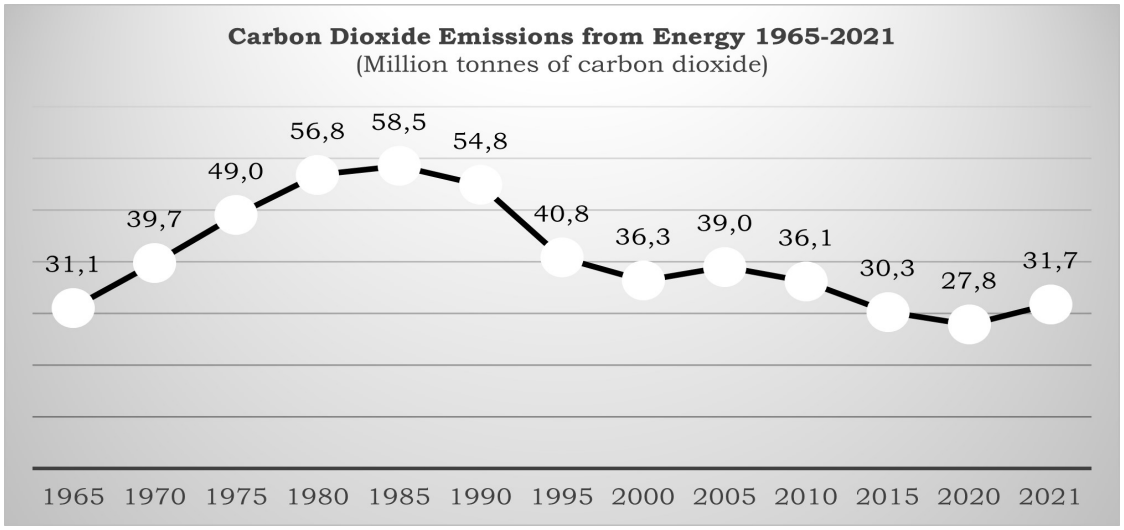
Geothermal power is a very promising source of renewable energy in Slovakia, due to the region's hydro-geothermal characteristics, Slovakia has extremely favourable conditions due to its high thermal gradient, which indicates the rise in temperature towards the depth of the earth, is 38 degrees Celsius per kilometer, whereas the global average is roughly eight degrees lower [PW energy n.d.]. Therefore, geothermal energy is a feasible option for environmentally friendly electricity and heating in Slovakia. However, the development of geothermal power in Slovakia is at a stalemate, as several legislative challenges hinder its widespread adoption. For example, geothermal wells are subject to comparable legal restrictions as oil extraction. As a result, the generation of energy from geothermal in 2021 reached 0,3%. [BP 2022] Nevertheless, the future of geothermal is expected to change. In March 2023, the Slovak Innovation and Energy Agency announced that the first call for new geothermal resources will be in 2024 and further, geothermal wells will receive support from European funds. [TREND 02.03.2023] Financing geothermal projects is one of the biggest obstacles to the development of this type of energy, therefore such moves will undoubtedly support the future of geothermal energy expansion.

[10] The primary source of blue hydrogen production is natural gas. Green hydrogen is produced by electrolyzing water with clean electricity generated from surplus renewable energy sources, such as solar or wind energy. Nuclear energy is used for the electrolysis that produces pink hydrogen. Blue, green and pink hydrogen are all low carbon types of hydrogen.

1.9. Reduction of the carbon dioxide emissions from energy

A period of abrupt decarbonization in the energy sector occurred in Slovakia between the 1990sand 2000s[11], caused by the changing structure of the economy, as well as improvements in technology. According to the graph (see Graph 3) the carbon dioxide emissions from energy have decreased from 58,5 million tons of carbon dioxide in 1985, to the lowest level recorded so far in 2020, with 27,8 million tons of carbon dioxide, representing a reduction of more than 50%. Even though the Slovak economy has greatly reduced its carbon footprint, further decarbonization is still necessary. When compared to other V4 countries in the region, Slovakia's climate targets have greatly expanded, particularly in terms of reducing CO2 emissions. [Kochanek 2021]

Graph 3. Carbon dioxide Emissions from Energy 1965-2021



Source: BP Statistical review 2022

Despite the advancements made so far, additional decarbonization is required to achieve 2030 decarbonization goals, which call for a 55% reduction in greenhouse gases from 1990 levels. By 2030, an additional 6.3 million tons of CO2 equivalent (approximately 15% of the current gross emissions) must be avoided. [Ministry of Finance SR 2022] According to the latest data, Slovakia is "close to achieving the EU-wide "Fit for 55" target to reduce emissions by 55% (6.3 MtCO2e) in 2030 compared to the 1990 levels." [Ministry of Finance SR 2022: 5]

Furthermore, the significant cut in emissions over the past thirty years occurred as a result of a switch from coal to gas, and a shutdown of large pollution-intensive industrial businesses. Many of these improvements were driven by Slovakia's EU membership. [Mindekova et al. 2022] However, the power and heating sector in Slovakia is still a large producer of emissions due to prominent coal usage. On that account, Slovakia has taken a resolute stance regarding coal mining, with plans to slowly phase

[11] Meanwhile the value of CO2 emissions from energy in 1990 was 54,8 million tons of CO2, in 2020 it was 27,8 million tons which is the lowest value since 1965.

out the generation of heat and electricity from coal by 2023[12] [European Commission, n.d.] Based on the study proposed by think thank Globsec: "The planned closure of Novaky coal power plant in 2023 is roughly the GHG reduction equivalent of replacing diesel/petrol cars by 2030." [Hubatka, Theisen 2021: 4] Similarly, a study devoted to decarbonization and transition within the V4 countries highlighted how the "Nováky power plant is the third largest producer of CO2 within Slovak operations in the EU ETS system." [Mindekova et al. 2020: 25] However, the social impact of closing coal plants in Slovakia, threatens approximately 4000 jobs. To mitigate this impact, Slovakia plans to transformation Novaky and Vojany from coal to biomass-producing hydrogen. The coal region in Slovakia has been granted an investment of 459 million EUR to support the climate transition in the most vulnerable regions and will create new job opportunities for the coal industry employees [European Commission 2022c]. These EU funds together with state subsidies are highly necessary for the full implementation of these transformation processes. [Mindekova et al. 2022]

1.10. Enhancement of energy efficiency

Throughout the past years, Slovakia has achieved one of the highest reductions in energy intensity in the EU. Slovakia has successfully improved its energy intensity by 50.8% between 2000 and 2015, showing significant progress in this area [Ministry of Economy SR 2019]. This positive development is the result of effective restructuring of the industry, the introduction of energy-saving manufacturing techniques, progress in the thermal and technical quality of buildings, and substitution with less energy-intensive equipment. Nevertheless, when considering constant prices, the Slovak Republic has the seventh-highest energy intensity among the 28 EU member states [Ministry of Economy SR 2019]. This is mainly the result of the industrial structure of the Slovak Republic, which favours energy-intensive industries. This means that in the future, energy efficiency policies and funding sources will place a greater emphasis on the industry sector and related services, such as energy. In order to boost improved energy efficiency in Slovakia. The European Commission has approved EU financial aid, exceeding1.1 billion EUR for Slovakia. These funds aim to enhance energy efficiency and decarbonize companies subject to the EU Emission Trading System (ETS) [European Commission 2022d].

2. CHALLENGES TO FUTURE SLOVAK ENERGY TRANSITION

The above-mentioned attributes of the energy transition and a significant reduction of greenhouse gases, provide Slovakia with a strong support to reach the 2030 targets and boost the energy transition. However, given Russia's invasion of Ukraine, there is a risk that the Slovak leadership gives priority to energy security and prolongs the usage of coal to substitute Russian gas. Consequently, reducing the short-term

[12] According to the Action Plan that the Slovak Government authorized on July 3, 2019, by passing Resolution No. 336/2019, support for energy generation from hard coal and lignite shall be eliminated.

impacts of decarbonization (Mišík & Nosko 2023) Nonetheless, taking into account the primary aim of the REPower EU plan, which is to become "independent from Russian fossil fuels well before 2030" ensuing decentralization of power generation would not only aid in lowering the costs, but would also contribute to the protection of energy security and lessen the reliance on imports of fossil fuels, particularly those from the Russian Federation. [Esser et al. 2018]. Slovakia must navigate a new path where energy transition could be the solution that addresses energy security and decarbonization. The country is one of the most energy-intensive economies within the EU member states, having various high-carbon manufacturing sectors. Therefore, the government often prioritizes protecting energy security over achieving low-carbon goals. (Furmanczuk, 2018). The most significant obstacles hindering the energy transition through the enhancement of zero-carbon energy sources stem from state barriers such as technological, economical, and regulatory causes. Furthermore, the aspirations for the development of RES are oftentimes hampered by ineffective governmental regulation (Rynska 2022) such as the example of geothermal energy potential.

Another challenge in advancing not only energy transition lies in solving not only technical issues such as transmission systems, new storage and grid technologies. but also addressing the issue of high electricity costs, which are among the highest in the EU. To further advance decarbonization by tapping into Slovakia's RES potential, most notably in solar power, the key factors to consider include geographical locations and "undiscovered" domestic sources such as liquid and gaseous energy resources.

In general, climate change is not a high-priority topic in Slovak politics, nor does it receive attention among the public or media. Even though, according to the survey (Klimatická Iniciativa, 2021) 72% of Slovaks think that RES should be the top energy priority of the state. However, the surveys also highlighted how people are concerned that the implementation of energy savings will not prevent rising household energy costs. On the other hand, topical political leadership has been missing. Legislative Proposal of Declaration of State Climate Emergency in Slovak Parliament was not supported in 2022, despite the petition "Climate needs you" having been signed by more than 128 000 people. However, in March 2023 the government brought a proposal of long-time expected Climate Law, even as the Slovak republic is scheduled for a snap election in September 2023. Notably the Slovak Presidential Office stands out as a unique example of promoting the topic. It undertook a policy to become the first climate-neutral public institution in Slovakia by 2030 and has committed to serve as an inspiration for other public institutions with the Polity of Green Stove (see more https://www.zelenapecat.sk.) Nevertheless, sustained political support of the energy transition will be needed after the upcoming election.

CONLUSION

This article identified the three main attributes of energy transition in Slovakia, namely the enhancement of green energy sources, the reduction of GHG emissions and the improvement of energy efficiency. Currently, the most dominant low carbon energy source is nuclear energy, covering a share of 53% of the energy mix [OKTE 2021] It also has the biggest potential among the RES, striving to cover up to 62% share of the energy mix, thus turning Slovakia the biggest producer of low carbon energy from nuclear power plants in the EU. With this in mind we predict that this is going to be Slovakia´s destiny in the energy transition.

By 2023, Slovakia's energy mix will have greatly improved, and the proportion of fossil fuels in the mix will have decreased by more than 5%. [Mindekova et al 2022] The commencement of the Mochovce 3 power plant, the initiation of the approval procedures for Mochovce 4 and the shutdown of Novaky power station, as well as the phase-out of Vojany, all significantly contribute to the goal of transitioning Slovakia into an economy with low and possibly zero greenhouse gas emissions, in the future. Although the article highlights how Slovakia´s energy transition is still relatively slow, there has been gradual progress towards the energy transition since 2005. During this time, the generation and consumption of energy from RES have been steadily growing, together with substantial improvements in energy efficiency. The process of reduction of GHG emissions started earlier and has been on a decline since 1985. [BP 2022]. As Blasquez et all [2029] argue that energy transition should be driven by policies, with Mišík and Nosko [2023] noting that "the role of policy choices and the degree of government involvement remained crucial" (p. 2). The future of Slovakia energy transition, according to Werner and Lazaro (2023) depends on the successful implementation of sustainable energy and climate policies, as well as political and public support.

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