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Transformation of Energy Resources in the Visegrad Group: Strategies, Results, and Climate Effectiveness

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Abstract: The climate challenges posed by the European Union are particularly difficult for emerging and developing economies. This causes reluctance to undertake them and even denial of their validity. For this reason, this article seeks to answer the question of whether it is possible to carry out an effective transformation of energy resources in the developing economies of the Visegrad Group. Analyses in this area are conducted in a long-term, 58-year research perspective (1965–2022) and concern the Czech Republic, Hungary, Poland, and Slovakia. The effectiveness of the examined transformation is assessed in two dimensions as follows: (1) resource and (2) emission, which are then synthesized using a multi-criteria analysis. This research shows that an effective resource transformation aimed at a zero-emission economy is possible even in emerging and developing economies, although it undoubtedly requires time and consistency in the implementation of the once-chosen energy policy. Hungary—a leader in assessed climate effectiveness—has systematically decarbonized while reducing the use of total non-renewable resources. The Hungarian resource transition strategy assumed the use of nuclear energy and an increase in the share of renewable resources. The result of these activities is a quite diversified energy mix, which is greater resource self-sufficiency and low carbon dioxide emissions. The Czech Republic also achieved a similar strategy and results. Poland and Slovakia coped much worse with the climate challenge: although they gave up coal, they replaced it largely with other non-renewable resources. It is worth emphasizing that Poland has managed to significantly increase the use of renewable resources, and nuclear energy and hydropower have also appeared in the Slovak mix. Nevertheless, this did not allow for achieving good climatic results.

Keywords: energy resources; energy transformation; energy strategies in the Visegrad Group; climate effectiveness; assessment of the effectiveness of energy resources transformation

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1. Introduction

Functioning within the structures of the European Union was and is a great economic challenge. Additionally, in the last two decades, it has also become a huge environmental challenge. Implementing the Green Deal [1,2], implementing the sustainable development goals [3,4], and pursuing zero emissions [5,6] has put many members of the European community in the face of completely new conditions, which they are not always willing or able to cope with [7–10]. This especially applies to emerging and developing economies, which still lag behind the economic leaders of the European Union. The real income distance certainly constitutes a significant barrier to the implementation of the EU's climate policy [11]. However, this barrier is also reinforced by unfavorable social habits, political instability, and technological deficiencies [12].

The accumulation and intensity of the above conditions make the transformation of energy resources and meeting EU challenges a difficult and long-term task, and, according to some, even impossible to achieve [13–15]. Given the above circumstances, it is worth asking about the feasibility of resource transformation in emerging and developing economies

and looking for evidence documenting changes in the energy strategies of these economies from an ex post perspective. In the context of the research problem formulated in this way, this article aims to identify the resource transformation strategies of the Visegrad Group countries combined with an assessment of their results and effectiveness (climate and emission). This goal is achieved over a long-time horizon, i.e., 58 years, which is a distinctive feature of the conducted analysis.

The next stages of the research analyze primary energy consumption per capita, the structure of energy mixes and their changes, and the volume of carbon dioxide emissions per capita in four Visegrad Group (V4) countries including the Czech Republic, Slovakia, Poland, and Hungary. The analysis period covers 1965–2022. The results of these stages are then synthesized using multi-criteria analysis.

The originality of the proposed research is summarized in the following circumstances:

- Searching for paths to the most effective resource transformation in emerging and developing economies, which is extremely important in the face of contemporary climate threats and improving the quality of life of future generations;
- Taking into account a very long analytical perspective of 58 years, which allows us to observe real changes in the directions of the use of energy resources and their results;
- Carrying out an assessment of the climate effectiveness of the adopted resource transformation strategies in an effective, not postulated, approach.

The next part of the considerations in this research presents literature studies in the field of economic and energy connections among the Visegrad Group countries. Then, the adopted methodology and research results are described. The entire analysis ends with a discussion, recommendations, and a summary of conclusions along with research limitations and directions for further research.

2. Literature Review

The literature review refers to two research threads in which the considerations are embedded. The first one concerns the Visegrad Group and the economic connections among its members. The second one refers to the similarities and differences in resources that characterize individual V4 countries and the detailed description of the issues described. The whole discussion ends with the identification of the research gap and the justification for undertaking this research.

2.1. Economic Interdependencies in the Visegrad Group

The informal association of Poland, the Czech Republic, Slovakia, and Hungary within the Visegrad Group took place in 1991. The common denominator of cooperation in this region was the post-communist history and the challenges of economic transformation. To this day, these relationships affect the socio-economic situation of the region and are identified in the literature on the subject in very different perspectives and contexts [16–20].

In addition to state cooperation, the Visegrad Group is also united by rivalry [21,22], which is particularly visible in the economic sphere. The research conducted by Ivanová and Masárová (2018) [23] shows that in the context of economic development and competitiveness, the Czech Republic is doing best, periodically catching up with the other countries in the Group, especially Slovakia. The authors also note that over time, differences between individual countries are decreasing, and they are developing in a more balanced way.

Bod'a and Považanová (2019) [24] note, in turn, that in the V4 economies in the post-transformation period, the prevalence of Okun's law, according to which an increase in forced unemployment is accompanied by a decrease in Gross Domestic Product, was not observed. This observation allows us to conclude that economic development is also possible in conditions of growing unemployment and that emerging countries are determined to resist the current economic regularities in synchrony.

Interestingly, financial interdependence in the Visegrad Group also exists at the microeconomic level. Pham and Hrdý (2023) [25] observed them for small and medium-sized enterprises in the process of shaping the capital structure. The determinants and decisions

accompanying this process were similar in all the examined economies of the region, which means common economic and management patterns.

Additionally, Svobodová and Hedvičáková (2015) [26] found, in the course of their research, that the conditions for running your own business in the V4 countries are similar, although they are definitely the best in Hungary. The principles and amounts of corporate taxation are also similar.

Regional dependencies, although not as common as in the case of economies and enterprises, are also identified in the behavior of households. Šubová et al. (2024) [27] describe the relationship between real Gross Domestic Product and the propensity to save in households. Their research shows that statistically significant relationships between these parameters occur in the Czech Republic and Hungary. These insights can be used by both economic decision-makers and representatives of the banking sector.

The examples presented above show that the Visegrad Group countries are developing economically at a similar pace and in a similar way. This is observable at every level and in every subjective scope. This is certainly due to common historical and political roots and a common beginning of changes related to systemic transformation. It is worth adding, however, that in some comparisons, the countries that stand out are Hungary and the Czech Republic, where economic development seems to be more effective in some respects.

2.2. Resource Interdependencies in the Visegrad Group

The similarity in patterns and achievements in economic development may, but not necessarily, be similar to the patterns of resource strategies. Therefore, this section focuses on the description of existing research in the area indicated by this article's title.

Examining the achievements and challenges of energy transformation in the Visegrad Group, Dzikuć et al. (2021) [28] conclude that the Czech Republic and Slovakia systematically implemented policies that increased the share of renewable resources in the energy mix. Poland was supported in achieving this goal by the COVID-19 pandemic and the resulting reduction in energy production from fossil fuels. The authors also emphasize that the Visegrad Group countries still face many challenges related to transforming energy resources. Furthermore, countries in this region should systematically change the rules of road transport and develop the use of electric cars to reduce greenhouse gas emissions multidirectionally.

Despite the achievements in the use of renewable energy sources described above, the Visegrad Group countries still remain strongly dependent on non-renewable energy sources, as shown in the results from, among others, research by Żuk et al. (2023) [29]. According to the authors, the Visegrad economies are still balancing between dependence on Russia and diversification of energy supplies. However, this does not mean that there is a common resource policy in the region.

Problems in achieving climate goals in the V4 region are also highlighted by Kovács et al. (2024) [30]. The authors state that the strategic provisions of individual countries in the region are consistent with the EU's climate assumptions, but they also note numerous gaps in the implementation of these provisions. These gaps result from the prioritization of economic goals and the desire to maximize energy security at the expense of changes in energy resources. According to researchers, management errors and lack of social involvement pose additional problems. An important conclusion summarizing the results of the above studies is the recommendation to use effective indicators to assess the implementation of climate policy, not only postulated changes based on energy mixes.

On the other hand, the study by Kułyk et al. (2023) [31] presents the topic of assessing the conditions for investments in photovoltaic installations in the V4. In this context, the authors emphasize the importance of government support but also draw attention to the need to adapt it to the development status of the photovoltaics market. Additionally, they note the current instability of support policies in Poland, Slovakia, and Hungary. An exception in this respect is the Czech Republic, which consistently pursues the chosen development path of renewable energy sources (RESs). The result of the variable conditions

for the development of renewable energy sources in the V4 countries is—according to the authors' conclusions—a different structure of energy mixes.

In the context of the research cited above, there is no doubt that the V4 countries have problems in implementing the European Union's climate policy, just like most emerging and developing economies [32,33]. Nevertheless, as Zapletalová and Komínková (2020) [34] show, the V4 is unable to develop a common position in the European Parliament that would allow for the development of the so-called alternate speed path in the process of achieving a zero-emission economy.

The transformation of energy resources in the V4 seems more coherent from the perspective of individual companies. Research by Sulich and Sołoducho-Pelc (2021) [35] shows that most companies generating electricity in the countries of the region systematically increase the use of non-renewable resources in production. These conclusions are also confirmed by analyses by Jonek-Kowalska and Rupacz (2023) [36].

In the study of resource dependencies among the Visegrad Group countries, there emerges the issue of connections among economic growth, volume of transport cargo, fuel consumption in transport, and carbon dioxide emissions. In this context, Suproń and Łącka (2023) [37] state the existence of long-term cointegration between economic growth and fuel consumption in road transport in the Czech Republic and Slovakia. Furthermore, in Slovakia, the above variables were also correlated with CO_2 emissions. In Poland, greenhouse gas emissions were only related to fuel consumption in transport.

Interestingly, despite problems with climate policy, the V4 countries are trying to protect natural resources. This is evidenced by the systematic adaptation of national legislation to the environmental requirements of the European Union, described by Gałaś et al. (2015) [38]. The authors also note that in the V4 countries, Natura 2000 areas constitute approximately 21.4% of the total area, while the average for the EU is 18.36%. The observed regularities may indicate awareness of the need to protect the environment while addressing simultaneous difficulties to actually keep up with climate challenges.

Because of their geographical location, the Visegrad Group countries also share similarities in terms of resource deficits. For example, Smol et al. (2023) [39] draw attention to the lack of phosphorus in all V4 countries, which may currently and in the future, cause problems with food production in the entire region. The authors also identify significant potential for obtaining this critical raw material from household waste. The exchange of good practices, knowledge, and experience regarding industrial phosphorus recovery may become the basis for regional cooperation and making the V4 independent of phosphorus supplies from politically unstable countries, such as Russia, Morocco, or China.

The considerations presented above show that the Visegrad Group countries have problems with meeting the climate challenges, in particular, with increasing the share of renewable resources in energy mixes. They are also still heavily dependent on non-renewable resources. Nevertheless, the V4 countries that cope better with EU environmental policy—in the view of previous research—are the Czech Republic and Slovakia.

The limitation of the studies and research cited above is the lack of a holistic approach to assessing resource transformation strategies. Individual research threads most often concern selected resource aspects or details of resource policy. Moreover, the analyses often refer to the last decade or two decades. Meanwhile, resource transformation is a very time-consuming and cost-consuming undertaking, and, therefore, a closer look should be taken at its course and effects from a long-term research perspective.

Given the above research gap (referring to the time and area of research), this article next assesses the effectiveness of the climate resource transformation in the Visegrad Group countries in two dimensions including (1) resource and (2) emission, which are then synthesized using a multi-criteria analysis. This brings holistic knowledge about the possibilities of pro-ecological changes in the energy strategies of emerging and developing economies, as well as the timing and effects of implementing these strategies.

In the context of the analyzed literature, the research undertaken also allows us to determine the degree of synchronization of energy policies in the Visegrad Group. In

this way, we obtain an answer to a previously unsolved research problem regarding the interconnections of the energy sector, the imitation effect, and copying good practices at the regional level. As Section 2.1 shows, the economies of the V4 countries are developing at a similar pace and direction. It is therefore worth clarifying whether the choice of directions and pace of energy transformation follow a similar pattern. The knowledge acquired in this area, especially in the long term, may constitute valuable guidance in the process of making energy decisions and shaping energy policy in the future. Comparing differences in decisions with their final effects provides the basis for identifying the most effective behaviors and reactions in terms of independence, supply, and the environment in the energy sector.

The obtained results will also allow us to verify the thesis indicating that GW is significantly dependent on non-renewable energy sources, and thus significantly dependent on Russia and other suppliers of these energy resources. Previous research shows that all countries in the region are perceived and assessed similarly, especially in the relatively short term of the last few years. This may result not only from a reluctance to change and economic problems but also from objective difficulties resulting from the geographical location determining access to similar non-renewable resources and the climatic possibilities of using renewable resources.

The research conducted in this article also allows us to answer the challenge formulated by Kovács et al. (2024) [30] regarding the assessment of energy policy in the context of its actual effects, and not only declarations, plans, and strategies for the future.

The presented research also leads to a general conclusion about the low involvement of the V4 countries in the development of renewable or low-emission resources. However, it is not known whether there are differences in the level and type of these sources in individual countries. Our analysis allows us to take a closer look at this issue. However, it is worth noting that the current research highlights the desire to protect the environment throughout the region.

Taking into account the above premises, the adopted research methodology is described in the next part of this article. The results are then presented and discussed in the context of the circumstances presented above. The Section 6 also formulates recommendations and defines the research limitations and directions for further research.

3. Materials and Methods

This article focuses on research concerning the Visegrad Group (V4) from the point of view of three key circumstances as follows:

1. The common historical past of the studied countries and the need to undergo a difficult and not fully completed economic transformation (transition from a centrally planned economy to a free market economy);
2. The economic ties sanctioned in 1991 by the creation of an informal community aimed at intensifying cooperation in the construction of democratic state structures, a free market economy, and participation in the process of European integration;
3. The availability of data on energy use and the structure of this use in a long-term research perspective dating back to 1965 (a 58-year analysis period allows for observing real changes and effects of the adopted energy strategies).

The analysis covered the period from 1965 to 2022. During the research process, the data from the Statistical Review of World Energy [40] were used. The research stages included the following:

1. Analysis of primary energy consumption per capita, illustrating the energy intensity of the economy and the synchronization of consumption in the V4.
   The research methods included dynamics analysis, trend analysis, and Pearson's linear correlation analysis.
2. Identification of changes in energy mixes allowing for the determination of the implemented energy strategy.
   The research methods included structure analysis.

3. Assessment of the effectiveness of the adopted energy strategy, taking into account the following:
   (a) The resource dimension, reflecting the scale of use of renewable and zero-emission resources (renewable plus nuclear energy);
   (b) The emission dimension, reflecting CO_2 emissions per capita.
4. A holistic assessment of climate effectiveness that takes into account both dimensions mentioned above.

The research methods included multi-criteria analysis allowing for the synthesis of various assessment criteria and the development of a ranking of the adopted strategies for the transformation of energy resources.

In the context of the measures adopted above, it is worth emphasizing that climate efficiency was defined based on key energy challenges facing all European Union countries [41–43] related to (1) increasing the use of renewable/zero-emission resources and (2) reducing greenhouse gas emissions.

The adopted research methodology is not mathematically complex, which may be both its advantage and its disadvantage. Certainly, the proposed approach is cognitively accessible and allows for research related to the energy sector to be replicated by both scientists and practitioners.

4. Findings

4.1. Strategies for the Transformation of Energy Resources in the Visegrad Group

The first part of this research identified paths for the transformation of energy resources in the Visegrad Group countries. This identification began with a long-term analysis of primary energy consumption in individual countries on a per capita basis [44]. The results of this stage are presented in Figure 1. The data show that in the first year of the analysis, the highest primary energy consumption—significantly different from other countries—occurred in the Czech Republic. It was over 2.5 times higher than in Hungary (the country with the lowest primary energy consumption). In Poland and Slovakia, the value of the analyzed variable was similar and amounted to approximately 88–89 GJ per capita. In the last year of the analysis, the ranking of primary energy consumption did not change, but the difference between the Czech Republic and Hungary decreased significantly. This was due to a reduction in primary energy consumption in the Czech Republic by over 8% and an increase in consumption in Hungary by over 46%. During the analyzed period, consumption also increased in Slovakia (by over 38%) and Poland (by over 20%).

The analysis of the data and trends presented in Figure 1 also shows that until 1989—the beginning of the economic transformation in the Central and Eastern European region—primary energy consumption per capita systematically and quite significantly increased over time in all the countries studied [45–47]. Then, in the first decade of political and economic changes, this consumption decreased significantly, which was most likely due to the liquidation of many enterprises and even entire industries, the transformation of the industrial structure into a less energy-intensive one, and the economic crisis forcing a more rational energy management.

Since 2001, primary energy consumption per capita has been increasing again, with periodic declines in 2018 and 2022 caused by global problems related to the COVID-19 pandemic and the Russia–Ukraine armed conflict. Notably, however, the level of analyzed consumption did not reach a maximum in the period before the economic transformation, which allows us to conclude that the examined economies have become more energy efficient, although their "appetite" for energy is still growing.

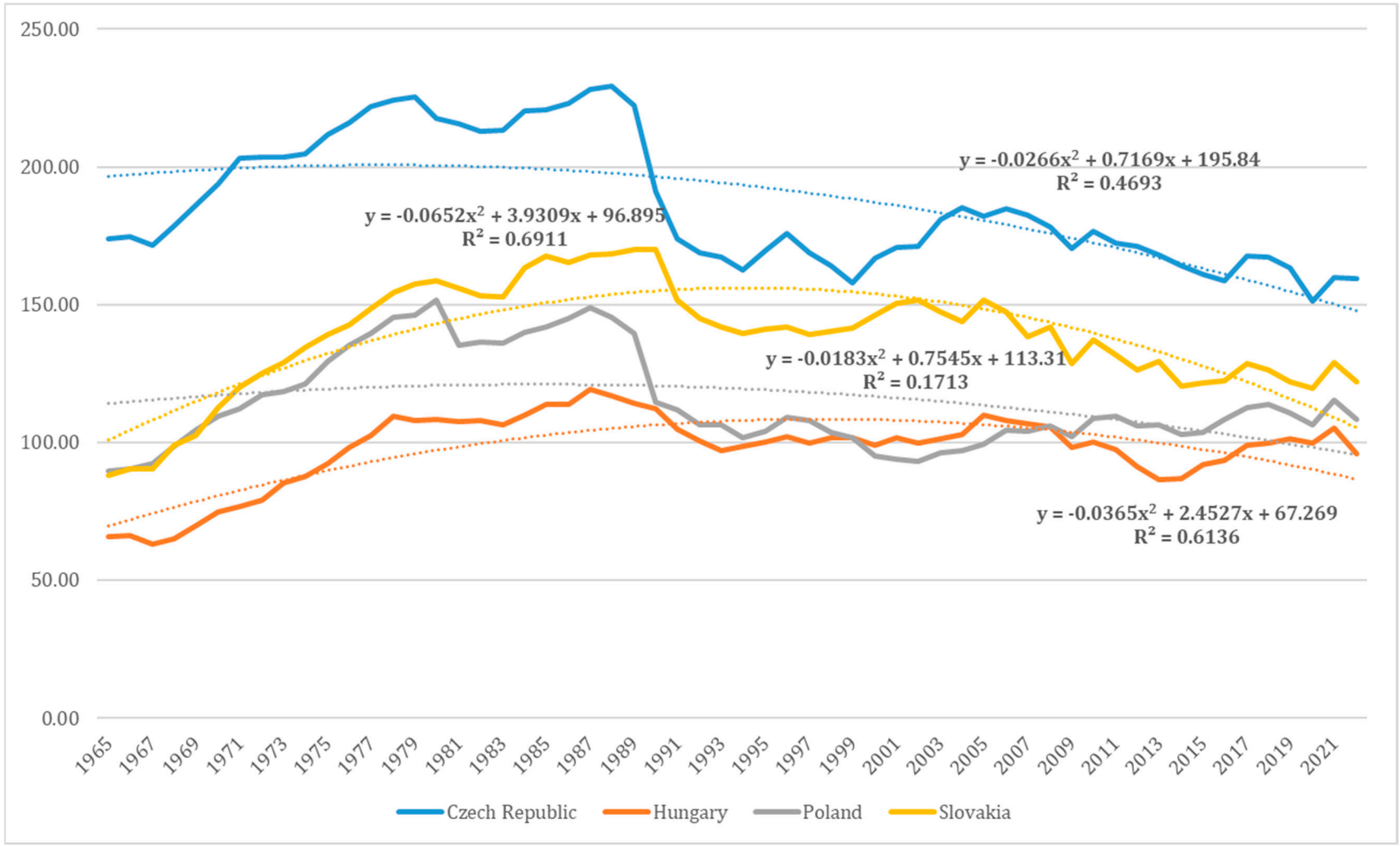


Figure 1. Primary energy consumption per capita in the Visegrad Group countries in the years 1965–2022 and trend functions for this consumption [GJ].

The observed development trends correspond to previous research conclusions relating to similar economic development paths in the Visegrad Group. This development is also very often synchronized with energy consumption, which is confirmed by the results of the above analyses. The conclusion regarding the possibility of significantly reducing energy consumption per capita is also interesting and valuable, confirming the potential of emerging and developing economies to improve energy efficiency. Economic and industrial transformation is therefore possible, although in the long term.

Observation of the system of consumption curves and their polynomial trend functions shows that energy habits in the studied countries are correlated over time. This is also confirmed by the values of Pearson's linear correlation coefficient presented in Table 1.

Table 1. Correlation matrix for primary energy consumption per capita in the V4 in 1965–2022.

Country	Czech Republic	Hungary	Poland	Slovakia
Czech Republic	1.0000	-	-	-
Hungary	0.3309 *	1.0000	-	-
Poland	0.8627 **	0.5426 **	1.0000	-
Slovakia	0.5474 **	0.9101 **	0.6298 **	1.0000

*—$p < 0.05$; **—$p < 0.01$.

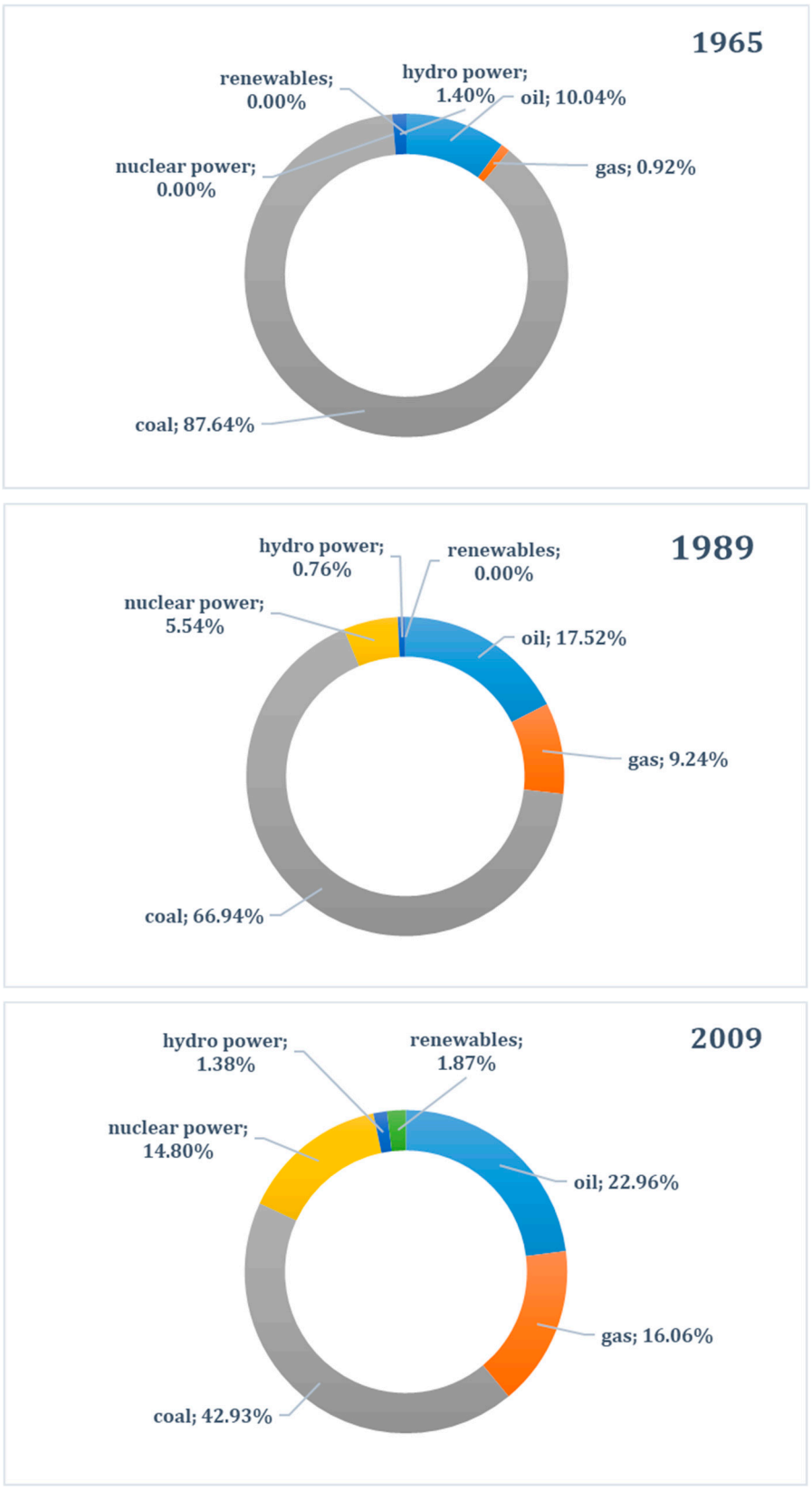
All observed correlations are statistically significant and positive, indicating that primary energy consumption in the studied countries changed in the same direction, which was most likely determined by economic changes in the world and the studied region. The strongest ties are in Hungary and Slovakia as well as Poland and the Czech Republic. Relationships with average correlation strength are found in the case of Hungary and Poland, as well as Slovakia and the Czech Republic. The lowest correlation is found in the Hungary and the Czech Republic pair.

The strongest identified correlations in terms of electricity consumption per capita may result from the similar economic structures of Slovakia and Hungary as well as Poland and the Czech Republic. The case of the first pair mentioned deals with less industrialized countries with a significant share of agriculture. These are also countries poor in natural resources, including energy resources. The second indicated pair includes more industrialized countries that are richer in natural resources. The above-mentioned circumstances may strengthen the connection between electricity consumption patterns.

To analyze the trends described above in more detail, it is worth taking a look at changes in the use of energy resources in the studied countries. They will determine the actual energy strategy implemented over the 58-year period covering the years 1965–2022. Taking into account the above observations and the literature studies conducted, the following four milestones were distinguished in the strategic analysis:

1. The year 1965—the beginning of the analysis;
2. The year 1989—the beginning of the economic transformation in the region of Central and Eastern Europe (during which, in 1993, Czechoslovakia also split into the Czech Republic and Slovakia);
3. The year 2009—implementation of the Climate Package setting the direction of energy balance changes in the European Union;
4. The year 2022—end of the analysis, allowing for an assessment of the current progress in the transformation of energy resources.

The structure of the use of energy resources for the periods distinguished above in individual countries is presented in Figures 2–5.



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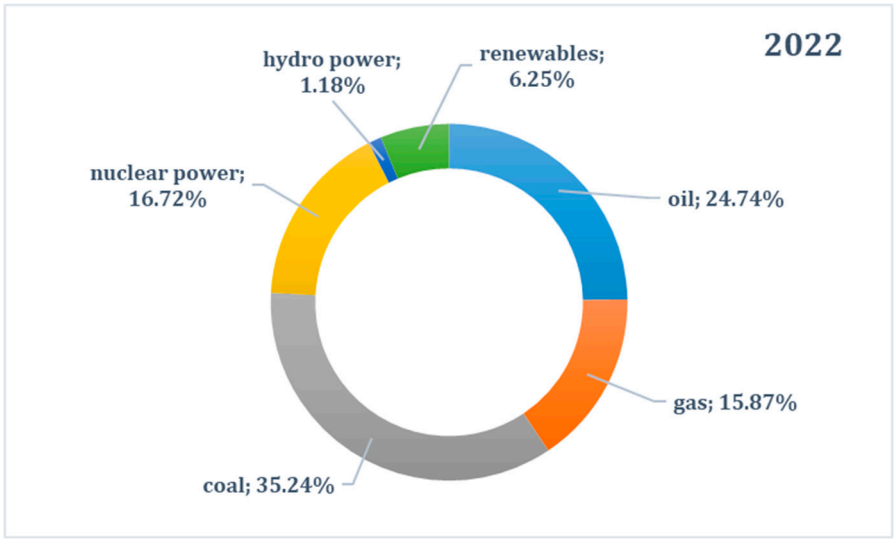
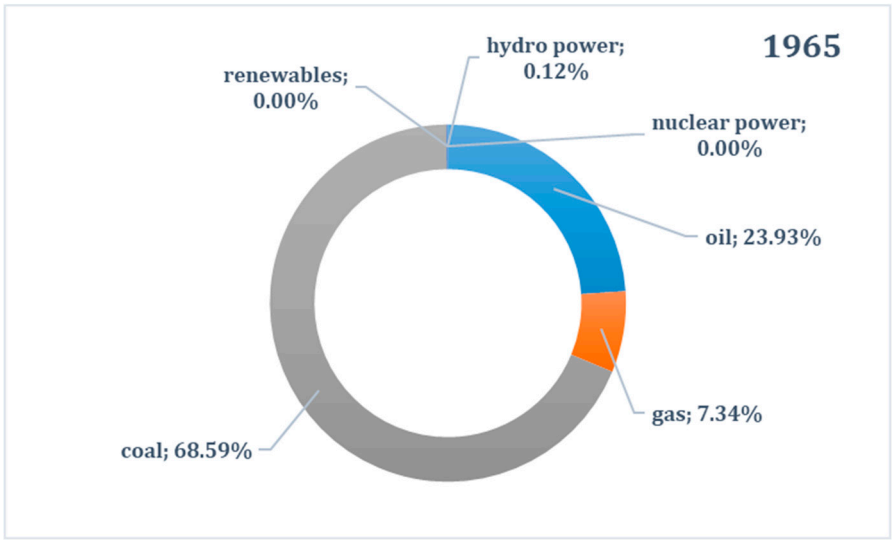
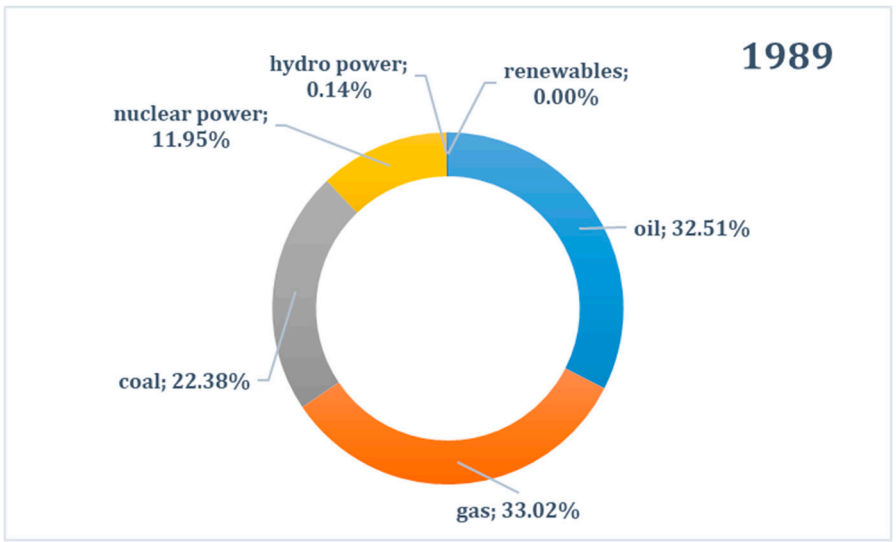


Figure 2. Transformation of energy resources in the Czech Republic in 1965–2022.





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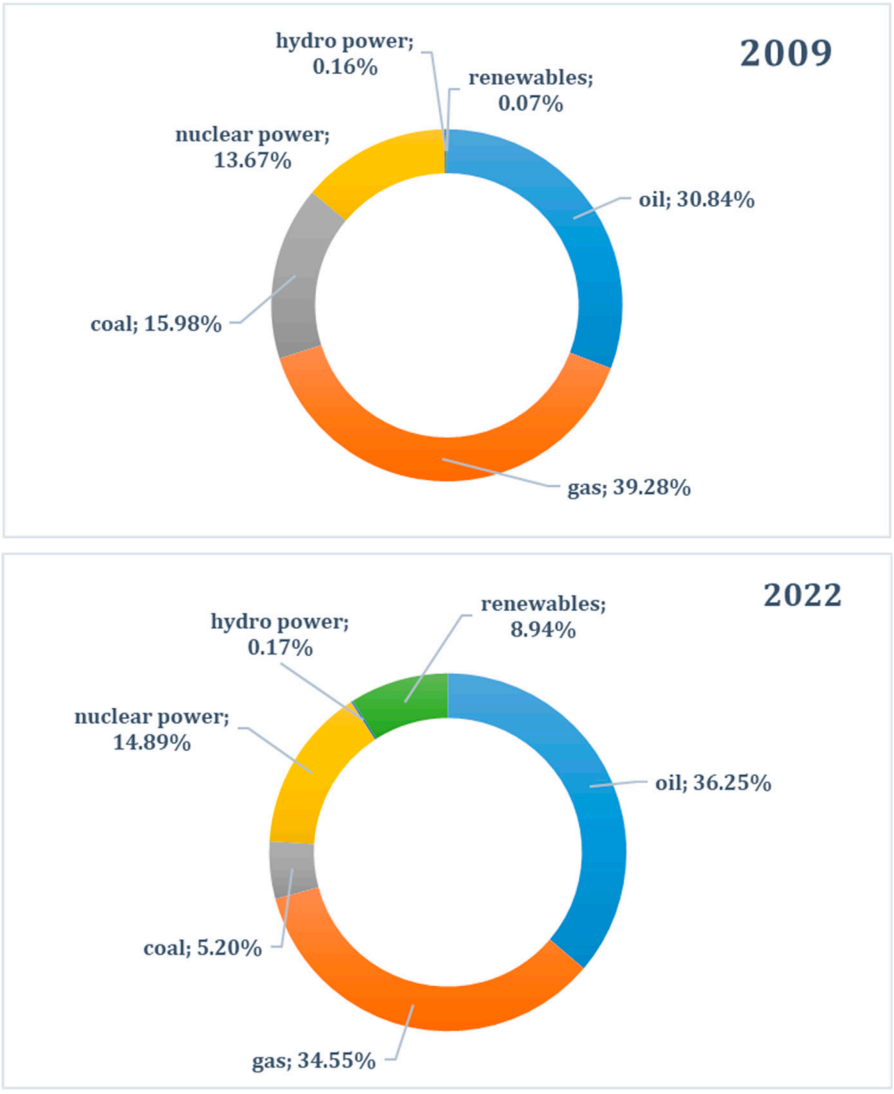
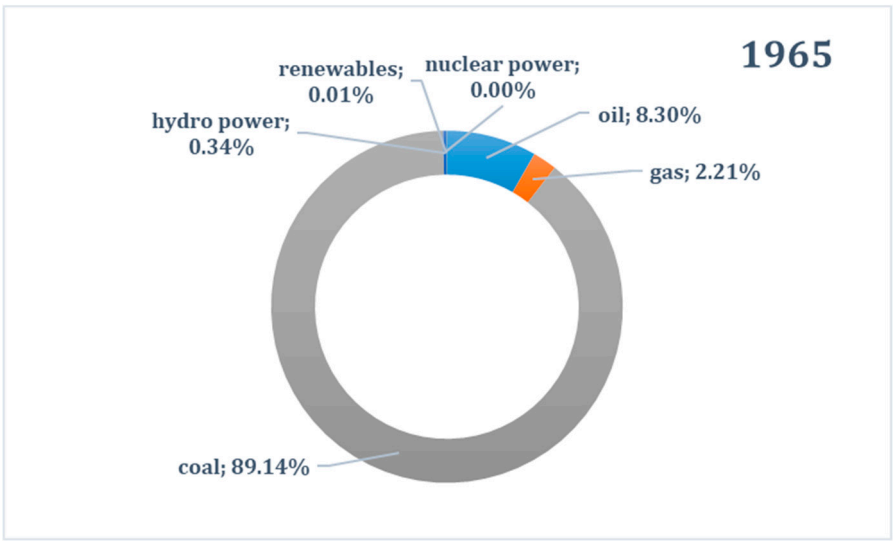


Figure 3. Transformation of energy resources in Hungary in 1965–2022.



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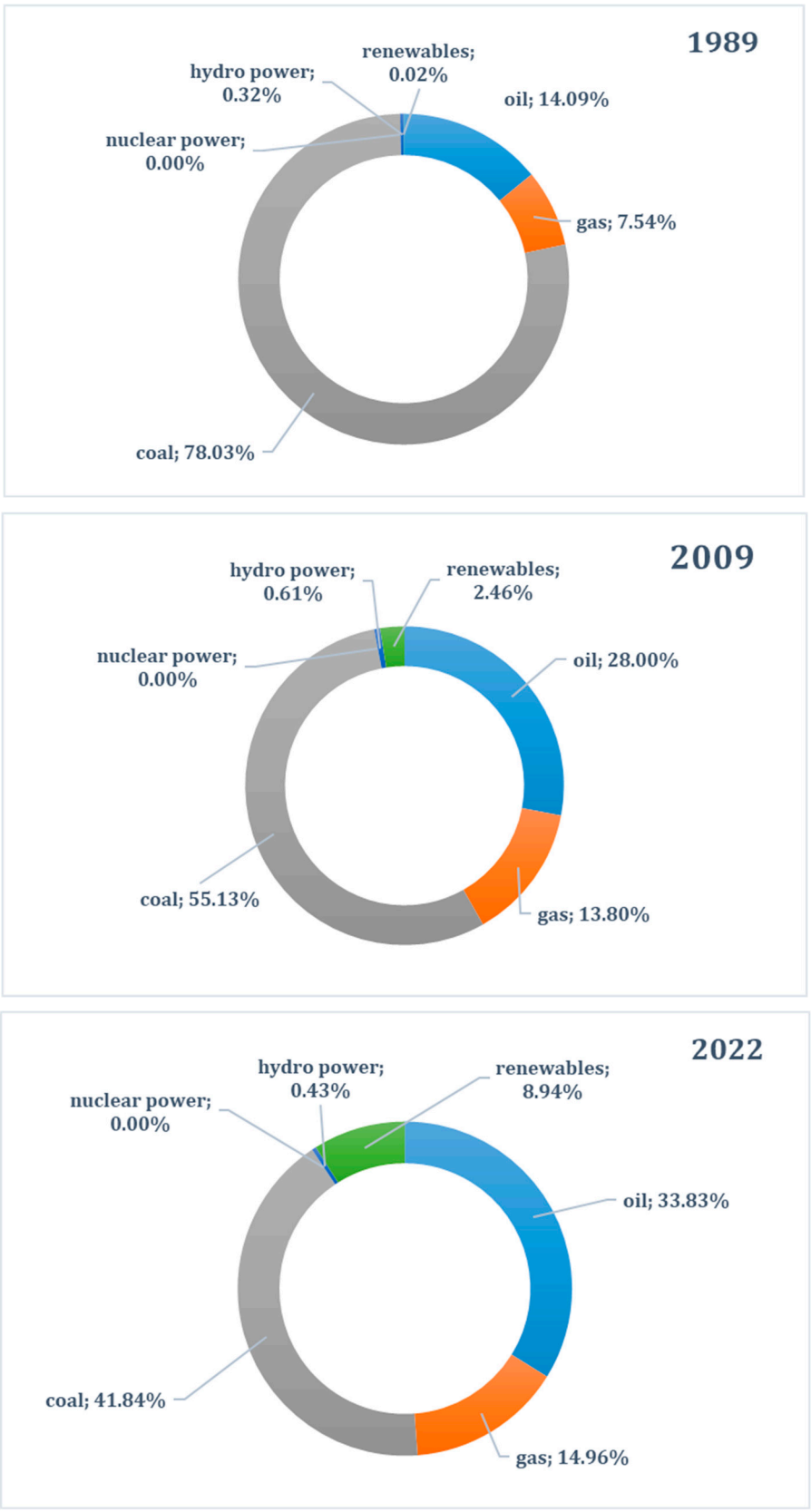
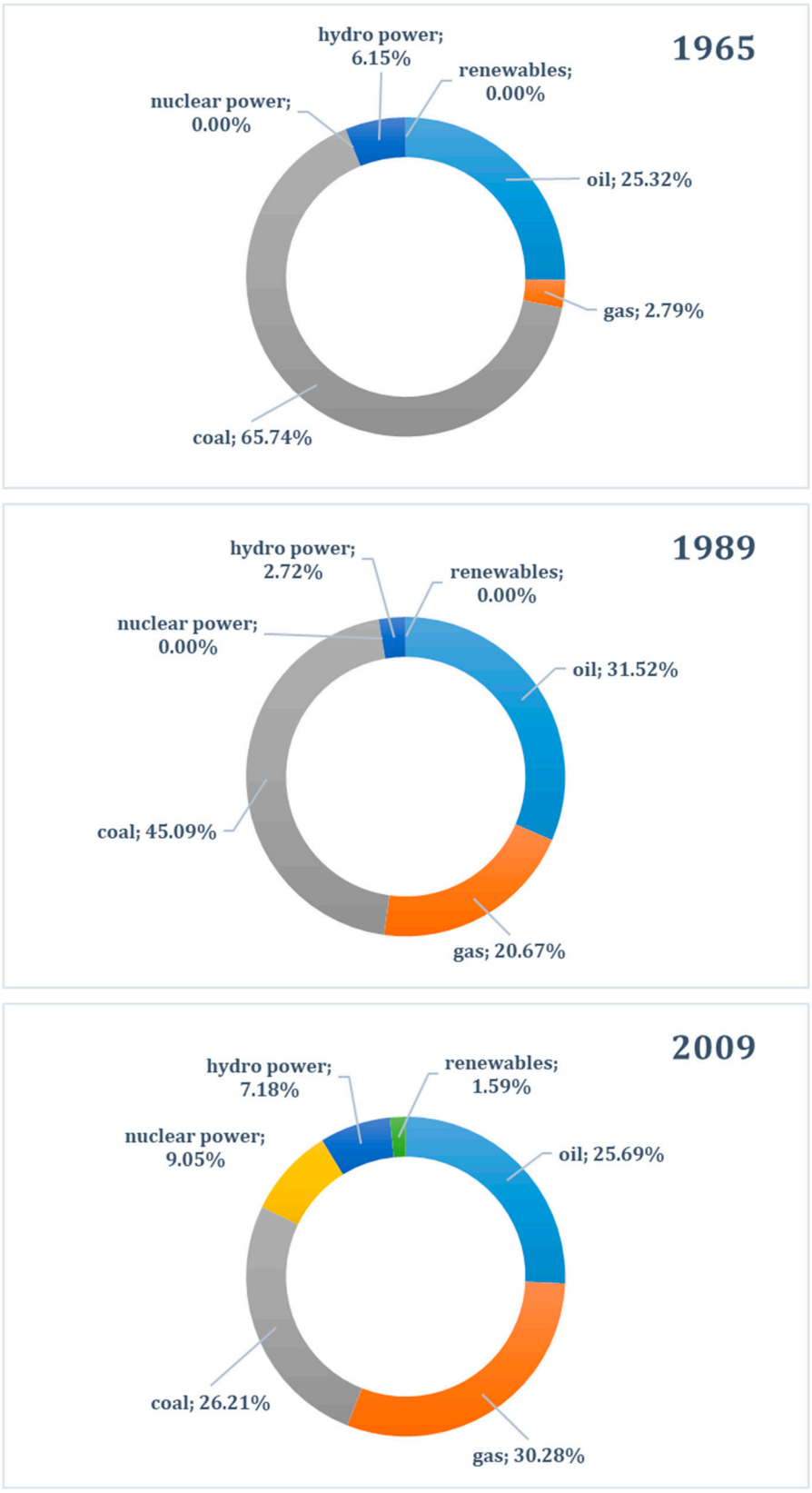


Figure 4. Transformation of energy resources in Poland in 1965–2022.



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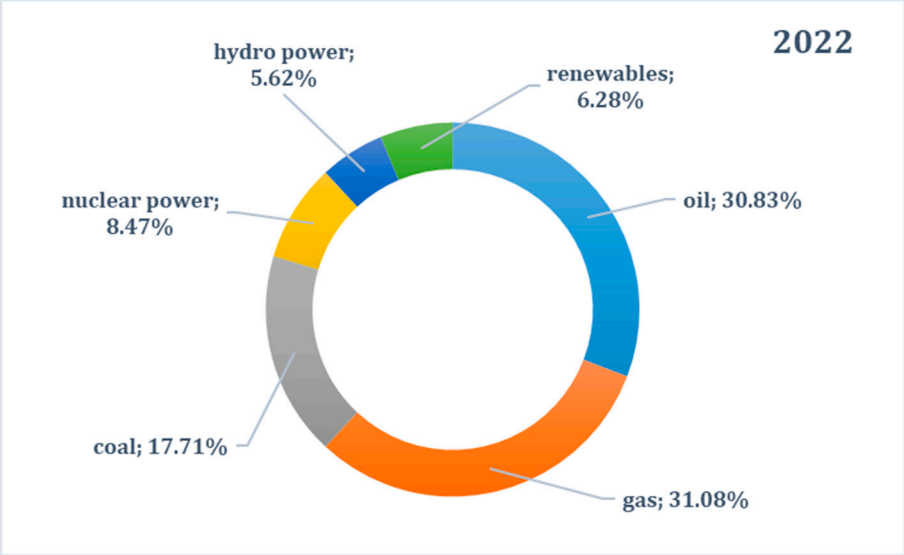

Figure 5. Transformation of energy resources in Slovakia in 1965–2022.

In the Czech Republic, coal dominated in the first year of analysis. It was supplemented by oil to a very small extent and by hydropower and gas in trace amounts. At the beginning of the systemic transformation, the share of coal in the energy balance decreased in favor of nuclear energy and gas. In the following years, the use of nuclear energy, gas, and oil continued to increase. Moreover, after 2009, the use of renewable raw materials in the energy mix increased (up to 6.25%).

In Hungary in 1965, coal was also the main source of energy. Oil constituted about one-fourth of the balance. In 1989, the share of coal was significantly reduced, and the share of oil and gas was increased. Nuclear energy also appeared in the energy mix. Until 2009, the share of coal was systematically reduced in favor of gas. Nevertheless, the balance was still dominated by non-renewable energy raw materials. In 2022, as a result of the introduction of the Climate Package, the share of coal was reduced to 5.20%, and the share of renewable resources increased to almost 9%.

The use of coal in Poland at the beginning of the analyzed period was the highest (almost 90%). This resource was supplemented to a small extent by oil and gas. In the following years, the share of coal decreased systematically. However, the share of oil and gas increased. In 2009, renewable resources also appeared to the greatest extent in the energy mix (almost 2.5%). Poland was the only country in the Visegrad Group that did not use nuclear energy during the period under study. This resulted in maintaining the highest share of coal in the V4 in 2022. It is worth adding, however, that the share of renewable raw materials in the energy mix was the highest among the analyzed countries—almost 9%.

In the Slovak economy, at the beginning of the analysis, the energy balance was also dominated by coal, supplemented one-fourth by oil. In addition, hydropower was used to a fairly large extent (over 6%). In the following years, the use of coal was reduced, and gas consumption was increased. Nuclear energy also appeared among energy resources. In 2022, as in other V4 countries, there was a significant increase in the share of renewable resources.

Based on the presented considerations and data, the following similarities can be identified that characterize the studied countries at the beginning of the resource transformation:

- The dominant share of coal as the primary energy raw material;
- Supplementing coal with varying proportions of oil and gas;
- A lack of renewable energy sources;
- A lack of nuclear energy.

All V4 members also chose a strategy to reduce the share of coal in energy balances, and since 2009, they have systematically increased the share of renewable resources. Addi-

tionally, three out of the four countries decided to use nuclear energy, which diversified and greened their energy balances. In addition, Slovakia has also focused on hydropower, diversifying its energy resources and increasing energy security.

Referring to the results of the analysis of the border points (1965, 1989, 2009, 2022), it can be noted that without institutional or internal environmental pressure, very little changed in the energy balances of the countries studied, especially in the field of renewable resources, which were practically not used at all until 1989. In the case of Hungary, the inclusion of nuclear energy in the balance was most likely due to the desire to strengthen energy independence because of the low abundance of energy resources. In turn, the Czech Republic made a similar decision, having significant deposits of hard coal and brown coal, which can be assessed as a very pragmatic and reasonable direction of energy transformation. Slovakia—despite its high energy dependence—used nuclear energy, but to a very small extent. In turn, Poland—operating on the largest coal deposits—remained completely passive towards the changes observed in the region.

Significant pro-environmental changes in energy balances were brought only in 2009 when the Climate Package was implemented. This proves the need for top-down regulations regarding changes in energy policies. Without them, very little would likely change in terms of energy balances. Nevertheless, it is worth adding that although in the period 2000–2022, the share of renewable resources in energy balances increased several times in each country, it did not ultimately reach very impressive levels, and on average annually, it increased by less than 1 percentage point. This confirms the low effectiveness of the V4 countries in the green energy transformation. The slow pace of growth of renewable energy sources in the balance sheets is also not a good prognosis for the coming years. It seems that the saturation of the energy balances of the examined countries with green energy has reached a critical point, after which it will be difficult to expect further intensive increases in the share of renewable energy sources.

4.2. Results and Climate Effectiveness of the Energy Resource Transformation Strategy in the Visegrad Group

The assessment of the effects of the energy resource transformation strategy in the Visegrad Group countries was based on its main goal, which in the European Union countries should be reducing carbon dioxide consumption, increasing the share of non-renewable resources in energy mixes, and systematic decarbonization.

Thus, in accordance with the assumptions presented in the Section 3, the assessment began with the resource dimension of climate effectiveness, including answers to questions about the following: (1) the scope of reducing the share of coal; (2) the scope of reducing the share of non-renewable resources; and (3) the level of use of renewable resources. The results of this research stage are presented in Table 2.

Table 2. Assessment of resource-based climate effectiveness in the V4 countries in 1965–2022.

Result Dimension	Country			
	Czech Republic	**Hungary**	**Poland**	**Slovakia**
Change in the coal share	↓ 52.41 percentage points	↓ 63.40 percentage points	↓ 47.29 percentage points	↓ 48.03 percentage points
Change in the share of non-renewable resources	↓ 22.73 percentage points	↓ 23.88 percentage points	↓ 9.02 percentage points	↓ 14.23 percentage points
Change in the share of renewable resources	↑ 6.02 percentage points	↑ 8.94 percentage points	↑ 8.93 percentage points	↑ 6.28 percentage points
Total change in the share of zero-emission resources	↑ 22.73 percentage points	↑ 23.88 percentage points	↑ 9.02 percentage points	↑ 14.23 percentage points

↑—an increase; ↓—a decrease.

Table 2 shows that in the case of the desired transformation of non-renewable resources, the best results were achieved in Hungary because of the highest reduction in

the share of coal and the share of total non-renewable resources. The Hungarian energy strategy also resulted in the largest increase in the share of zero-emission resources, i.e., renewables, nuclear energy, and hydropower. Good resource results were also achieved in the Czech Republic, especially in terms of reducing the share of coal and total non-renewable resources, largely because of the development of nuclear energy.

It is worth recalling that while Hungary faced stronger pressure for change resulting from its high energy dependence, the Czech efforts were less externally motivated but equally effective.

In Poland and Slovakia, the transformation of energy resources has brought similar and not the best results. The share of coal in the total balance was significantly reduced. Unfortunately, this was largely due to the increase in the share of oil and/or gas. As a result, the share of non-renewable resources in the energy balance changed little. Furthermore, in the case of Poland, which did not decide to use nuclear energy, the change in the share of zero-emission resources was ultimately only slightly over 9 percentage points.

In this context, the lack of action in Slovakia is surprising, which, like Hungary, was characterized by less energy independence and yet did not take sufficient dynamic actions to transform energy balances. Polish slackness in this respect is undoubtedly justified by the abundance of hard coal, but in the face of climate change, this is an explanation of questionable quality.

Given the above observations, the next research step focused on assessing the emission effectiveness of the energy resources transformation strategies used. This effectiveness, in accordance with the assumptions presented in the Section 3, was assessed using CO_2 emissions per capita. Changes in the value of this indicator are included in Table 3. Its value throughout the entire analysis period is also presented in Figure 6.

Table 3. Assessment of climate emission effectiveness in the V4 countries in 1965–2022.

Result Dimension	Country			
	Czech Republic	Hungary	Poland	Slovakia
CO_2 emission per capita in 1965 [in tons]	16.10	5.87	8.10	7.11
CO_2 emission per capita in 2022 [in tons]	9.05	4.31	7.42	6.21
Change in CO_2 emission per capita in 1965–2022	↓ 43.76%	↓ 26.57%	↓ 8.43%	↓ 12.74%

↑—an increase; ↓—a decrease.

According to the data presented in Table 3, in 1965, the highest level of CO_2 emission per capita was recorded in the Czech Republic, which was certainly also related to the very high primary energy consumption in this country described in the first part of this article. Nevertheless, with both the reduction in energy consumption and the transformation of energy resources, it was possible to significantly reduce the value of this indicator. In 2022, it was still the highest in the V4, but it did not differ so drastically from the value in Poland or Slovakia.

Given the results obtained, Hungary undoubtedly had the best climatic efficiency. In the first period of the analysis, the CO_2 emission per capita was the lowest in this country (primary energy consumption was also the lowest in relative terms). Despite this, in the following years, emissions were reduced by more than one-fourth, which allowed Hungary to outclass the other analyzed countries.

Poor climate effectiveness was dominant in Poland and Slovakia. In these countries, despite the passage of 58 years, CO_2 emission has decreased only by 8.43% and 12.74%, respectively, which is definitely insufficient in the face of current climate challenges.

Until 1989, changes in CO_2 emissions were undoubtedly positively influenced by the reduction in capital intensity of economies, manifested in the previously analyzed and clearly decreasing energy consumption per capita. Additionally, the effectiveness of climate change has been strengthened by the introduction of nuclear energy into the energy balances of three out of the four countries.

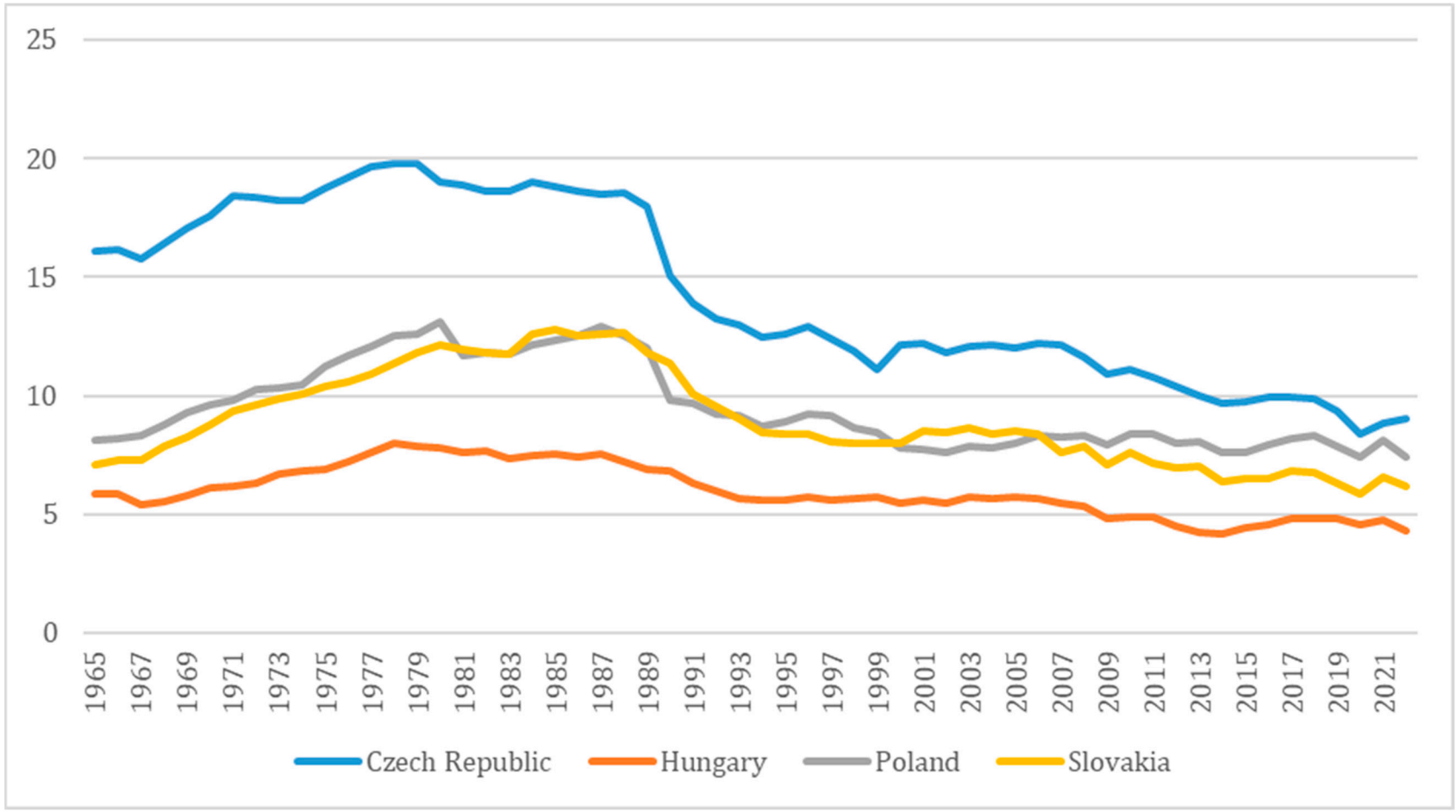

Figure 6. CO_2 emission per capita in the V4 in 1965–2022 [in tons].

After this period, the factor stimulating further changes was the increase in the use of renewable sources. As emphasized, it was not significant, and, therefore, the observed reduction in CO_2 emissions was not impressive either. As shown by the data presented, declines were observed in the entire Visegrad Group, but in the period of the greatest EU pressure covering the years 2009–2015, greenhouse gas emissions ultimately changed very little.

Given the diversity of the results of the energy resources transformation strategy (its resource and emission dimensions), in the next research step, a multi-criteria analysis was used to conduct a synthetic assessment of climate effectiveness. This analysis included data on the following:

- The level of reduction in carbon shares (stimulant);
- The level of reduction in the share of non-renewable resources (stimulant);
- The level of increasing the share of renewable resources (stimulant);
- The level of increasing the share of zero-emission resources (stimulant);
- The level of CO_2 emission reduction per capita (stimulant);
- The CO_2 emission level per capita in 2022 (destimulant).

The results of this stage are presented in Table 4. It can be concluded on their basis that the highest climate effectiveness determined by both analyzed dimensions was recorded in Hungary, which, since 1965, has systematically abandoned not only coal but also other non-renewable raw materials. They replaced them in the resource mix with nuclear energy and renewable energy sources. In this way, they have become the leader in zero-emission energy sources in the region. Additionally, Hungary managed to achieve the lowest level of CO_2 emission per capita in 1965 and 2022 and its significant reduction throughout the analyzed period. It can therefore be concluded that this country's strategy was consistently implemented and brought the best climate effectiveness.

Table 4. Synthetic assessment of climate emission effectiveness in the V4 countries in 1965–2022.

Country	Assessed Areas						
	Level of Reduction om Carbon Shares	**Level of Reduction om the Share of Non-Renewable Resources**	**Level of Increase the Share of Renewable Resources**	**Level of Increase the Share of Zero-Emission Resources**	**Level of CO_2 Emission Reduction per Capita**	**CO_2 Emission Level per Capita in 2022**	**Synthetic Multi-Criteria Assessment**
Czech Republic	0.45915	0.92261	0.00000	0.92261	1.00000	0.0000	0.5507
Hungary	1.00000	1.00000	1.00000	1.00000	0.51344	1.0000	0.9189
Poland	0.20719	0.00000	0.99658	0.00000	0.00000	0.3439	0.2579
Slovakia	0.00000	0.35061	0.08904	0.35061	0.12199	0.5992	0.2519

In the process of change, Hungary was guided by both internal and external considerations. The low sufficiency of their own energy resources pushed them towards nuclear energy, increasing energy independence. In turn, EU policy required a systematic increase in the use of renewable energy sources. The factor contributing to the greatest effectiveness in energy transformation was undoubtedly the low level of energy consumption per capita throughout the period under study.

The Czech Republic coped slightly worse with environmental challenges, adopting a strategy similar to Hungary's, but in 1965, it had record primary energy consumption and, as a consequence, a very high level of CO_2 emission per capita. Interestingly enough, despite difficult initial conditions, they managed to achieve the second-highest climate effectiveness in the Visegrad Group.

The energy transformation strategy adopted by the Czech Republic deserves recognition. It was not as strongly internally motivated as Hungary because it had its own coal deposits. It also had the highest energy consumption per capita. Despite these unfavorable

circumstances, the Czech Republic managed to take second place in the Visegrad Group in assessing the effectiveness of the energy transformation.

Poland's and Slovakia's results were much worse. Coal was phased out quite slowly in these countries, and this raw material was replaced mainly by oil and gas. Poland achieved the best results in terms of increasing the share of renewable sources. Slovakia stood out with a relatively low level of CO_2 emissions per capita in 2022. In other categories, the scores of these countries were very low compared with Hungary—the ranking leader.

Both of the countries mentioned above have not made sufficient efforts towards green transformation. Ultimately, this resulted in very low effects in reducing CO_2 emissions. Taking into account the long-term nature of energy changes in the near future, both Poland and Slovakia will find it difficult to cope with the EU's environmental challenges.

5. Discussion

Referring to the synchronization of the transformation of energy resources in the Visegrad Group countries, it can be stated that it is less intense than the synchronization of the economic transformation, which—as shown by the analyses to date—takes place at various levels [Ivanova; Boda] and affects businesses in a similar way [Pham; Svobodová] as well as households [Šubová].

The above observation is new and allows us to conclude that despite regional similarities in economic development and similar trends in changes in electricity consumption, the energy development paths may be different. Additionally, the example of Hungary documents that the low level of its own energy resources does not have to determine and justify the low effectiveness of the green transformation. It is therefore also fully possible in developing economies. In turn, the example of Poland indicates that the availability of its own resources is convenient and provides an argument for not implementing changes in the form of the need to maintain energy independence.

In the initial period of changes, all the surveyed countries used non-renewable resources almost exclusively, primarily hard coal. Over time, it was also difficult for them to maximize the use of renewable resources, which was already pointed out by Dzikuć et al. (2021) [28]. As a result, in 2022, the energy mixes of the studied countries still contained a significant share of non-renewable raw materials, which is also confirmed by the research of Żuk et al. (2023) [21] and Kovács et al. (2024) [23].

The European Union's climate policy has been developing since 2009. To date, all the analyzed countries have therefore had fifteen years to implement visible and sufficient changes in the use of renewable energy sources. Even though the use of renewable energy sources in the V4 countries increased several times during this period, none of the countries managed to exceed 10% of the share of renewable energy sources in their energy balances. This means that annual changes did not even exceed 1%. The pace of green transformation in the region is therefore very slow and does not guarantee its effectiveness.

This is confirmed by CO_2 emission data. In the years of the greatest climate pressure, emission reductions were the lowest. The trend observed in this respect resembled stagnation, despite much more visible changes in the years 1965–1989, i.e., before the Climate Package. At that time, the reduction in greenhouse gas emissions was supported by the decreasing consumption of electricity per capita, the transformation of the industry into being less energy-intensive and harmful to the environment, and the introduction of nuclear energy into the energy balances of three out of the four countries.

Currently, these factors no longer influence emission changes so intensively. This circumstance, combined with the low increase in the share of renewable energy sources, means that the V4 countries are far behind Western European countries in the green transformation. It also seems that the analyzed countries do not make further efforts to strengthen the use of renewable energy, because their initial growth potential has clearly decreased, which may result in stagnation of the effectiveness of the transformation in the near future.

Additionally, this effectiveness may be negatively affected by the increase in political uncertainty in the European Union, growing nationalist tendencies, and the Russia–Ukraine conflict, which increases the need to maintain energy security.

Nevertheless, it is difficult not to notice the systematic decarbonization that involved all countries in the region under study. The greatest successes in this area have been achieved by Hungary and the Czech Republic. These countries have also significantly reduced the share of oil and gas in the energy mix. The results achieved by Poland and Slovakia were worse, as these countries systematically abandoned the use of coal, but supplemented the resource gaps with other non-renewable raw materials.

Therefore, the countries studied have adopted different strategies for transforming their energy resources achieving different and not always sufficient climate performance. The aforementioned decarbonization leaders—the Czech Republic and Hungary—focused on the use of nuclear energy, which certainly allowed them to achieve better results in terms of reducing greenhouse gas emissions. This strategy usually also ensures high energy independence. Nuclear energy was also used by Slovakia (although to a lesser extent), which additionally supported itself with hydropower. It is true that Poland achieved the largest increase in the share of non-renewable resources in the V4, but it was the only one that did not reach for the potential of nuclear energy.

The adoption of the above strategies brought the best climate effectiveness (increase in zero-emission resources and CO_2 reduction) for Hungary and the Czech Republic. These countries diversified their resource mix and, taking into account the difficulties in using renewable energy, decided to use nuclear energy. This decision brought the expected climate results. It is worth adding that the Czech Republic's achievements in this respect are impressive, considering that primary energy consumption per capita was more than twice as high at the beginning of the analysis (the highest in the V4).

In the case of Poland and Slovakia, decarbonization can hardly be considered effective. It is rather feigned in nature. Coal is being phased out at a slower pace, and this raw material is replaced by other, slightly less emission-intensive, non-renewable sources. The result is a low increase in zero-emission resources and a low reduction in CO_2 emissions. This efficiency will be very difficult to improve because infrastructure changes in the energy sector take place over a long period of at least several years, and the construction of nuclear power plants requires up to a dozen or so years.

Summarizing the above observations, it can be said that the transformation of energy resources in emerging and developing countries is possible but requires the passage of a significant amount of time, consistency in action, and supporting decarbonization with the use of nuclear energy.

Individual and other energy transition strategies were driven by the following two key factors: energy independence and climate pressure, which can be illustrated by the energy transition motivation matrix presented in Figure 7.

This matrix clearly shows that climate pressure may have a positive impact on countries both with high primary energy independence (Czech Republic) and those with significantly lower sufficiency of their own energy resources (Hungary). Both of these countries achieved very good results in terms of the effectiveness of the energy transformation, expressed mainly by reducing CO_2 emissions and increasing the use of renewable energy sources. Although the use of nuclear energy undoubtedly helped them achieve this goal.

In turn, Slovakia and Poland downplayed climate motivation. Poland justified itself mainly by wanting to maintain high energy independence. Slovakia has not made any significant efforts towards independence or climate, which is reflected in the lowest assessment of the effectiveness of the energy transformation. It is also worth adding that the two countries mentioned above have a large difference in efficiency compared with Hungary and the Czech Republic—the leaders of the ranking.

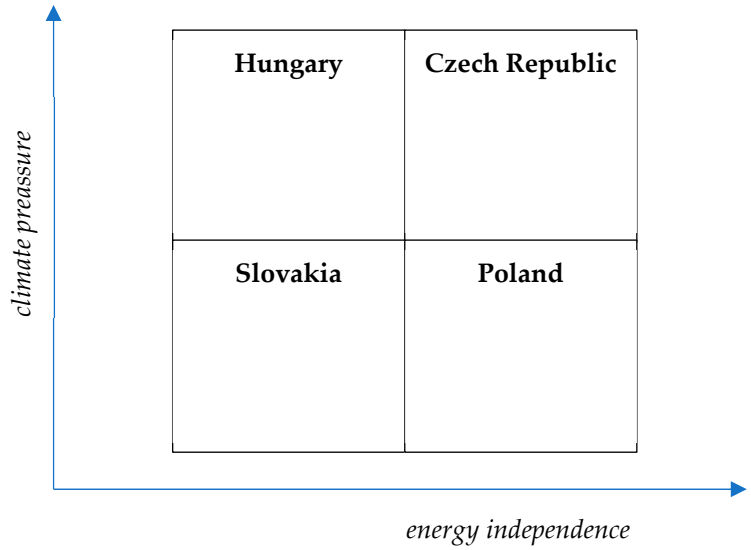

Figure 7. Matrix for energy transition motivation.

It is worth comparing the obtained results with the EU average. The average share of renewable energy for the EU in 2022 was approximately 21%. This means that all the Visegrad Group countries have quite a large difference from the average. Moreover, all Visegrad Group countries are in the bottom ten of the EU-27. Western European countries such as Iceland, Norway, Sweden, and Finland have been among the leaders of energy transformation for years. Nevertheless, it is worth emphasizing that representatives of emerging and developing economies are also at the forefront including Estonia, Lithuania, and Croatia. Countries aspiring to join the EU, such as Albania and Montenegro, also achieve very good results in the development of renewable energy sources. The above data clearly indicate that the success of energy transformation does not have to be associated only with a high level of economic development, which often becomes an excuse for countries that cannot keep up with the leaders of pro-environmental energy changes.

The obtained results and related considerations suggest the following recommendations:

- Poland should engage in the development of nuclear energy because its absence may significantly limit progress in decarbonization and thus improvement in climate effectiveness;
- Slovakia, Hungary, and the Czech Republic should continue to consistently abandon the use of non-renewable resources, making greater use of nuclear energy, hydropower, and other renewable resources;
- All V4 countries will certainly benefit from developing and systematically implementing programs to support the development of renewable energy (individual strategies for the development of these resources indicate the possibility of simultaneous development of wind and solar energy) [Kułyk];
- Agreeing on a common position on the transformation of energy resources in the region is equally important. This includes the exchange of experiences, good practices, and a stronger representation of the V4 in the European Parliament because the current analyses show that the problems are common, but there is no common voice in a common cause [Zapletalová].

In connection with the above recommendation, it is worth considering strengthening all possible renewable energy sources, not only those that are currently of interest to a given political option. Diversity means not only the possibility of increasing the scope of use of renewable energy sources but also increasing the security of the continuity of energy supplies.

The effectiveness of the green transformation is certainly not supported by changes in the direction of renewable energy development because the energy sector and the existing

infrastructure adapt to changes very slowly. This, in turn, makes their effects visible in a very distant perspective.

High volatility means high risk, which also discourages investors and consumers from using renewable energy.

The obtained results can be used to improve energy policy planning in the Visegrad Group countries and other developing economies that have problems with implementing the green transformation. According to research studies and their synthesis, the effectiveness of energy transformation can be enhanced by three circumstances. The first is to reduce the energy intensity of the economy. The second one refers to the use of nuclear energy, which also allows for maximizing energy security. The third is to consistently maximize the share of all possible renewable energy sources.

The planning process should also include an assessment of the possibilities of obtaining renewable energy from individual sources, from a supply and demand perspective. This would allow us to identify renewable energy sources with the greatest development potential. Meanwhile, the experiences of these and many other countries indicate rather intuitive or political motives for making decisions about support for individual (selected) renewable sources.

6. Conclusions

The considerations presented in this article on the 58-year-old resource transformation in the Visegrad Group countries allow us to formulate the following partial conclusions:

- The use of primary energy per capita in the studied countries in the years 1965–2022 changed in similar directions, which proves the strong economic and cyclical economic connections of the region;
- In 1965, all energy balances were dominated by coal, supplemented mainly by gas and oil;
- From 1965 to 2022, the studied countries underwent a transformation of energy resources, which took place in different directions and with different climatic effectiveness;
- Hungary and the Czech Republic systematically and quite efficiently abandoned the use of coal and other non-renewable raw materials; in Slovakia and Poland, this process was much slower;
- All countries managed to increase the use of renewable energy sources;
- Hungary, the Czech Republic, and Slovakia have also taken advantage of zero-emission nuclear resources;
- The highest climate effectiveness expressed in increasing the use of zero-emission resources and reducing CO_2 emission per capita was achieved by Hungary, so its transformation strategy turned out to be the best.

The above observations can certainly be generalized by saying that an effective resource transformation aimed at a zero-emission economy is possible even in emerging and developing economies, although it undoubtedly requires time and consistency in the implementation of the once-chosen energy policy. Hungary—a leader in assessed climate effectiveness—has systematically decarbonized while reducing the use of total non-renewable resources. The Hungarian resource transition strategy assumed the use of nuclear energy and an increase in the share of renewable resources. The result of these activities is a quite diversified energy mix, greater resource self-sufficiency, and low carbon dioxide emissions. The Czech Republic also achieved a similar strategy and results.

Poland and Slovakia coped much worse with the climate challenge. Although they gave up coal, they replaced it largely with other non-renewable resources. It is worth emphasizing that Poland has managed to significantly increase the use of renewable resources, and nuclear energy and hydropower have also appeared in the Slovak mix.

The main limitation of the presented research is the narrowing of the analysis area to the V4 countries. Another drawback is the simplicity of the research methods used. Nevertheless, the approach used is very clear and enables replication of studies and

comparative analyses in other regions. It can also be easily used in the process of creating energy policies and benchmarking by decision-makers at various levels.

The resource and environmental analyses presented in this article would be worth enriching in the future with economic and social threads related to the resource transformation. A cost–benefit analysis could be used in this regard, which would broaden the context of the considerations. It would also be worth analyzing further directions and possibilities of resource transformation as well as barriers related to this process.

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