UNIVERSITY OF PECS

Faculty of Sciences

Doctoral School of Earth Sciences

ON THE PATH TO A SUSTAINABLE ENERGY TRANSITION

THE ENERGY TRILEMMA IN THE PERSPECTIVE OF THE EU ELECTRICITY MARKET

SUMMARY BOOKLET OF PHD DISSERTATION

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„Energy and geopolitics are very interconnected, but in a world that is becoming more fragmented, the need for a framework to serve as a roadmap to better outcomes in a future disrupted by energy transition and a difficult and rocky globalization is critical."

- Daniel Yergin, author of The New Map: Energy, Climate, and the Clash of Nations

I. Introduction

Throughout human history, the way energy is produced, transformed and used has been a critical factor in the progress, development and sometimes decline of society. As the Czech-Canadian Professor Vaclav Smil points out in his book, the last 300 years have seen some of the most amazing advances in human existence, and almost all of these advances can be directly attributed to the exploitation of the potential of new forms of energy. The various forms of energy and the solutions that humanity has harnessed have influenced social and economic structures, technological developments, supply chains, settlement patterns, and have redrawn the geopolitical map of the world in countless ways.

The quote above contains similar considerations from a different perspective. It brings up the phenomena of energy, geopolitics, interconnectedness and fragmentation, forward planning, energy transition and globalization, and the establishment of a particular framework that interacts with all these elements. This is one of the greatest challenges of our time, as this framework also provides the arena for dynamically changing global and regional political games.

In this playing field, the issue of sustainability is becoming increasingly important. As Caradonna points out, the histories of sustainability and the environment share some common ground, but the history of sustainability is as much a social, political and economic history as it is an environmental history. It is, as the concept will unfold later, a general objective to ensure that the needs of the present are met without compromising the ability of future generations to meet their own needs. This implies explicitly that geopolitical struggles throughout history have often been over resources, the regional distribution of which has largely determined the opportunities and constraints for a given country.

In all cases and ultimately, these opportunities and constraints mean access to the exploitation of natural resources, i.e. energy. However, it is not always the same where that primary energy comes from, how it is converted into useful energy and when and how it reaches the consumer. Answering this question requires an integrated systems approach. From the user's point of view, the answer is very simple: *instant, available everywhere and at all times, and affordable*. However, this perspective is necessary but not sufficient in the context of sustainability, which the world has only really woken up to in the last few decades. The growing importance of taking account of the natural and environmental aspects is therefore the basis for sustainability, and a quasi-essential condition for it.

Sustainability in the energy context is based on sustainable energy transition. Although the restructuring of energy systems based on previously dominant energy sources has taken place many times in history, the success of the energy transition of our time is the most critical for humanity. It is not its economic and social aspects that are of primary importance, but its role in environmental sustainability. There are also positive socio-economic and security of supply benefits from the uptake of renewables, ranging from the development of commercial electricity prices, through health benefits, to the possibility of energy independence and system stability.

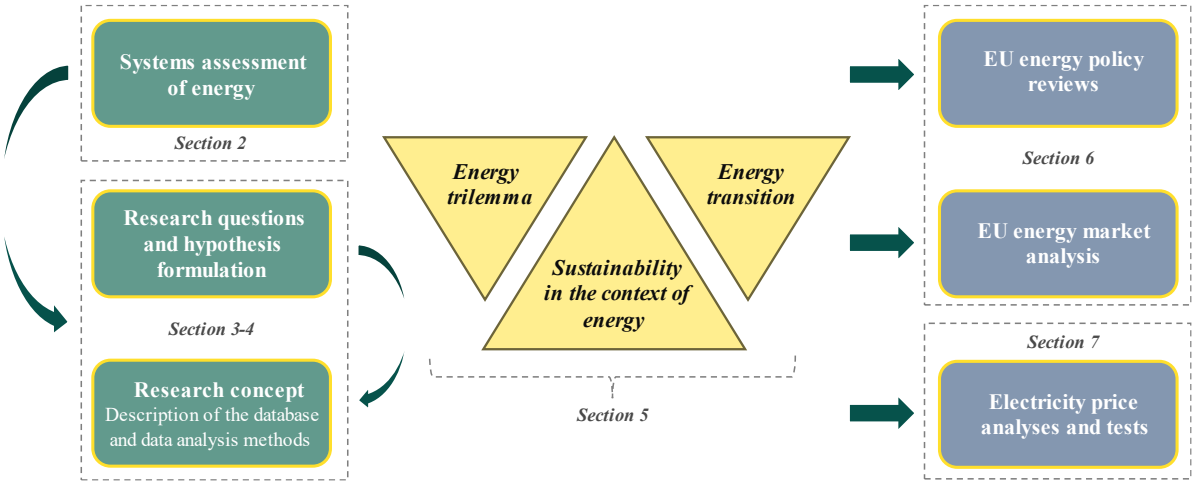
This energy transition, which is essentially a shift from fossil fuels to clean and renewable energy sources, will be crucial for the viability of our planet for future generations. Society cannot really have a more important objective.

However, energy transition alone is not enough to achieve sustainable energy use. The key lies in the qualitative indicator - a more complex and comprehensive approach is needed to address the sustainability issue. What is good for the environment will not necessarily be good for society and the economy. We don't want hydrocarbons, but we want everything they can create. We often solve one problem while generating three others. You cannot do without certain aspects in the long term, because then it will be at the expense of the primary objective. Therefore, the importance of a systemic approach comes up again in this energy perspective.

It is undeniable that the sustainable energy transition has become one of the most important global tasks, challenges and opportunities of our time. It is therefore no coincidence that sustainable energy transition has now become one of the EU's key objectives. Nothing is better proof of this than the energy policy and strategy orientations and decisions of the last decades, which have been shaped not only by internal institutional changes but also by inevitable changes caused by external events. In the latter respect, it is not necessary to go back very far, since we are currently living under the impact of such a geopolitical conflict. The COVID-19 pandemic that erupted at the end of 2019, which set the stage for the energy crisis that will begin in 2021, has brought unprecedented, record high electricity and gas prices to people around the world, leaving a wide swath of society vulnerable to energy poverty. This energy crisis has been exacerbated by the outbreak of the Russia-Ukraine war in early 2022. This has had geopolitical and economic consequences to which, among other things, energy policy has had to respond. But have these crises influenced the priority given to sustainable energy transition by strengthening the security of supply aspect? Will policy makers succeed in finding a direction for energy policy that is acceptable from all points of view, while the world's tendency to fragmentation is only increasing? Will policymakers succeed in finding a direction for energy policy that is acceptable from all points of view, while the world's tendency towards fragmentation is only increasing? Will the framework mentioned at the beginning of this introduction provide the right response to the constraints of the energy crisis? Where and on what (if any) compromises will have to be made? These and many other similar thought-provoking questions have arisen since the start of my research, some of which I will try to answer, from a certain perspective and within a certain framework, beyond the scope of this doctoral thesis.

Consequently, like the research field, the structure of my thesis requires a systems approach (*Figure 1*).

Figure 1. Conceptual framework of my research and structure of the thesis



Source: Own creation

II. Research objectives, questions and hypotheses

The three main objectives of the research are:

Research goal (RG1): To map the interrelationship between sustainable energy management, the energy crisis and the energy transition, the evolution of their concepts and their measurement possibilities.

The topic is complex, requiring primarily a historical and literature review to explore the basic principles and definitions, the interrelationships, the different approaches and their evolution in space and time to the extent and depth necessary to fulfil the objective. Various international organizational reports, documents, descriptions and other literature collections will help me in this. My aim is not merely to collect the relevant literature, but to organize it, examine the underlying assumptions and, after critical analysis and synthesis, draw conclusions by drawing a conceptual map of the concepts, findings and interrelationships related to sustainable energy management.

Research goal (CK2): Review and evaluate the energy strategy and policy of the European Union as a whole over the past decades, mainly in the context of the electricity market, in the framework of the previous point.

This understanding of energy sustainability will provide a framework to identify and analyze the EU's energy policy and strategy over the past decades, with a focus on promoting energy transition. For this purpose, EU legislation, regulations and other documents are my primary sources for energy policy, while the related energy market dynamics are provided by situation and trend

analysis based on data from various statistical databases. It is particularly important to analyze the impact of recent multicrises on energy markets.

Research goal (RG3): Finally, my aim is to empirically support the energy market effects of all these historical and regulatory insights using descriptive and inferential statistical methods.

It is also important to investigate the theoretical aspects from a practical point of view, which implies the application of various statistical procedures, as my research topic implies. This will make the historical and legal overview more comprehensible and tangible if related quantitative characteristics are also presented in an analytical or graphical way. However, the scope is not limited in this thesis to traditional descriptive statistical analysis; my empirical research also includes the use of multivariate inferential statistical techniques to identify relationships or to allow time series analysis.

The following specific research questions and related hypotheses were formulated to address my objectives:

1. **Research question (RQ1): What is the common ground between energy crisis, energy transition and sustainable energy management?**
    - **Hypothesis (H1):** The energy trilemma concept puts equal emphasis on security of supply, energy equality and environmental sustainability.
    - **Hypothesis (H2):** Relying on the energy transition, the energy trilemma can be balanced.
2. **Research question (RQ2): Can the prioritization of a dimension of the energy crisis be paralleled with different EU energy policy decisions?**
    - **Hypothesis (H3):** The main focus of EU energy policy orientations in the years 1951-2021 has shifted from security of energy supply to competitiveness and then to environmental considerations.
3. **Research question (RQ3): To what extent do the EU's long-term climate neutrality objectives override the short- and medium-term challenges of security of supply? Or, to turn the question around, is the need for energy security a challenge to the pursuit of carbon neutrality?**
    - **Hypothesis (H4):** Recent geopolitical tensions have completely shifted the order of priorities, pushing the importance of energy transition into the background.
4. **Research question (RQ4): Which energy commodity market prices and other factors have a statistically significant impact on wholesale electricity price developments when the effects of multicrises are taken into account?**
    - **Hypothesis (H5):** In all cases, the share of renewables in electricity generation shows a strong and opposite significant relationship with wholesale electricity prices.
    - **Hypothesis (H6):** Wholesale electricity prices are expected to decrease less in a period of multicrises if the share of electricity generated from renewables

increases by one unit ceteris paribus compared to the period before the onset of multicrises, while the opposite is true for the behavior of natural gas prices.

5. **Research question (RQ5): Have the predictive capabilities of various traditional statistical models been weakened by the energy crisis?**
    - **Hypothesis (H7):** Statistical estimates for the period of the energy crisis are less accurate than forecasts for the period before the energy crisis, but multivariate models are more accurate than their univariate counterparts for the periods before and during the energy crisis.

III. Research methods

The research objectives and the more specifically formulated research questions and hypotheses essentially determined the direction of my research, which included both exploratory and specific research elements, as well as ***qualitative*** and ***quantitative*** research depending on the specific study area/research question/hypothesis statement.

Due to the scope and depth of the research topic, it is important to first define the spatial, temporal and thematic framework of my thesis. In terms of the ***spatial specificities of my study***, it is essentially situated on two planes - global and regional (EU). Global investigations contribute primarily to the understanding of sustainability and its energy perspective, as the historical development of these concepts is not limited to specific geographical areas. In addition, some of the static and dynamic states of the energy market (e.g. distribution of natural resources, primary energy needs, status of the SDGs, renewable energy production, etc.) were also considered necessary to be presented in a global context, thus placing the EU in the context of the world's major powers. My main focus, however, is clearly on regional European, or more precisely EU, geography, energy policy choices, economic events and strategic developments. When I talk about the EU in general, I basically consider the aggregated results of the 27 EU Member States from 2020 onwards (post-Brexit), except in cases where data and information related to a particular Member State are not available or are limited (these are clearly marked in the relevant context).

In terms of the ***temporal aspect of my research***, I could say that as my analysis moves forward along the time axis from a given starting point, moving closer to recent events, the emphasis is increasingly on examining events, developments and market implications affecting the energy sector. The early 2020s, i.e. the analysis of the energy market implications of multicrises, are particularly cardinal. However, I cannot ignore the fact that there are research questions and related hypothesis statements (RQ2-H3) that require a full historical analysis and evaluation. Consequently, a comprehensive understanding of the EU energy strategy requires an account of the events of the 1900s, in addition to a numerical analysis of energy market developments from the 2000s onwards. Thus, while the presentation of the evolution of the concept of energy sustainability is not strictly speaking time-bound, the energy economic analysis aspects of the EU will focus essentially on the last two decades but will also extend back to the study of

pre-millennial events in a limited way. In most cases, the paper considers economic and political events up to the third quarter of 2023, i.e. the end of September 2023.

Finally, in addition to the spatial and temporal scope, I consider it necessary to define the ***scope of my study***. The EU energy system is a highly complex and integrated system in which the coal, oil, gas and electricity markets are separately energy markets, critical infrastructures and specific regulatory frameworks that influence the supply, demand, pricing and trade of primary and secondary energy sources within the EU. Ultimately, they are interconnected in terms of energy supply and have a dynamic impact on each other's functioning. Within the framework of this thesis, the focus will be on the EU electricity market, in which legislative changes, energy market effects, static and dynamic indicators will be discussed in detail. To this end, the physico-logical background of electricity as a secondary energy carrier and the functioning of the electricity market are also reviewed in the necessary depth in the energy overview chapter. It is important to underline that, precisely because of the complexity and interconnectedness of the energy system, the nature of other energy markets has also been touched upon and their components and indicators (e.g. the level of natural gas imports or the evolution of fossil fuel market prices) will form an integral part of the contextual exploration in the following.

All of this also outlines what is not part of this paper. It is not my aim to examine energy locally within the EU, i.e. country-specifically, to go into detail on energy market developments before the 2000s and after September 2023, or to analyze in depth the fossil fuel and nuclear fissile material markets. Furthermore, I do not intend to make subjective statements about the consequences of any EU energy policy decision; my aim is to provide an analysis based on an objective approach.

Due to the nature of the topic under study, I was able to rely mainly on ***secondary data collection***, so the data and information derived from this serve as the source of the theoretical and empirical results of my thesis. The varied and results-oriented research methodology used for my research was coupled with a variety of data and information needs:

- My research is *qualitative* in nature, directly related to energy sustainability, while indirectly related to practically all the sub-areas studied. The theoretical framework for my work was provided, among others, by the works of authors such as Daniel Yergin, Vaclav Smil, Zoltan Kaposi, Bela Munkacsy, Istvan Szilagyi, Gyorgy Vajda, who are internationally very well versed in the field of sustainable energy management / energy policy / geopolitics. Thus, a significant number of publications in scientific and professional journals, books, textbooks, monographs have helped to understand the research topic in a broader scientific and professional context. In addition, technical reports, working papers, studies, publications, analyses and recommendations, conference proceedings and conference proceedings published by governmental bodies, international institutions, research institutes and consultancy firms have helped to achieve the objectives. I would highlight the importance of the UN, IEA, IRENA, WEC, EC, Energy Institute and BP institutions and companies. Furthermore, I was able to draw from other online professional sources and press coverage during my research;
- My *quantitative* research, the other aspect of my thesis, based on numerical data, was mainly based on data collected from online and partly subscription-based international statistical databases and platforms. Among these, I would like to highlight the Eurostat,

IEA, Energy Institute and EMBER Climate databases, which have served as a high quality and reliable source of energy market data. Unfortunately, a lot of inaccurate, distorted or simply false data is nowadays published on the internet, which cannot be validated and can have a significant negative impact on the conduct of empirical research. I therefore considered it of paramount importance to exercise maximum care in the collection, preparation and use of data.

I also used ***primary data sources***, such as a review of international and national laws and regulations.

The data collection was carried out until the end of the third quarter of 2023, in line with the time horizon of the survey. The collected and prepared data were used in several ways. Firstly, I used a ***descriptive statistical methodology*** at several points, which helped me to make static and dynamic interpretations of the structure, patterns and trends of the data under study, provided a starting point for more complex analyses and served as a basic tool for visualizing the data. The other part of my quantitative research involved ***inferential statistical procedures***, including multivariate correlation and regression calculations to investigate the interrelationships of relational systems, as well as more complex time series analyses.

For the statistical analyses of my empirical research, I used Microsoft Excel, XLSTAT, a related add-on software from Lumivero, a market leader in data analysis and statistical solutions, and IBM SPSS Statistics 27.

IV. Summary of results

My first research question was **to understand the common ground between the energy crisis, energy transition and sustainable energy management**.

In general, sustainability defines the boundaries within which development can take place in a sustainable way, while the end goal is sustainability, the manifestation of which for us is, in practice, nothing more than sustainable life and well-being. Sustainability in the energy context is made up of similar elements, since sustainable energy management is the process by which we can achieve sustainable energy use. This process, which assesses the nature of processes along broad economic, social and environmental dimensions, needs a more concrete, tangible and measurable assessment system for policy makers to put into practice. This has been helped by the Energy Trilemma concept developed by the WEC, which looks at countries from the perspective of energy supply, equity and environmental sustainability. It does so with the energy transition at the centre of our energy strategy, which is generating a change in the structure and basic functioning of the energy system for the first time in history. I have formulated two hypotheses related to this research sub-theme:

H1: The energy trilemma concept puts equal emphasis on security of supply, energy equality and environmental sustainability.

In the energy trilemma concept developed by WEC, these three aspects are equally emphasized. On the one hand, this is reflected in the quantification of the Energy Trilemma Index, where each dimension represents 30-30-30% of the final index (the remaining 10% being country-

specific context). On the other hand, it was recognized early on that there is an imbalance between these three aspects for all countries. This implies a trade-off, i.e. energy policy makers have to make choices in a given country-specific context that reinforce one or two aspects against the third. The aim, in WEC's terms, is to balance the three aspects in each decision.

This therefore runs counter to sustainable energy management, which, following the principle of strong sustainability, focuses primarily on long-term environmental sustainability, whereby natural resources and ecosystems should not be fully exploited or replaced. Only if this is achieved can social and economic sustainability be achieved. So, at this theoretical level, there can be no compromise with environmental sustainability.

This means that the hypothesis is proven to be true.

H2: Relying on the energy transition, the energy trilemma can be balanced.

Already during the development of the WEC energy trilemma concept, the big question was asked: can the energy sustainability trilemma be balanced without compromise? The answer was given immediately after this question was posed, namely that, in the light of current knowledge, a perfect balance in all three dimensions is not possible. But the emphasis was already on 'current', because the energy transition of our time, which is not the first in human history, could theoretically lead to this balance. It is important to stress that meeting the energy transition is not sufficient, as a switch to clean and renewable energy sources from fossil fuels - the main objective of environmental sustainability - does not necessarily lead to a balance in the energy trilemma. No energy source can be considered fully sustainable in all respects if it is not used in the right way. Thus, in order to achieve the ultimate goal of sustainable energy use, it must also be sustainable in the overall economic-social-environmental context. Hence, a sustainable energy transition must be achieved in order to reach the long-term goal.

This means that the hypothesis is only partially proven to be true.

My second research question was to see **if the preference for a dimension of the energy crisis could be paralleled with different EU energy policy choices**.

My research has shown that it is not possible to conclude ceteris paribus that a directive or regulation or geopolitical event has had a measurable impact only in terms of supply, economic or environmental aspects. The multipolar nature of the consequences of energy policy decisions illustrates the need for a systems approach given the complexity of energy systems. Nevertheless, for decision-makers, the search for a theoretical balance in the energy crisis often implies prioritizing a dimension in the short or medium term, i.e. a decision imperative. The following hypothesis was part of my research:

H3: In the years 1951-2021, the main focus of EU energy policy has shifted from security of energy supply to competitiveness and then to environmental concerns.

While the issue of systemic and interconnectedness is indisputable, an attempt can be made to organize the major internal events of the EU and the external geopolitical and geo-economic influences on the EU's energy strategy according to which perspective was the primary focus in a given context, and what was the development of what. The emphasis is on 'focus', as willingness to change can be measured directly and indirectly in other perspectives. My analysis has led me to the conclusion that, while the issue of security of energy supply was the primary focus of all the

documents reviewed until the early 2000s, from the late 1900s to the first decade of the millennium, a reorientation of the structure of energy markets towards economic considerations was evident - while the security of supply dilemma also gained prominence from the second half of the 2000s onwards. The main indicators of this were the Russian-Ukrainian gas crises of 2006 and 2009. At the same time, and as climate conferences and sustainable development objectives gained ground globally, environmental concerns also came to the fore, and in effect shaped the EU's energy strategy for the second decade. Thus, over the entire time horizon observed, no one perspective has been completely eclipsed.

The hypothesis has thus been proven to be true.

My third and final exploratory research question asked to **what extent do the EU's long-term objectives of climate neutrality override the challenges of security of supply in the short and medium term? Or, to turn the question around, is the need for energy security a challenge to the pursuit of carbon neutrality?**

From a geostrategic point of view, the EU must constantly monitor the challenges posed by the changing global and regional markets for energy sources. The COVID-19 pandemic, the Russia-Ukraine war and the energy crisis triggered during and by these two events have caused a disruption to EU society and economy that has never been experienced before. These multicrises have also put the EU's energy policy for the past decade in a new perspective, with geopolitical tensions making it necessary to redesign the roadmap to carbon neutrality by 2050. The following hypothesis was part of my research:

H4: Recent geopolitical tensions have completely shifted the order of priorities, pushing the importance of energy transition into the background.

Multicrises in the 2020s, in particular the energy consequences of the Russia-Ukraine war, have brought the issue of security of energy supply back to the fore. The REPowerEU, which responds to the energy challenges of the Russia-Ukraine war, stipulates that the EU will not waive, modify or postpone the climate change objectives of the Green Deal. This essentially means that energy transition remains a priority, reinforcing the long-term objective of sustainable energy. In fact, it is precisely the greater investment in clean and renewable technologies that policy makers see as the solution, contributing to the building of the renewable capacity that is constantly being built, notably solar and wind. At the same time, this geopolitical conflict has profoundly reshaped the energy puzzle. The issue of security of supply has become a priority in the short and medium term, in the context of Russian aggression and the EU's dependence on gas imports, bringing energy security instruments and measures to the fore, and thus a major change in the agenda and instruments of the 2050 objective is conceivable. For example, coal-fired power plants - one of the biggest enemies of environmental sustainability - could therefore play a renewed role in security of supply until such time as gas supply diversification is resolved - or gas fired power is needed at all. So increasing energy security may temporarily come at the expense of environmental sustainability. All in all, policymakers are once again faced with the need to rethink and redefine the energy crisis so that the EU can cut off Russian gas at all costs. However, in the long term, this could also lead to an acceleration of the energy transition, which of course remains to be seen.

This means that the hypothesis has not been proven true overall.

The fourth research question related to my quantitative research was **to find out which energy commodity market prices and other factors have a statistically significant impact on the evolution of wholesale electricity prices, taking into account the effects of multicrises**.

After reviewing the functioning of the electricity market, I can conclude that there are a number of factors that influence the evolution of the wholesale electricity price, of which the demand side is directly influenced by the demand for electricity, which is determined by weather conditions (temperature), economic activity, industrial production, technological development, population size and daily habits, among others. On the supply side, the price is essentially determined by the nature of production during intermediate and peak periods. Thus, through the merit-order mechanism, the share of renewables in total production should have a significant impact on the wholesale electricity price, as well as the cost of the last marginal plant (i.e. the price of the energy carrier) that needs to be connected to fully satisfy consumer demand. Furthermore, since EU ETS EUA quota prices are closely linked to fossil fuel prices, I also consider CO_2 quota prices as one of the factors affecting the wholesale electricity price. In relation to this research sub-theme, I formulated two hypotheses:

H5: In all cases, the share of renewables in electricity generation shows a strong and opposite significant relationship with wholesale electricity prices.

Based on my quantitative analyses, the partial regression coefficient of the share of renewable electricity generation was -0.756 for the time series before the onset of the multicrises, while for the whole period under study I found a slightly lower, but also strong (-0.662) and significant relationship. Furthermore, in both cases, the 90 and 95% confidence intervals also yielded negative values, further strengthening the conclusion that the relationship between the share of renewable electricity generation and wholesale electricity prices will be negative.

This means that the hypothesis is proven to be true.

H6: Wholesale electricity prices are expected to decrease less in a period of multicrises if the electricity generation from renewables increases by one unit ceteris paribus compared to the period before the multicrises, while the opposite is true for the behavior of natural gas prices.

In the regression analysis, I conclude that the model estimates that a 1% increase in the share of renewable electricity generation from one period to the next is associated, ceteris paribus, with an average 0.95% decrease in wholesale electricity prices over the same period, before the onset of the multicrises. This increased to 0.96% for the extended time series. So there was no measurable decrease. In comparison, while for natural gas prices, a 1% increase in natural gas prices from one period to the next is estimated by the model before the onset of the multicrises to be associated with an average increase in electricity prices of around 0.19%, other things being equal, over the same period, this value has increased to 0.55% in the model for the full period considered. This implies that, ceteris paribus, a unit increase in the TTF between two consecutive periods contributed more to the change in EP over the whole period of the multicrises than it did before the multicrises.

Thus, the hypothesis was partially confirmed.

Finally, my second quantitative and fifth research question asked **whether the predictive capabilities of various traditional statistical models have been weakened by the energy crisis.**

Forecasting wholesale electricity prices is of paramount importance for the efficient functioning of energy markets, the operational efficiency of network management and the protection of consumers. However, the characteristics of the electricity market and all its drivers make medium and long-term electricity price forecasting challenging. Not to mention the examination of a period of multi-crisis, such as the recent one, which has brought new challenges and lessons for electricity price forecasting. The literature on electricity price modelling and forecasting has grown over the last decades, where the chosen price forecasting techniques may vary according to the properties of the available time series and the research objectives. For this last sub-theme of my research, the following hypothesis was proposed:

H7: Statistical estimates for the period of the energy crisis are less accurate than forecasts for the period before the crisis, but multivariate models are more accurate than their univariate counterparts for the periods before and during the energy crisis.

After evaluating all the methods used, I concluded, in the context of the methodology, the time series observed and the evaluation criteria, that the use of multivariate models generally resulted in better forecast accuracy for monthly average wholesale electricity prices, especially in volatile conditions during the energy crisis period. This suggests that in order to capture the more complex dynamics of each time series, it is worth including external regressors in the forecasting models.

The hypothesis is thus confirmed.

List of scientific journal articles published and submitted for publication in this field:

1. **HERCZEG, B.** & PINTÉR, É. (2024): A fenntartható fejlődés átfogó elemzése: Történelmi perspektívák, keretrendszerek és indexek. *Tér-Gazdaság-Ember (bírálat alatt)* [MTA IX. GJO / RTB: "B" kategória]
2. **HERCZEG, B.** & PINTÉR, É. (2024): A természeti erőforrások egyenlőtlen regionális eloszlása – Fókuszban az EU Villamosenergia-termelési lehetőségei és korlátai. *Gazdaság és Társadalom (bírálat alatt)* [MTA IX GJO/GDMB: "D" kategória]
3. **HERCZEG, B.** & PINTÉR, É. (2024): A globális éghajlatváltozás jelensége és következményei regionális és szektorális aspektusban. *Economica (bírálat alatt)*
4. **HERCZEG, B.** & PINTÉR, É. (2024): A fenntarthatóság koncepciója energetikai szemléletben – Fókuszban az energiatrilemma és -átmenet, valamint a kapcsolódó innovációs potenciál. *Vezetéstudomány / Budapest Management Review (közlésre elfogadva)*

   [MTA IX GJO/GMB: "A" kategória]
5. **HERCZEG, B.**, CSISZÁRIK-KOCSIR, Á. & PINTÉR, É. (2024): Assessing the accuracy of electricity price forecasting models before and after the impact of energy crisis using univariate and multivariate methods. *Acta Polytechnica Hungarica (közlésre elfogadva)*

   [WoS: SCIE; SCJR: Q2]

6. **HERCZEG, B**. & PINTÉR, É. (2024): Energiapiaci trendek a közelmúltbeli események tükrében. Fókuszban a villamos energia és a megújulók. *Jelenkori társadalmi és gazdasági folyamatok (közlésre elfogadva)*

   [MTA IX GJO/DOÁB: "D" kategória]

7. **HERCZEG, B.** & PINTÉR, É. (2024): The Nexus between Wholesale Electricity Prices and the Share of Electricity Production from Renewables: An Analysis with and without the Impact of Time of Distress. *Energies* 17(4): 857, pp. 1–25. https://doi.org/10.3390/en17040857

   [WoS: SCIE; SCJR: Q1]

8. **HERCZEG, B.**, PINTÉR, É. & Bagó, P. (2023): How green and digital transformation shapes industries: Twin transition to a green and digital future. *Vezetéstudomány / Budapest Management Review* 54(5), pp. 51–63. https://doi.org/10.14267/VEZTUD.2023.05.05
   [MTA IX GJO/GDMB: "A" kategória]

List of conference proceedings published in this field:

1. **HERCZEG, B.** & PINTÉR, É. (2024*):* Energy Trilemma and the EU's Energy Economy: Empirical Evidence of Moving Toward the Sustainable Energy Transition. *10th International Scientific Conference on Knowledge Based Sustainable Development* (ERAZ 2024 conference, 6 June 2024, Lisbon, Portugal). ISBN 978-86-80194-85-1
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