ANDRIUS ZUOZA

EVALUATION OF INDUSTRY COMPETITIVENESS DIMENSION OF ENERGY EFFICIENCY

SUMMARY OF DOCTORAL DISSERTATION

SOCIAL SCIENCES, ECONOMICS (S 004)

Kaunas
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KAUNAS UNIVERSITY OF TECHNOLOGY
KLAIPEDA UNIVERSITY
LITHUANIAN ENERGY INSTITUTE

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INTRODUCTION

Relevance of the topic

Setting ambitious environmental targets has been a trademark of the European Union (EU) policy for several decades. The EU's Framework Strategy for a Resilient Energy Union and a Forward-Looking Climate Change Policy (2015) simultaneously pursues three very different objectives: (1) a significant reduction of greenhouse gas emissions in the EU by 2030; (2) sustainable economic development; and (3) affordable energy prices for consumers. The EU Energy Efficiency Directive (2018) sets even more ambitious energy efficiency targets. The Directive highlights the importance of energy efficiency for EU Member States' energy security, public health and environmental protection. The European Commission, aware of the challenges faced by energy-intensive industries, is focusing on energy efficiency in its Communication "Clean Energy for All Europeans" (2019a) and proposes energy efficiency improvements as one of the critical measures. In 2019, the European Commission set out an even more ambitious vision in its long-term strategy "European Green Deal" aiming for European Union to become climate-neutral by 2050. It also aims to decouple the EU's economic growth from the use of energy resources and to transform the economy towards zero net greenhouse gas emissions. To realise this vision and maintain the EU industry's competitiveness, improving energy efficiency must become a priority for industrial policy in every EU Member State. To make this vision a reality, among other instruments, the EU plans to invest in environmentally friendly technologies, support innovative industry, reduce the energy sector's dependence on fossil fuels and improve energy efficiency.

The relationship between energy efficiency, climate change mitigation policies, and competitiveness is complex and multi-layered. As Garnier (2014) notes, the concept of energy efficiency is very intuitive, however, it is not easy to define it clearly. It is often much easier to describe increases or decreases in energy efficiency than energy efficiency itself. Lovins (2018) defines energy efficiency as "the lunch you are paid to eat". Hasanuzzaman and Rahim (2020), referring to the International Energy Agency (IEA), argue that energy efficiency can be seen as a different energy resource that all countries have. In contrast, the IEA considers energy efficiency the cheapest energy source, as it does not need to be produced. On the other hand, the energy saved is comparable to the energy produced, therefore, energy efficiency is considered worldwide as the most cost-effective means of simultaneously reducing greenhouse gas emissions and the cost of production (IEA, 2020d). Meanwhile, Baublys et al. (2015), analysing energy consumption trends in the EU and Lithuania and the energy policies of NATO countries, argue that exploiting the available energy-saving potential increases a country's energy security and reduces greenhouse gas and other emissions.

As noted by Kušic and Grupe (2004), there is a general consensus in the academic literature that a firm is competitive when it can offer a higher quality product (or service) at lower production costs than its competitors and, at the expense of its competitors, to increase its market share or earn higher profits than its competitors. Reiljan et al. (2003) claim that the competitiveness of an industry is directly derived from and dependent on the competitiveness of the firms operating in that industry. The determinants of industry competitiveness are similar to the determinants of the competitiveness of a firm. Meanwhile, the actual competitiveness of industrial and manufacturing firms is reflected by the share of exported products (Pilinkienė, 2014), the change in exports and market share (Balkyte & Tvaronavičiene, 2010; Bruneckienė & Paltanavičienė, 2012), industry productivity and operating costs (Meiliene & Snieška, 2010), and influenced by the firm's ability to create long-term added value (Safdar, 2016, etc.). A comprehensive study commissioned by the German Ministry of Economic Affairs and Energy (Grave et al., 2015) has shown that low electricity costs are a critical component of the competitiveness of energy-intensive industries. Studies of small and medium-sized businesses have found (Cagno & Trianni, 2012; Locmelis et al., 2020; Paramonova & Thollander, 2016; Thollander et al., 2007, etc.) that the most significant potential for energy efficiency improvements is found in auxiliary processes, not in production processes.

With forecasts of continuing energy demand in the industry (IEA, 2020e) and increasing environmental requirements (European Commission, 2019b), investments in energy efficiency are inevitable to maintain competitive advantages. And the primary motivation for energy efficiency investments is to reduce the cost of energy consumption (IEA, 2014).

The domestic industry plays a crucial role in reducing greenhouse gas emissions (K. M. Smith et al., 2021). As some researchers have noted, strong climate policies can influence business decisions. There is a consensus in the academic literature that taxing greenhouse gas emissions is one of the most effective ways to achieve mitigation goals (Markard & Rosenbloom, 2020). It is generally agreed that taxing greenhouse gas emissions increases the cost of goods and services produced by firms and can significantly affect competitiveness (Holmes et al., 2011; Ismer & Neuhoff, 2007). This view is also supported by Rivers (2010), who argues that market-based carbon policies in a regulated region can reduce the competitiveness of energy-intensive industries. Some researchers have argued on the basis of classical economic theory that firms will be able to pass on the increased costs of goods and services to customers and that emissions taxation will not affect firms' net profits (Smale et al., 2006). However, this is only the case if all countries have the same environmental requirements. As Rivers (2010) notes, with widely differing legal requirements for greenhouse gas emissions between countries, industries may decide to relocate to a less stringent country to avoid strict requirements. This can lead to a reduction in employment and the value of industrial output in a country, and a reduction in the effectiveness of the environmental policy. This process is referred to in the scientific literature as 'leakage'. Fisher and Fox (2012) concluded that adjusting customs duties and establishing a volume-based emissions system are the most effective measures to combat emissions leakage and competitiveness losses. As Felder and Rutherford (1993) noted that in countries with strong environmental policies the demand for fossil fuels should decrease, which should reduce their price. However, in countries with less stringent environmental policies, the fall in the price of fossil fuels should encourage additional consumption. As a result, global greenhouse gas emissions should not decrease overall and the effectiveness of environmental policies will be reduced. As Rivers (2010) mentions, if countries perceive that stringent environmental policies reduce their international competitiveness, they will avoid such commitments. This further underlines the importance of a common international environmental policy.

The relationship between environmental policy and competitiveness at the macro level has been examined using both econometric (Convery, Ellerman, & de Perthuis, 2008; Tobey, 2001) and modelling (Babiker & Rutherford, 2005) approaches. Babiker (2005) concluded, on the basis of empirical modelling results, that in energy-intensive industries with homogeneous output and Kyoto compliance, firms' competitiveness can be reduced by 75% compared to countries that have not ratified the Kyoto Protocol. Fisher and Fox (2012) used a partial equilibrium model to investigate the Canadian energy-intensive products industry and found that at a low CO2 price (USD 14 per tonne of CO2 emissions), the industry would experience a reduction in output of between 2 and 8% per year. Demailly and Quirion (2008), using a similar methodology, also concluded that a low CO2 price (EUR 20 per tonne of CO2 emissions) would not affect the international competitiveness of the European iron and steel industry. In the EU, one of the main instruments of climate change mitigation policy is the EU Emissions Trading Scheme. Thema et al. (2013) consider the ETS to be one of the best climate change policy instruments currently in use.

In the context of the complex interrelationship between energy efficiency, environmental protection and industrial competitiveness, the question arises as to whether the competitiveness of energy-intensive industries in the context of European countries can be reasonably assessed and compared.

Scientific problem and its investigation level

Competitiveness research has received considerable attention in the literature (Katane & Kristovska, 2015; Krugman, 1996; Kušić & Grupe, 2004; Matuzevičiūtė et al., 2015; McFetridge, 1995; Porter, 1990; Snieška & Bruneckienė, 2009; Wignaraja & Joiner, 2004; etc.); nonetheless, there is a consensus that the most important tool for improving a country's competitiveness is a comprehensive assessment of the competitiveness factors of a country's industry and the development of measures to promote these factors. It also makes no sense to analyse a country's competitiveness solely through the prism of economic indicators, but rather to include social, political, energy, environmental, cultural and other dimensions in the analysis. The competitiveness of various industries has been analysed by both Lithuanian and foreign authors (Balzaravičienė & Pilinkienė, 2012; Bhawsar & Chattopadhyay, 2018; Buturac et al., 2019; Fetscherin et al., 2010; Głód & Flak, 2017; Grebliauskas & Stonys, 2012; Kaušylienė et al., 2013; Meilienė & Snieška, 2010; Pilinkienė, 2014; Stankevičiūtė & Čiarnienė, 2015; etc.).

The analysis of scientific works on competitiveness has revealed that the assessment of competitiveness is a multifaceted, complex process, requiring an appropriate assessment methodology and a system of indicators. Different researchers (Bruneckienė & Paltanavičienė, 2012; Elenurm, 2007; Hiziroglu et al., 2013; Krugman, 1994, 1996; Seyoum, 2007) propose various methods of assessing the competitiveness of a country or region, and, as Rugman et al. (2012) claim, analogous methods can also be used to assess both firm and industry competitiveness. No single assessment method is considered to be absolutely accurate, and the results of assessments based on different methods do not overlap, all methodologies rather seek to assess the relative position of the object under study in relation to other objects at the same level (Bruneckienė, 2010; Grebliauskas & Stonys, 2012; Meiliene & Snieška, 2010; Staskevičiūtė & Tamošiūnienė, 2010). The competitiveness of a lower-level object is not comparable to the competitiveness of a higher-level object, rather the competitiveness of a lower-level object affects the competitiveness of a higher-level object (Collatto, Dresch, & Pacheco Lacerda, 2018).

Energy efficiency has been studied in the academic literature from different perspectives: the concept of energy efficiency (Garnier, 2014; Hasanuzzaman & Rahim, 2020), the relationship between energy efficiency and the political system (Lu et al., 2021; Yao et al, 2021), changes in energy consumption and efficiency (IEA, 2017, 2019, 2020b), energy management (Thollander & Ottosson, 2010), energy prices and efficiency (Birol & Keppler, 2000; Chai et al., 2009; Fisher-Vanden et al., 2004); Sue Wing, 2008; etc.) industrial structure (Al-Mansour, 2011; Bhadbhade et al., 2020), technology (Doms & Dunne, 1995; Fei & Lin, 2016; Golder, 2011; Huang et al., 2017), and others. Energy efficiency and energy security are separate groups of studies (Baublys, Miškinis, Konstantinavičiūtė, & Lekavičius, 2015; Bazilian et al., 2013). When analysing companies' investments in energy efficiency, it has been observed that there is a discrepancy between the theoretically possible and practically achieved investment effects, which is why energy efficiency barriers have been extensively addressed in the scientific literature (Apeaning & Thollander, 2013; Cagno et al., 2017; Cagno et al., 2013; Rohdin & Thollander, 2006; Sorrell, 2004).

The importance of energy efficiency is highlighted in various legal documents of the European Commission (European Commission, 2012, 2014, 2019a, 2019b; European Parliament & Council of the European Union, 2018, etc.) and of Lithuania (Seimas of the Republic of Lithuania, 2002a, 2002b, 2016; Government of the Republic of Lithuania, 2018, etc.).

The relationship between economic development and energy efficiency has been studied by a number of foreign researchers (Al-Mansour, 2011; Aramendia et al., 2021; Asafu-Adjaye, 2000; Bastos et al., 2014; Bhadbhade et al., 2020; Brown, 2001; Chai et al., 2009; Cornillie & Fankhauser, 2004; Fisher-Vanden et al, 2004; Neuhoff et al., 2014; Semieniuk et al., 2021; Shen & Lin, 2021; etc.) and Lithuanian (Baležentis et al., 2021; Malinauskaitė et al., 2020; Štreimikienė, 2020; etc.).

Research on energy efficiency, climate change mitigation policies and competitiveness has also received considerable attention (Gielen et al., 2019; Howells et al., 2013; Ismer & Neuhoff, 2007; Kemfert, 2020; Markard & Rosenbloom, 2020; Schmitt, 2017, etc.). The prevailing view in the academic literature is that it is not a single climate policy instrument, but rather a set of instruments and a level playing field across many countries that maintain the integrity of climate policy, guarantee the best efficiency of climate policy and do not distort competitive conditions. The use of renewable energy sources and energy efficiency are also considered to be the most important mitigation measures in industry. When comparing these two measures, energy efficiency improvements are more advantageous as they not only reduce GHG emissions but are also one of the cornerstones of maintaining the long-term competitiveness of industry (Andrei et al., 2021; Štreimikienė, 2020).

In summary, competitiveness has been addressed quite extensively in the scientific literature, and energy efficiency has also been addressed in various dimensions, however, there is a lack of an integrated methodology for assessing industrial competitiveness from the perspective of energy efficiency, which would allow for the assessment and comparison of the competitiveness of energy-intensive industries in different countries.

Scientific problem - How to assess the industry's competitiveness in terms of energy efficiency.

Scientific research object – Competitiveness of energy-intensive industries in terms of energy efficiency.

The purpose of the scientific research is to develop a conceptual model for assessing industrial competitiveness, including the components of energy efficiency and climate change mitigation; based on the conceptual model, create an energy efficiency index for assessing industrial competitiveness and apply it empirically in energy-intensive industries.

Objectives:

1. to clarify the concept of industrial competitiveness in the context of energy efficiency, highlighting the interrelationship between energy efficiency and the components of industrial competitiveness;
2. to analyse the methodologies for measuring energy efficiency and industrial competitiveness;
3. to develop a conceptual model for the assessment of industrial competitiveness from the perspective of energy efficiency;
4. to develop a methodology of industrial competitiveness index from an energy efficiency perspective;
5. to empirically apply the industrial competitiveness index from an energy efficiency perspective in energy-intensive industries.

Research methods

- Analysis, systematisation and summarisation of various information sources and documents, scientific articles by foreign and Lithuanian researchers, their research results and monographs in Lithuanian, English, and German;
- Correlation, regression and cluster analysis methods were used to examine unbalanced panel data. These methods were used to assess changes in the competitiveness of the industry in terms of energy efficiency and to highlight key trends and relationships. The structural decomposition analysis method and the fixed market shares analysis method made it possible to decompose the energy intensity of industry and the change in industrial exports into their constituent parts and to use them in the competitiveness assessment. The two-factor analysis of variance approach is used to test the hypotheses about differences in competitiveness across industries. The method of analysis of variance allowed to assess the sensitivity of the constructed index of industrial competitiveness in terms of energy consumption to changes in its components;
- Mathematical, cluster and systematic analysis of the results of the empirical study was carried out using MS Excel and R software tools.

The scientific novelty of the research:

- The dissertation refines the concepts, drivers, barriers and measurement methods of industry competitiveness and energy efficiency. The dissertation presents an approach to the impact of energy efficiency and climate change mitigation policy factors on the competitiveness of energy-intensive industries.
- A conceptual model for assessing industrial competitiveness in terms of energy efficiency is developed, integrating economic, energy and environmental factors. The model is complementary to the methodologies used in practice and research to assess competitiveness. The model integrates

economic, financial, energy efficiency and greenhouse gas emission indicators for the industry as a whole.

- An index for assessing the industry competitiveness in terms of energy efficiency (hereafter also abbreviated as KEVA) has been developed. The index proposed in the dissertation allows for comparing the competitiveness of industries in different countries, monitoring changes in competitiveness over time and grouping the countries studied according to their competitiveness. The KEVA index is an equal-weighted, 14-indicator approach to assessing industrial competitiveness that is robust to changes in indicators and weights.
- The KEVA index assesses the competitiveness of four energy-intensive industries (pulp and paper product manufacturing and printing and reproduction of recorded media, chemicals and chemical products manufacturing, other non-metallic mineral products manufacturing and basic metals manufacturing) in 19 selected European countries. The methodology used to calculate the index and the indicators chosen are easily adaptable to other industries for competitiveness studies and monitoring long-term changes.
- The methodology used in the KEVA index allows the competitiveness of each industry to be assessed through the impact of exports, energy efficiency, and greenhouse gas emissions.

The Defended Statements

1. To assess the competitiveness of an industry in terms of energy efficiency, it is proposed to use the composite index consisting of 14 indicators grouped into 3 sub-indices, which allows showing differences in competitiveness between the countries.
2. The competitiveness of an industry depends on the generated value added, the industry investment, the energy costs and the greenhouse gas emissions.

Research limitations

In the opinion of the author of the dissertation, the developed competitiveness index model can better reflect the competitiveness situation of the industry if it is supplemented with some specific indicators (e.g. indirect support of countries to energy-intensive industries, hidden country-specific taxes, the amount of self-generated and consumed energy in the industry, the cost of consumed self-generated energy, also amount of industry-specific emissions, etc.). However, at the time of writing, the author was not aware of a reliable source of such information, and therefore such indicators are not analysed. The structure of the KEVA index also does not take into account the country's overall energy production and consumption structure and the share of renewable energy.

The empirical research provides a comparative assessment of the selected countries using a composite indicator. While the empirical study tracks the evolution of each country's sub-index and index scores over time, it does not assign each country's index score to a specific qualitative category (e.g., "good", "average", "bad", etc.) or the impact of the variation range in the index scores on a country's final index score.

The statistical data for the empirical study were taken from several different databases. In order to compare the statistics from the different databases, data classification matching tables were used. However, it is not possible to completely rule out the possibility of misclassification.

The dissertation was started in 2016, the empirical research was carried out in 2019-2020, and the analysis and interpretation of the results of the research in 2021. The European Commission's European Green Deal strategy, launched in mid-2019, has implications for industry across the EU. The dissertation does not address the costs of future energy efficiency investments, their potential benefits for industry and society, and the impact of these investments on competitiveness.

Structure and volume of the dissertation

The dissertation consists of 115 pages (excluding appendices), 47 figures, 13 tables and 5 annexes. 417 sources of scientific literature were used. The dissertation is structured into 3 main chapters.

The first chapter "Theoretical Analysis of the Concepts of Industrial Competitiveness and Energy Efficiency" discusses the concepts of competitiveness and energy efficiency and their relation to contemporary environmental policy. It also examines the barriers to competitiveness and energy efficiency, as well as the enabling factors. Chapter 2 "Methodology for Assessing Industrial Competitiveness in Terms of Energy Efficiency" provides a detailed analysis of the methods and measurement approaches to assessing industrial competitiveness and energy efficiency, the links between energy efficiency and energy prices, industrial structure, technological change and climate change policy. It also examines the assessment of industrial competitiveness by means of an index, the rationale for the index indicators, their transformation, weights, the calculation of the index score and the methodology for assessing the sensitivity of the results. The chapter concludes with a model of the index for assessing industrial competitiveness in terms of energy consumption. Chapter 3 "Empirical Study on the Energy Competitiveness of Industry" presents the methodology of the empirical study on the energy competitiveness of industry, which has been carried out in four energy-intensive industries (i.e. pulp and paper product manufacturing, printing and reproduction of recorded media (Divisions 17 and 18 of NACE Rev. 2); manufacture of chemicals and chemical products (Division 20 of NACE Rev. 2); manufacture of other non-metallic mineral products (Division 23 of NACE Rev. 2); and manufacture of basic metals (Division 24 of NACE Rev.

2)) in 19 European countries over the period 2009–2019. For each industry, the selected countries were assessed in the context of other countries using the KEVA index. The results of the empirical study are used as a basis for drawing conclusions.

1. THEORETICAL ANALYSIS OF INDUSTRIAL COMPETITIVENESS AND ENERGY EFFICIENCY CONCEPTS

1.1. The concept and levels of competitiveness

The concept of competitiveness is intensively analysed as well as in scientific literature, in journalism as strategic planning documents of national importance in Lithuania (Beniušienė & Svirskienė, 2008; Bruneckienė, 2010; Matuzevičiūtė et al., 2015; Meilienė & Snieška, 2010; Pilinkienė, 2014; Stankevičiūtė & Čiarnienė, 2015) and abroad (Krugman, 1996; Porter, 1990; Rugman & D'cruz, 1993; Safdar, 2016; Schwab, 2019; Wignaraja & Joiner, 2004; etc.). Depending on the context, the term competitiveness has a variety of meanings, however, there is no consensus or universally accepted definition (Mulatu, 2016). The most general meaning of the term is to be better than others in certain, comparative parameters (Bhawsar & Chattopadhyay, 2018).

Porter (1990) can be considered a pioneer of the modern concept of competitiveness. As Porter (1996) observes, the concept of competitiveness refers to the behaviour of market participants, market efficiency, economic efficiency and behavioural antecedents, and he defined competitive advantage as "the ability of a country to create an environment that allows firms to develop and innovate faster than foreign competitors". Meanwhile, Beniušienė & Svirskienė (2008) observe that competitiveness is a complex, cross-cutting category, rather than a one-off state or situation that is easy to categorise or measure. The definition of competitiveness also depends on its level of aggregation (Gries & Hentschel, 1994). Meanwhile, Travkina & Tvaronavičienė (2010), summarising research by a number of authors, argue that competitiveness can be analysed at levels (micro, meso, macro), domains (economy, politics, society and technology) and time perspectives (medium or long term). It is important to stress that comparisons can only be made within the same levels of competitiveness.

Industry competitiveness. In modern language, the term 'industry' is also used in the context of other economic activities or sectors, however, in this paper, the traditional definition of an industry is used to define an industry. The definition of industry competitiveness used in this dissertation is defined as the ability of a country's industrial enterprises to profitably sell, increase and maintain sales of their sustainably produced products in domestic and export markets. It can be observed that lower-level (e.g. firm) competitiveness leads to higher-level (e.g. industry) competitiveness and that industrial competitiveness significantly influences and underpins the competitiveness of a country (Bosma et al., 2020).

1.2. The concept of energy efficiency

As Garnier (2014) notes, the concept of energy efficiency is intuitive, yet clearly defining the definition is very difficult. It is often easier to describe an increase or decrease in energy efficiency than energy efficiency itself. The US

Energy Administration defines energy efficiency in one of two ways: from a service perspective or a mechanistic perspective. Meanwhile, the International Energy Agency (Garnier, 2014) defines energy efficiency in its publications as "using less energy to provide the same service". European Union legal documents define energy efficiency as "the ratio of energy produced to the energy consumed in terms of work, services, goods or energy produced" (European Commission, 2012).

Hasanuzzaman and Rahim (2020) define energy efficiency as the fraction of the total energy fed into a system that is used for useful work, rather than wasted as useless heat or otherwise. They also state that energy efficiency measures the energy consumption of a system in achieving a desired level of performance. Hasanuzzaman and Rahim (2020), referring to the IEA, argue that energy efficiency can be considered a distinct energy resource. Energy efficiency is the cheapest source of energy because it does not require energy production in the first place, and it is the only source of energy available to all countries in the world. As the IEA (2020d) notes, the energy saved is comparable to the energy produced, therefore, energy efficiency is considered worldwide to be the most cost-effective means of delivering energy sustainably while reducing greenhouse gas emissions.

In the context of this paper, energy efficiency is understood as the ratio of energy consumed to the value added of produced goods, services or labour. Energy efficiency is often expressed in terms of energy intensity.

1.3. Energy transition, climate change and competitiveness

Kemfert (2020) argues that research over the last 40 years has demonstrated the link between human economic activity and climate change. He argues that in order to mitigate the effects of climate change while maintaining current levels of prosperity, countries' energy and transport systems need to be restructured. According to the IEA, between 1990 and 2017, the industrial sector globally consumed around 30% of all energy resources (IEA, 2019). The transport sector accounts for a similar share (around 30%), while business and public services consume around 20% of total energy resources.

As noted by Štreimikienė (2020), the most important climate change mitigation measures in the industry are the use of renewable energy sources and energy efficiency improvements. When comparing these two measures, energy efficiency improvements are more advantageous as they not only reduce greenhouse gas emissions but also save money (Štreimikienė, 2020).

The relationship between climate change mitigation policies and competitiveness is complex and multi-layered. Increasing energy demand and production by the population and industry has a direct impact on greenhouse gas emissions. A large number of researchers now believe that mitigation of climate change is not possible without reducing greenhouse gas emissions (Gielen et al., 2019; Howells et al., 2013; etc.). As some researchers have noted, strong climate policies can influence business decisions in several ways.

As Gielen et al. (2019) explain, a shift towards less polluting technologies creates conditions for economic and employment growth. In addition to contributing to climate change mitigation, a shift to less polluting technologies will generate an additional USD 52 trillion of GDP globally by 2050.

There is a consensus in the scientific literature that taxing greenhouse gas emissions is one of the most effective ways to achieve mitigation targets (Markard & Rosenbloom, 2020). It is generally agreed that taxing greenhouse gas emissions increases the cost of goods and services produced by businesses and can significantly affect competitiveness (Holmes et al., 2011; Ismer & Neuhoff, 2007). This view is also supported by Rivers (2010), who argues that market-based carbon policies in a regulated region can reduce the competitiveness of energy-intensive industries. Some researchers have argued, based on classical economic theory, that firms will be able to pass on the increased costs of goods and services to customers and that emissions taxation will not affect firms' net profits (Smale et al., 2006). However, this is only the case if all countries have the same environmental requirements. As Rivers (2010) notes, with widely differing legal requirements for greenhouse gas emissions between countries, industries may decide to relocate to a less stringent country to avoid stringent requirements. This can result in lower employment and lower value of industrial output in the country and reduce the effectiveness of climate policy. Fisher and Fox (2012) concluded that adjusting customs duties and establishing a volume-based emissions system are the most effective means of combating emissions leakage and competitiveness losses. As Rivers (2010) mentions, if countries perceive that aggressive environmental policies reduce their international competitiveness, they will avoid committing to strong climate policies.

A range of climate policy measures has been proposed in the academic literature to reduce emissions leakage, ranging from international convergence of minimum environmental standards to various tax concessions to investments in environmental or energy efficiency technologies. However, as Rivers (2010) and Markard, with Rosenbloom (2020) note, it is not a single climate policy instrument, but rather a mix of instruments and a level playing field across countries that maintain the integrity of climate policy and ensures that it is most effective.

1.4. Energy efficiency and the EU Emissions Trading Scheme

The EU's main instrument for climate change mitigation policy is the EU Emissions Trading Scheme (hereafter also EU ETS). The main objective of the scheme is to reduce greenhouse gas (GHG) emissions. As noted by Thema et al. (2013), the scheme is one of the best climate change policy instruments. Theoretically, in a competitive market, the free allowances provided by the EU

ETS are allocated efficiently and emission reductions are made at the least cost (Fritsch, 2018; Perman et al., 2003). The EU ETS also plays a key role in indirectly encouraging energy efficiency investments by industry (Cowart, 2011). The EU ETS is not only available in the EU Member States but also in the UK, Iceland, Norway, and Liechtenstein. Similar emissions trading schemes also exist globally – in Switzerland, Australia, New Zealand, China, Kazakhstan, and regional emissions trading schemes in Canada and the US (Schmitt, 2017).

The idea behind the EU ETS is that the number of allowances issued to each company decreases steadily year by year. In 2013, companies were collectively allocated free of charge around 80% of their historical annual allowance demand, while in 2020 only around 30% of allowances will be allocated free of charge, and from 2027 onwards there will be no free allowances at all. Thema et al. (2013) concluded that EU ETS has the potential to reduce both industry costs and the price of emission allowances if the EU declares ambitious environmental goals. Smale et al. (2006) also point out several shortcomings of the EU ETS.

Some researchers, who have studied the impact of the EU ETS on the company's competitiveness, concluded that the high price of allowances increases the production costs and thus reduces the competitiveness. This is particularly the case when some countries participate in EU ETS or a similar system and others do not (Demailly & Quirion, 2008; Zapletal, 2021).

2. METHODOLOGY FOR ASSESSING INDUSTRIAL COMPETITIVENESS IN TERMS OF ENERGY EFFICIENCY

This chapter of the dissertation analyses the development of a conceptual model for assessing the competitiveness of an industry in terms of energy efficiency. Firstly, the interaction between energy efficiency and industry competitiveness processes, the variety of methods and indicators are analysed. After assessing the experience of competitiveness assessment in the scientific literature, the quantitative indicators of competitiveness assessment in terms of energy efficiency are selected and a conceptual model of competitiveness assessment of the industry in terms of energy efficiency is developed. The chapter concludes with a summary of the methodology for the calculation of the industrial competitiveness index for energy efficiency.

2.1. Methods for assessing industrial competitiveness

The analysis of scientific literature on competitiveness has shown that the assessment of competitiveness is a multifaceted, complex process, requiring an appropriate assessment methodology and a system of indicators. Different researchers (Bruneckienė & Paltanavičienė, 2012; Elenurm, 2007; Hiziroglu et al., 2013; Krugman, 1994, 1996; Seyoum, 2007) propose different methods of assessing the competitiveness of a country or region, and, as Rugman et al. (2012) mentioned, similar approaches can also be used to assess the competitiveness of both firms and industries. No single assessment method is considered to be absolutely accurate, and the results of assessments based on different methods do not overlap, nevertheless, all methodologies seek to assess the relative position of the object under study in comparison with other objects of the same level (Bruneckienė, 2010; Grebliauskas & Stonys, 2012; Meiliene & Snieška, 2010; etc.). The competitiveness of a lower-level object is not comparable to the competitiveness of a higher-level object, but the competitiveness of a lower-level object affects the competitiveness of a higher-level object (Collatto et al., 2018).

2.1.1. Measuring industrial competitiveness through indexes

In practice, competitiveness analysis models analyse and compare a number of competitiveness indicators and combine them into an overall competitiveness index. Index authors (Głód & Flak, 2017; Schwab, 2019; Wignaraja & Joiner, 2004) combine economic, financial, political, social and infrastructural factors, as well as the environment influencing these factors, into a homogeneous system. The index usually combines the political, social, financial and economic environments into a single entity. This chapter starts with a discussion of the indices used to study the competitiveness of a country, followed by an analysis of the indices used to assess the competitiveness of economic sectors.

The Global Competitiveness Index, the EU Regional Competitiveness Index and the World Competitiveness Yearbook are the most commonly cited country-level competitiveness indices (Balzaravičienė and Pilinkienė, 2012).

A number of indices have been used to assess the competitiveness of economic sectors, yet the most frequently mentioned in the scientific literature (Zagloel & Jandhana, 2016; Balzaravičienė & Pilinkienė, 2012) are the Competitiveness Industrial Performance Index, the Global Manufacturing Competitiveness Index or the OECD Competitiveness Indicators.

2.1.2. Measuring industrial competitiveness through indicators

As Ca'Zorzi and Schnatz (2007) point out, there is no consensus in the research community as to which single indicator can be considered the ideal indicator of competitiveness. A number of methods have been used in scientific and applied research to assess the relationship between exports and the competitiveness of a country's industries, including the following: revealed comparative advantage (RCA), relative trade balance index, net export RCA, export competitiveness index, relative export advantage (RXA), relative export prices (RXP), real effective exchange rates (REER), Grubel-Lloyd index, Hirschman-Herfindahl index, export specialisation index (ESI), trade intensity index, trade complementarity index, export diversification (concentration) index, export similarity index, constant market share analysis, etc. Kuodis points out that a country's competitiveness is defined by two indicators: the volume of exports of goods and services and the prices achieved.

The revealed comparative advantage index (RCA) is often used to assess the competitiveness of industrial exports in the academic literature (Civan & Serin, 2008; Deb & Hauk, 2017; etc.). The RCA approach was proposed by Balassa (Balassa, 1965) and despite criticism by some scientists (Hillman, 1980) and various modifications of the index (Havrila & Gunawardana, 2003; Laursen, 2015), the index proposed by Balassa is still widely used in empirical research. The index measures the export-import ratio of a country for a particular commodity group relative to the overall export-import ratio of the country. Empirical studies based on the Balassa index have noted two major shortcomings of this index: the asymmetric nature of the index (Hinloopen & Van Marrewijk, 2001) and the underestimation of the demand effect of the importing country (Fukasaku, 1992).

A number of researchers have used industry export growth rates to describe the competitiveness of industry or to incorporate this indicator into the structure of a competitiveness index (Athanasoglou et al., 2010; Ruzekova et al., 2020; etc.). Other researchers have also used the industry's export share as a proxy for industry competitiveness in their empirical studies (Fetscherin et al., 2010; Ioannidis & Schreyer, 1997).

The industry's competitive advantage is also reflected in its faster export growth rate, leading to an increase in market share compared to other industries. The constant market share analysis (CMSA) approach allows for the decomposition of industry export developments into market, product and competitiveness effects. The CMSA approach compares an industry's exports with the overall change in the world or regional exports and assumes that the volume of a country's exports relative to world exports remains constant over time (Leamer & Stern, 1970). The CMSA approach decomposes the change in a country's exports into the change in demand for the exported product, the change in demand for the export market and the change in competitiveness. The CMSA allows for the assessment of all these aspects, yet it does not show a causal relationship between them. Due to the relative ease of estimation and availability of data, the constant market share approach is popular in empirical export research (Braja & Gemzik-Salwach, 2020; Buturac et al., 2019; Cheptea, Gaulier, & Zignago, 2005; Grebliauskas & Stonys, 2012; Mauro et al., 2005; etc.). In the CMSA, the competitiveness effect is considered to capture a country's ability to increase its export market share solely as a result of competitiveness factors (Braja & Gemzik-Salwach, 2020; Buturac et al., 2019; etc.).

2.2. Energy efficiency assessment

As Tanaka (2008) points out, energy efficiency indicators need to be reliable, relevant and verifiable. Clark (2010) states that energy efficiency is a measurable quantity and depending on the characteristics of the object, can be evaluated by the observation of:

- thermodynamic indicators;
- physical indicators;
- economic indicators.

The most commonly used economic indicator to describe the energy efficiency of a given region, country or industry is energy intensity (IEA, 2020d). Energy intensity is calculated as the ratio of the amount of energy consumed to the amount of product or value added created. The International Energy Agency (IEA, 2020d) states in its publications that energy intensity and its change is one of the main long-term trend indicators of energy efficiency. A number of researchers have studied the relationship between energy intensity and economic development in different countries, industries or companies (IEA, 2014; Liu & Wang, 2015; etc.). Recent research (Magazzino, 2015, 2016; Omri et al., 2015) examining the relationship between a country's GDP and its energy consumption shows that the rate of increase in GDP is higher than the rate of increase in energy consumption. However, as Cornillie and Fankhauser (2004) point out, differences in energy intensity between countries cannot be equated with differences in energy efficiency; a country with a relatively low energy intensity does not necessarily have high energy efficiency.

Clark (2010) proposes that energy efficiency should be measured as the percentage of energy produced and consumed or work created by energy consumption. Andersson et al. (2018) propose the use of Energy Efficiency Cost Curves (EECC) to assess the potential for energy efficiency in relation to the cost of technology and energy resources.

In summary, in the scientific literature, energy intensity is often used as a proxy for energy efficiency.

2.2.1. Energy efficiency and energy prices

The price of energy is one of the main variables influencing energy demand and energy efficiency (Birol & Keppler, 2000; etc.). The relatively low cost of energy and a lack of awareness among company managers discourage energy-saving and favour cheaper but more energy-intensive production equipment. Some scientific studies have found a negative correlation between energy intensity and the energy price index (Fisher-Vanden et al., 2004; Sue Wing, 2008; etc.). Chai et al. (2009) argue that an adequate pricing system for energy resources is one of the most effective economic levers to promote energy efficiency improvements.

Riker (2012) finds that energy cost is one of the main factors influencing industrial competitiveness. Crespo et al. (2014) conclude that the increase in energy prices has a negative impact on industrial exports. Bassi et al. (2009) also find that energy prices have a significant impact on the industry's export potential. In summary, the energy price has an impact on energy consumption, energy efficiency investments and competitiveness.

2.2.2. Energy efficiency and industrial structure

Both the structure of the industry and the availability of primary energy sources influence energy efficiency. Compared to other primary energy sources, energy production from coal is one of the least efficient (IEA, 2020b). Changing the structure of a country's primary energy mix requires significant investments in time and money. The link between energy efficiency and industrial structure can be assessed using both natural and financial indicators.

Al-Mansour (2011), Bhadbhade et al. (2020) and others have used a combined energy efficiency index to investigate the relationship between energy efficiency and industrial structure.

The relationship between changes in industrial structure and energy intensity using financial indicators has been widely studied in the literature (Román-Collado & Economidou, 2021; Wang et al., 2020; etc.). There are several methods for this type of research, such as structural decomposition analysis, econometric analysis or other research methods.

The structural decomposition analysis decomposes the change in energy intensity into the industry energy intensity effect, the overall country energy intensity effect and other effects (Boyd et al., 1988; Cornillie & Fankhauser, 2004; Tan & Lin, 2018; etc.). The structural decomposition analysis decomposes both total energy consumed and total energy intensity into energy intensity in the industry, share of product generated in the industry, and the total product generated.

In summary, it is possible to use natural indicators of energy consumption, various ratios of these indicators to other indicators, financial indicators, and index decomposition techniques to monitor changes in energy efficiency in the industry.

2.2.3. Energy efficiency and technological change

Technological change is considered to be one of the main and most effective ways to increase energy efficiency and reduce energy intensity (Shen and Lin, 2021). Analysis of the literature shows that there is a significant inverse relationship between technological change and energy intensity or energy efficiency (e.g. Doms and Dunne, 1995; Fei & Lin, 2016; Golder, 2011; Huang et al., 2017). The research and development literature views technological progress as a consequence of deliberate investment in R&D (e.g. (Romer, 1990; Young, 1998; Howitt, 1999)), yet the technological change in an industry is only achieved through significant investment.

In general terms, investments in energy efficiency not only stimulate technological change but are also the cheapest way to reduce greenhouse gas emissions. This is because the savings from energy efficiency improvements largely offset the investment costs of renewable energy (Diesendorf, 2007).

2.3. Relationship between energy efficiency, climate change mitigation, and industrial competitiveness

The relationship between environmental policy and competitiveness has been explored using both econometric (Convery et al., 2008; Tobey, 2001) and modelling (Babiker & Rutherford, 2005) approaches. A review of empirical studies on the impact of environmental measures on competitiveness using econometric analysis concludes that no positive relationship has been found between climate change mitigation measures and competitiveness (Rivers, 2010). However, studies using both general and partial equilibrium models typically find a strong link between competitiveness and environmental policies (Rivers, 2010).

Thema et al. (2013) studied EU energy efficiency policies and proposed a causality model of the impact of energy efficiency policies on the electricity market, arguing that ambitious policy targets can reduce both GHG emissions and industry costs. According to the causality model (Thema et al., 2013), energy efficiency policies influence the demand for energy and reduce the amount of electricity consumed. The effect of reduced electricity consumption is twofold: (1) it reduces the price of electricity and (2) it reduces the demand for and price of EU ETS units. Each of these effects, separately and together, reduces costs for the population, industry, and the service sector.

Leaving aside the climate change aspect and considering the impact of energy efficiency investments on the competitiveness of the industry in isolation, it can be argued that an increase in investment leads to an increase in energy efficiency, a decrease in production costs, an increase in demand for the products produced, and an increase in export volumes. And an increase in export volumes, in the context of this paper, is seen as an increase in competitiveness. The addition of climate change mitigation to the model results in an extended model of energy efficiency, competitiveness and climate change mitigation. Taking into account the scientific literature analysed and understanding the need to mitigate climate change, it can be argued that one of the mitigation measures is an investment in energy efficiency improvements. These investments not only reduce CO_2 emissions but also reduce the cost of production, increase demand for the products produced and increase export volumes. An increase in export volumes leads to an increase in competitiveness, and an increase in competitiveness leads to an increase in the profitability of the company, which allows for an increase in investment. In turn, the reduction of CO_2 emissions in industry has an impact on climate change mitigation.

In summary, the price and quantity of CO_2 emissions, the amount of investment in an industry, the change in investment volumes, and the value added created can all be used to monitor the impact of climate change on the competitiveness of the industry.

2.4. Constructing a model for assessing industrial competitiveness in terms of energy efficiency

Researchers often note that energy efficiency improvements can or do influence the competitiveness of an industry. Summarising the results of previous research and taking into account the shortcomings found in these studies, this chapter develops a conceptual model for assessing industrial competitiveness in terms of energy efficiency.

A theoretical analysis of the interaction between energy consumption and climate change mitigation measures and industrial competitiveness provides a conceptual model that reflects the topic under analysis. The conceptual model of energy efficiency improvement, climate change mitigation and industry competitiveness are presented graphically in Figure 1, which also shows the structural parts of the model.

The conceptual model of energy efficiency improvements, climate change mitigation impacts and industry competitiveness is constructed on the assumption that a deductive approach can be used to identify the most important factors and barriers or groups of barriers that determine the competitiveness of each industry. Both factors and barriers and groups of barriers influence the competitiveness of an industry. The contemporary understanding of industrial competitiveness is analysed in detail in Chapter 1.1, the specificities of energy efficiency in Chapters 1.2 and 1.3, the impact of climate change mitigation, and the relationship between energy efficiency and climate change mitigation policies and measures in Chapters 1.4 and 1.5.

On the basis of the literature and empirical studies analysed, it is assumed that changes in energy efficiency resulting from the need to mitigate climate change have an impact on industrial enterprises, which affects their competitive capacity and influences the competitiveness of the industry in a given country. In turn, increased competitiveness increases the profitability of industrial enterprises, which leads to increased investment in energy efficiency and climate change mitigation.

The literature analysis has shown that there is a feedback relationship between competitiveness and changes in energy efficiency, but that more detailed studies are needed to assess this relationship, which is why it is not examined in this dissertation (the feedback relationships are shown by the dashed line in Figure 1).

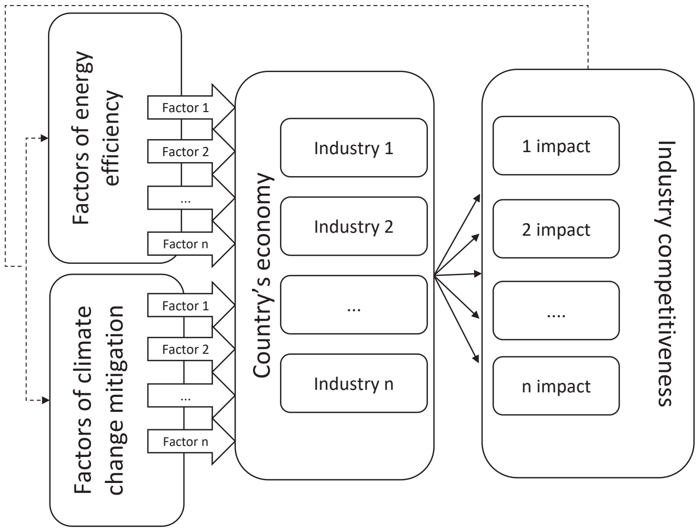

Figure 1. A conceptual model for energy efficiency, climate change mitigation and industrial competitiveness

The interrelationship between energy efficiency, industry competitiveness and climate change mitigation has been analysed in the previous chapters. Based on the analysis of empirical studies and scientific literature, it is concluded that the most important areas of impact of energy efficiency improvements on the national economy are:

- the economic-financial impact of energy efficiency on industry (change in value added, export volumes, investment);
- the impact of energy efficiency on energy consumption (change in energy resource prices, change in final energy consumed, change in energy costs);
- impact of energy efficiency on the environment (reduction of CO_2 emissions).

The analysis shows that the directions of the impact of changes in energy efficiency on industrial competitiveness and the environment are likely to be interlinked: the need to mitigate climate change leads to an increase in investment in energy efficiency, and improvements in energy efficiency contribute to a reduction in the cost of production of energy-intensive industries and indirectly influence changes in the demand for manufactured goods, which in turn partly contributes to a change in the competitiveness of an industry. The change in the competitiveness of the industry creates opportunities for increased investment and has an impact on climate change mitigation. The following hypotheses are put forward to empirically test the process described:

1st Hypothesis (H_1): There is a direct relationship between the competitiveness of an industry and the industry's investments, the cost of energy consumed and the amount of greenhouse gas emissions.

2nd Hypothesis (H_2): The competitiveness of the countries in the different industries is the same.

The conceptual model developed (Figure 1) allows assessing the impact of energy efficiency on competitiveness. The theoretical model is used to quantify the change in the competitiveness of different countries' industries in terms of energy efficiency.

2.5. Methodology for the calculation of the industry competitiveness index in terms of energy efficiency

An analysis of the literature shows that combining different indicators into a single index is a commonly used method for assessing complex phenomena. Indexes allow the aggregation of different indicators into a single measure (Saisana, et al., 2005). In order to construct an index for assessing competitiveness a selection of the indicators, the assignment of weights to the indicators, the transformation of the indicators and the calculation of the index are needed.

2.5.1. Background to the choice of indicators for the index

The analysis of the literature and the results of previous empirical studies have identified 22 preliminary indicators that can be used to calculate the competitiveness index: gross investment in machinery and equipment in industry; value added in industry; export volumes of the industry; share of industry exports in total national exports; change in export volumes of the industry; industry's competitiveness effect; energy intensity of the industry; energy intensity of the industry in the previous period; final energy consumed in the industry; final energy consumed in the industry in the previous period; effect of a change in the energy intensity of the industry; cost of energy consumed in the industry; natural gas price for industry; last period's natural gas price for industry; electricity price for industry; last period's electricity price for industry; CO_2 emissions from the industry; CO_2 emissions from the industry in the previous period; CO_2 emission intensity of the industry; CO_2 emission intensity of the industry in the previous period; CO_2 emission price; ratio of verified emissions and freely allocated allowances from EU ETS. In this dissertation, the empirical investigation is carried out in the context of EU countries. Due to the characteristics of the EU legal framework and the EU ETS, the CO_2 emission price is the same for all companies operating in the EU. Therefore, the CO_2 emission price is not included in the index calculation.

Pearson correlation coefficient was used to select the most relevant indicators. For the purpose of this dissertation, the interpretation of the correlation coefficient values proposed by Cohen (2013) is used to select the most appropriate criteria.

The final composition of the index includes the 14 indicators, which can be found in Table 2.

2.5.2. Background to the choice of weights for the index indicators

Once all indicators have been normalised, individual weights are assigned to each indicator. The selection of indicator weights is considered highly controversial in the scientific literature and there is no consensus on a single acceptable method (Dolge et al., 2020; Singh et al., 2007). However, there is consensus that the sum of all weights should be equal to one (Pranulis & Dikčius, 2012).

As noted by Dolge et al. (2020) and Gigerenzer and Todd (1999), some empirical studies in the environmental, sustainable development, financial or heuristic sciences use equal weighting indices. Gigerenzer and Todd (1999) argue that models with equal weights assigned to indicators and where the number of indicators does not exceed 10 often perform as well as multiple regressions. Moreover, other empirical studies have shown that indices and models with equal weights are more reliable and produce significantly better average results than weighted models (DeMiguel et al., 2009; Malladi & Fabozzi, 2017; Plyakha et al., 2012). Marewski et al. (2010) argue that research models using equal weights of indicators at the same time are simple and sufficiently robust for the prediction of complex phenomena.

In this dissertation, the method of assigning equal weights to indicators is used to assess competitiveness. The choice of equal weights for indicators and sub-indices is based on the concept of sustainable development, which emphasises the equal importance of all relevant factors (Barrera-Roldán & Saldívar-Valdés, 2002).

2.5.3. Transformation of the index indicators and calculation of the index score

The indicators used in the research model are expressed as statistical data in very different sizes and units of measurement, which are difficult to compare with each other and unreliable for further analysis. Data normalisation allows transforming different scales of indicators into one common scale, which is a prerequisite for combining indicators into a common index (Čekanavičius & Murauskas, 2004; Krajnc & Glavič, 2005). For data normalisation, the standardisation procedure was chosen.

The final index score is obtained by summing up all the indicators with their assigned weights.

2.5.4. Assessment of the sensitivity of the index results

The competitiveness index is based on a number of key assumptions: the selection of indicators, the transformation of the indicators, the estimation of missing values, the selection of weights, and the choice of the method for calculating the final index score. To assess the sensitivity of the index scores, a rank variance analysis method is used (Cîrstea et al., 2018; Lee & Zhong, 2015). This method allows assessing how the calculated index estimates change as the underlying assumptions change.

In this paper, four assessments of the sensitivity of the index are carried out.

2.5.5. Structure of the industry competitiveness index in terms of energy efficiency

Based on the literature analysis, the conceptual model of energy efficiency improvement, climate change mitigation and industry competitiveness (Figure 1) and the results of the correlation analysis, the structure of the index for assessing the industry's competitiveness in terms of energy efficiency is proposed (Table 1).

The industry competitiveness index in terms of energy efficiency (KEVA) can, theoretically, obtain the values from $-\infty$ to $+\infty$, but due to the choice of transformation and weighting methods, its average value should be close to 0. An index value of 0 is understood as the average value of the index in the industry under study. The higher or lower the value of the index is, the more distant the industry in the country under study is from the industry average. The structure and calculation indicators of the KEVA index are presented in Table 1.

Table 1. KEVA index indicators and weights

Sub-index	Sub-index weight	Indicator	Indicator weight	Calculation of the indicator
Economic sub-index	⅓	Value added in the industry	⅙	The indicator estimate is taken from the official IEA Energy Efficiency Indicators database
		Export volumes of the industry	⅙	The indicator estimate is taken from the official Eurostat database
		Industry's competitiveness effect	⅙	The indicator is calculated according to the method of constant market share analysis. The exact calculation methodology is presented in Formulae 4 and 5. The data for the indicator estimate is taken from the UN Comtrade database.
		Change in the volume of exports of the industry	⅙	Export volumes of the industry in year t / Export volumes of the industry in year (t-1)
		Gross investment in machinery and	⅙	The indicator estimate is taken from the official Eurostat database

		equipment in the industry		
		Share of industry exports in total national exports	⅙	Industry export volumes/country export volumes
Energy sub-index	⅓	Final energy consumption in the industry	¼	The indicator estimate is taken from the official IEA Energy Efficiency Indicators database
		Cost of energy consumed in the industry	¼	The indicator estimate is taken from the official IEA Energy Efficiency Indicators database
		Final energy consumed in the industry in the previous period	¼	Final energy consumption in the industry (t-1) in years
		Energy intensity of the industry	¼	The indicator estimate is taken from the official IEA Energy Efficiency Indicators database
Emissions sub-index	⅓	CO_2 emissions from the industry	¼	The indicator estimate is taken from the official IEA Energy Efficiency Indicators database
		CO_2 emissions from the industry in the previous period	¼	CO2 emissions from the industry (t-1) in years
		CO_2 emission intensity of the industry	¼	The indicator estimate is taken from the official IEA Energy Efficiency Indicators database
		Ratio of verified emissions and freely allocated allowances from EU ETS	¼	Number of free allowances received/number of allowances used. The data for the indicator estimate is taken from the EEA database

Based on the selected economic, energy and emission indicators, statistical information is collected for selected industries and countries, an estimate for each indicator is calculated, the transformation of the indicators is performed and the index value is calculated. The index estimates for each country and industry are then sorted in ascending order using the ranking method and average values.

2.6. Methodology of the empirical study on the assessment of industry competitiveness in terms of energy efficiency

The empirical study includes the following steps:

1. Defining the countries, industries and time period of the empirical study;
2. Defining the aim and objectives of the empirical study;
3. Selection of the methods of the empirical study to achieve the stated aim and objectives;
4. Conducting the empirical study;

5. Analysis of the obtained results, assessment of the reliability of the index results, formulation of conclusions.

19 European countries were selected for the empirical study: Ireland, Austria, Belgium, Czech Republic, Denmark, Greece, Italy, Spain, Poland, Lithuania, Netherlands, Portugal, France, Slovakia, Finland, Sweden, Hungary, Germany, Great Britain.

There are several reasons for choosing this set of countries: (1) they are all located in the same region; (2) the availability of comparable statistical information, compiled to the same standards; (3) all these countries are members of the IEA.

The following energy-intensive industries are analysed in empirical research: the manufacture of pulp and paper products and printing (NACE rev. 2 Divisions 17 and 18), the manufacture of chemicals and chemical products (NACE rev. 2 Division 20), the manufacture of other non-metallic mineral products (NACE rev. 2 Division 23), and the manufacture of basic metals (NACE rev. 2 Division 24) (IEA, 2020c). The period of 2009–2019 was chosen for the empirical study of the index. The data come from Eurostat, the European Union Emissions Trading System (EU ETS), the United Nations Comtrade and the IEA Energy Efficiency Indicators databases. If the databases used do not contain values for a given indicator for a given period, the study uses the arithmetic mean of the preceding periods.

The aim of this empirical study is to conduct an empirical investigation of an index model for assessing industry competitiveness in terms of energy efficiency and to compare the competitiveness of energy-intensive industries in European countries.

3. AN EMPIRICAL STUDY ON THE ASSESSMENT OF INDUSTRY COMPETITIVENESS IN TERMS OF ENERGY EFFICIENCY

This section provides estimates of the calculated KEVA index for the analysed countries and industries. It starts with brief statistical information and interpretation of the index indicators, followed by the results for each sub-index and the summary results of the index estimates, and in the last part of the Chapter, index sensitivity analysis is presented.

3.1. Results of the industry competitiveness index in terms of energy efficiency

The first part of this chapter presents an analysis of the results of the KEVA sub-indexes. After the results of each sub-index have been calculated, a final calculation of the KEVA index is carried out. For all industries, the results of the KEVA index are sorted in ascending order of the 10-year average and ranked separately for each year. The ranks are assigned according to the index score for each year. The aggregated results of the KEVA index for all analysed industries are presented in Table 2 (countries sorted by alphabet).

The results of the KEVA index of the pulp and paper products industry showed, that 5 countries (Germany, Italy, France, Spain, and Poland) had always a higher index result than the market average. In the context of this dissertation, these countries had the highest competitiveness in this industry. In contrast, the KEVA index of 7 countries (Austria, Sweden, Greece, Hungary, Portugal, Denmark, and Lithuania) has always been below the average of the index. The average score of the most competitive countries (mean 0.82; standard deviation (further in the text also as SD) 0.46) is statistically significantly higher (t-statistic 4.1; df = 4; p = 0.01) than that of the least competitive countries (mean -0.45; SD 0.03). There are also eight groups of the countries, the index of which has a strong correlation.

The highest index scores were estimated in the German pulp and paper products industry (mean 1.70; SD 0.05), also the slope of the German KEVA index values in this industry is positive ($\beta_0 = 30.2$; $p = 0,17$; $R^2 = 0,11$), nevertheless, the results are not statistically significant.

Index results suggest that there is one leading country in the paper and paper products industry (Germany) that is wasting its competitiveness vis-à-vis other countries. An analysis of the components of the index shows that the distinctive value of the German KEVA index in this industry is due to the significantly higher generated value added, the industry's export volumes, the overall investment in machinery and equipment in the industry, while the energy intensity is higher, the ratio of free and used emission allowances is lower than the average of the other countries, and the energy consumption and energy costs are higher than in the other countries. In this context, it can be argued that compared to the other countries studied, the German paper and paper product industry, although relatively more energy-intensive and expensive, uses energy more efficiently than other countries and produces higher value-added products and exports more products. Also, this German industry does not incur high additional costs in the purchase of emission allowances.

In the chemicals and chemical products industry, the average KEVA index value of the five countries (Germany, the Netherlands, Belgium, France, and Poland) was always higher than the market average. Meantime the average KEVA index value of seven countries (Lithuania, Portugal, Hungary, Slovakia, Sweden, Greece, and Denmark) was always below the index average. The average score (mean 0.75; SD 0.55) of the most competitive countries (the 5 countries with higher average index value) is statistically significantly higher (t-statistic 3.57; df = 4; p = 0.02) than that of the least competitive countries (mean = -0.44; SD 0.01). It suggests that, in this industry, the most competitive countries keep their competitive advantage over time. Strong correlations ($r > 0.7$) were observed between six country groups in this industry.

The German industry had the highest index scores (mean 1.97; SD 0.1), in the chemicals and chemical products industry. The German index value was always at least twice as high as that of the country in second place (the Netherlands industry) and it increased over time. The analysis of the index component showed, that the German industry generates higher value added and bigger export quantities. Despite that investment in machinery and equipment in Germany is relatively high, the energy intensity is close to the average and the ratio of free and used emission allowances is lower than in the industry.

Table 2. Aggregated results of the KEVA index for all industries

Country	Pulp and paper industry			Chemicals and chemical products industry			Non-metallic mineral industry			Basic metals industry		
	Mean	Rank	Linear chart	Mean	Rank	Linear chart	Mean	Rank	Linear chart	Mean	Rank	Linear chart
Austria	-0.080	10		-0.273	11		-0.489	15		-0.170	12	
Belgium	-0.393	14		0.353	3		-0.121	9		0.042	9	
Czechia	-0.246	11		-0.137	9		-0.266	11		-0.118	10	
Denmark	-0.613	18		-0.600	19		-0.381	13		-0.653	18	
Finland	1.284	2		-0.283	12		-0.668	18		-0.138	11	
France	0.131	5		0.321	4		0.440	4		0.269	3	
Germany	1.705	1		1.967	1		1.423	1		1.984	1	
Greece	-0.497	16		-0.539	18		0.179	7		-0.342	15	
Hungary	-0.456	15		-0.387	15		-0.397	14		-0.483	16	
Ireland	-0.704	19		-0.172	10		-0.169	10		-0.191	13	
Italy	0.207	4		0.129	6		1.049	2		0.516	2	
Lithuania	-0.543	17		-0.306	13		-0.534	17		-0.735	19	
Netherlands	-0.252	12		0.949	2		-0.489	16		0.078	8	
Poland	0.082	6		0.165	5		0.263	5		0.171	6	
Portugal	-0.039	9		-0.328	14		0.258	6		-0.554	17	
Slovakia	-0.303	13		-0.431	16		-0.350	12		0.099	7	
Spain	-0.030	7		0.027	8		0.920	3		0.205	5	
Sweden	0.778	3		-0.514	17		-0.746	19		-0.219	14	
United Kingdom	-0.030	8		0.059	7		0.077	8		0.239	4	

In the other non-metallic minerals industry, the average KEVA index value of the six countries (Germany, Italy, Spain, France, Poland, and Portugal) was always higher than the market average and eight countries (the Czech Republic, Denmark, Hungary, Austria, the Netherlands, Lithuania, Finland, and Sweden) always has lower KEVA index value than the market. The average score (mean 0.73; SD 0.23) of the most competitive countries is statistically significantly higher (t-statistic 6.02; df = 4; $p = 0.00$) than that of the least competitive countries (mean = -0.50; SD 0.02). It can be concluded, that these countries are keeping their competitive advantage over less competitive countries. In this industry the strong correlation ($r > 0.7$) was observed between eleven country groups.

In the other non-metallic minerals industry Germany (mean 1.42; SD 0.88) had the highest index performance during the analysed period and the performance of the German index value improves over time ($\beta_0 = 18.33$; $p = 0.00$; $R^2 = 0.88$), moreover German KEVA index results for this industry have a strong autocorrelation ($r = 0.92$) with the previous values. The analysis of index component highlighted that German industry generates higher value added, has bigger export quantities and bigger investment. However, energy consumption and energy costs are higher and the ratio of free and used emission allowances is lower than the average of the countries surveyed.

In the basic metals industry, the average KEVA index value of the five countries (Germany, Italy, France, Great Britain, Spain and Poland) was always higher and the average index value of seven countries (Austria, Sweden, Greece, Hungary, Portugal, Denmark and Lithuania) was always lover then the market. The average score (mean 0.63; SD 0.59) of the most competitive countries (the 5 countries listed above) is statistically significantly higher (t-statistic 3.05; df = 4; $p = 0.04$) than that of the least competitive countries (mean -0.45; SD 0.05). It can be concluded, that these countries are keeping their competitive advantage over less competitive countries. In this industry, a strong correlation ($r > 0.7$) was observed between eight-country groups.

The German basic metals industry had the highest index scores over the period analysed (mean 1.98; SD 0.08). The German index score was always significantly (2 to 5 times) higher than that of the country in second place (Italy). The slope German index score is positive ($\beta_0 = 24.78$; $p = 0.04$; $R^2 = 0.38$), indicating that the performance is improving over time. These results imply that there is one leading country (Germany) in this industry, which is wasting its competitiveness vis-à-vis other countries.

The German industry's KEVA index score was the highest in all the industries surveyed, with a few exceptions in some years. In addition, the French and Polish industries had all positive (above the average for all countries studied) KEVA index estimates in all the industries surveyed. Meanwhile, in all the industries studied, four countries had all negative estimates of the KEVA index: Hungary, Denmark, Sweden, and Lithuania.

The analysis of the KEVA index scores and the sub-index scores suggests that there is a relationship between the competitiveness of an industry and the industry's investment, energy costs and greenhouse gas emissions. This observation is close to the first hypothesis of the study (H_1), namely that there is a direct relationship between the competitiveness of an industry and the industry's investment, energy costs and greenhouse gas emissions. As discussed in Section 3.1, a multiple factorial regression analysis method is chosen to test this hypothesis.

The analysis of the results of the KEVA sub-indices and the index, as well as of the literature, shows that the competitiveness of an industry, as calculated by the KEVA index, is related to the energy costs consumed and the investments made in the industry. This assumption is close to the first hypothesis put forward in the paper that there is a direct correlation between the competitiveness of an industry and the industry's investment, energy costs and greenhouse gas emissions. As discussed in Section 3.1, a regression analysis method is chosen to test this hypothesis.

The empirical study carried out a stepwise regression analysis to test whether changes in the competitiveness of an industry can be predicted by the competitiveness variable, the industry's exports, the industry's share of exports, the industry's investment, the cost of electricity, the cost of primary energy consumed and the greenhouse gas emissions emitted. The results of this analysis show that the model presented in Formula 20 best describes the relationship between the competitiveness of an industry and the level of investment, the cost of energy consumed and CO_2 emissions.

$$k = \beta_0 + \beta_1 c_{ef} - \beta_2\, eks + \beta_3 eks_d + \beta_4 inv - \beta_5 el + \beta_6 ec + \beta_7\, co_2 + e \quad (20)$$

here: k – industry competitiveness, c_{ef} – competitiveness effect, eks – industry export, eks_d – share of the industry export, inv – industry investments, el – electricity price, ec – cost of the energy, co_2 – CO_2 emission.

The determination coefficient of the model is high ($R^2 = 0.62$) and the statistics of the model ($F(7,628) = 150.3$; $p < 0.000$) are statistically significant. All data requirements are met and there were no exceptions. The results of the Shiro-Wilk's W test show that the residual errors are normally distributed and that there is no multicollinearity problem (all VIFs < 4).

Based on the results of the regression analysis, there is no reason to reject the first hypothesis of the study and it can be concluded that there is a direct relationship between the competitiveness of an industry and the industry's investment, energy costs and greenhouse gas emissions.

To summarise, the competitiveness of the German industry was, with very few exceptions, the highest in the context of the countries studied. The empirical results obtained are partly in contradiction with the findings of Graichner et al. (2009), which predicted a decline in the competitiveness of the German chemical industry as a result of rising environmental protection requirements. In addition, the French and Polish industries also had all positive KEVA index scores. In contrast, for all industries studied, industries from as many as four countries - Hungary, Denmark, Sweden and Lithuania - had all negative competitiveness index scores throughout the period under investigation.

3.2. Results of the cluster analysis of the competitiveness index in the term of energy efficiency

Once the KEVA index estimates for all the industries surveyed have been calculated, a cluster analysis of the results is carried out. The aim of clustering is to form groups of countries that are internally similar and coherent at the same time, but externally significantly different from each other. The hierarchical clustering was help to highlight prevailing trends. As noted in Section 3.1, one of the most important decisions to be made by the researcher in the clustering exercise is the choice of the number of clusters. The author made two assumptions in choosing the number of clusters:

1. The number of clusters should be the same in all industries;
2. A single cluster should not cover more than 50% of the countries studied.

In order to meet both assumptions, the number of found to be 6.

In the pulp and paper products industry, due to its very high and distinctive index, the German industry forms a separate cluster (I). Within this industry, the Finnish pulp and paper products industry had the second highest index values (mean 1.23; SD 0.10) and also belonged to a separate cluster (II). The Swedish pulp and paper products industry (mean 0.77; SD 0.08) was also classified in a separate (III) cluster. Cluster IV consists of 7 countries (France, Italy, Poland, Great Britain, Portugal, Austria, Spain), with a mean index of 0.03 and a SD of 0.12. The largest cluster (V) combines 8 countries (Czech Republic, Netherlands, Belgium, Slovakia, Lithuania, Denmark, Greece, Hungary), with a mean index of -0.403 and a SD of 0.18. Cluster VI consists of one industry, the Irish paper and paper products industry (mean of -0.69; a SD 0.18).

In the chemicals and chemical products industry, the industry with the highest average KEVA index score was Germany (mean 1.92; SD 0.21). Due to its very high and remarkable (in average, more than 2 times higher as country with 2nd rank) index values the German chemicals and chemical products industry classified to a separate cluster (I). Within this industry, the Dutch chemicals and chemical products industry (mean 0.93; SD 0.14) was also included into a separate cluster (II). Cluster III (mean 0.17; SD 0.17) combines 6 countries (Belgium, France, Great Britain, Spain, Italy, Poland). Cluster IV consists of 4 countries (Finland, Czech Republic, Austria and Lithuania), the average KEVA index for this cluster is -0.24 and SD of 0.19. Cluster V (mean -0.46; SD 0.15) combines the industries of 6 countries (Sweden, Denmark, Greece, Portugal, Hungary and Slovakia). The cluster VI consists of one - Irish industry (mean -0.16; SD 0.28).

As in the case of the non-metallic mineral product industry, Germany had the also the highest average KEVA index (mean 1.39; SD 0.21). Due to such high result the German non-metallic mineral products industry forms a separate cluster (I). The Italian and Spanish industries belong to a separate cluster (II). The cluster III combines industries from 5 countries (Greece, France, Great Britain, Poland and Portugal), with a mean of 0.24 and SD of 0.16. Cluster IV consists of 3 countries (Ireland, Belgium and the Czech Republic), the average index value in this cluster is -0.18, SD of 0.15. Cluster V (mean -0.43; SD 0.15) combines the industries of 6 countries (Denmark, Slovakia, Lithuania, Hungary, Austria and the Netherlands). Cluster VI consists of Finland and Sweden industries (mean -0.69; SD 0.11).

In the basic metals industry Germany had the highest average KEVA index (mean 1.94; SD 0.17) and belong to separate cluster (I). In this industry, the Italian basic metals industry had the second highest index values (mean 0.50; SD 0.13) and also belonged to a separate cluster (II). Cluster III consists of the UK industry (mean 0.23; SD 0.29). Cluster IV (mean 0.02; SD 0.28) combines industries from 6 countries (Belgium, the Netherlands, Slovakia, Spain, France, and Poland). Cluster V (mean -0.19; SD 0.14) brings together industries of 6 countries (Greece, Czech Republic, Austria, Sweden, Finland and Ireland). Cluster VI (mean -0.59; SD 0.16) consists of the main metals manufacturing industries of 4 countries (Hungary, Lithuania, Denmark and Portugal).

These clustering results can be interpreted as meaning that cluster IV combines all countries with a KEVA index score close to the average of the countries studied, clusters III and V combine countries with a KEVA index score slightly above or below the average of the countries studied, and clusters I and VI are composed of countries with a KEVA index score that is either much above or much below the average.

Germany is the only country where all four analysed industries have a very high average KEVA index score. The uniqueness of the index score is also demonstrated by the fact that Germany forms a distinct cluster in all four industries.

The results of the cluster analysis highlighted that - the competitiveness of countries measured by the KEVA index varies across industries. This assumption is opposite to the H_2 hypothesis - the competitiveness of countries is the same in different industries. As described in Section 2.6, a two-factor ANOVA is chosen to test this hypothesis.

The ANOVA assumptions was tested before calculation and all test was satisfied. The Shapiro-Wilk's W test was used to test whether the variables are normally distributed. The Levene's test was used to test for equality of variances. The available empirical data and ANOVA method allow the formulation of three null hypotheses:

$H_{2.1}$: All industries are equally competitive;

$H_{2.2}$: All countries are equally competitive;

$H_{2.3}$: Country-industry interactions do not affect competitiveness.

The results of the two-factor analysis of variance are shown in Table 2.

Table 2. Results of the two-factor ANOVA

	Sum of Squares	df	Mean of Squares	F statistic	p value	η^2	η^2 90% CI*
Industry (A)	0.03	3	0.01	0.58	0.629	0.00	
Country (B)	194.40	18	10.80	690.11	0.000	0.94	[0.94; 0.95]
Industry x Country (AB)	81.68	54	1.51	96.65	0.000	0.87	[0.85; 0.88]
Total	11.69	747	0.02				

*CI – confidents interval

From the ANOVA results table the $H_{2.1}$ hypothesis cannot be rejected ($F = 16.5$; $df = 3$; $p > 0.05$) and that the competitiveness of the industries is equal. However, the $H_{2.2}$ hypothesis ($F = 690.1$; $df = 18$; $p < 0.05$) can be rejected, which means that the competitiveness of the countries is not equal. Furthermore, the calculated η^2 coefficient suggests that 94% to 95% of the variance of the KEVA index is due to differences in the competitiveness of the countries. The null hypothesis $H_{2.3}$ should also be rejected ($F = 96.6$; $df = 54$; $p < 0.05$). The estimated η^2 coefficient suggests that 85% to 88% of the variance of the KEVA index is due to the impact of country-industry interaction on competitiveness differences.

3.3. Sensitivity analysis of competitiveness index in the terms of energy

The sensitivity analysis of the KEVA index is carried out by testing four changes to the assumptions used to build the index:

- Eliminating each index indicator. At this stage, one indicator is eliminated from the index calculation, while all other indicators remain unchanged.
- Changing the weights of the sub-indexes. Three scenarios of sub-index weights are examined: (1) 0.50/0.25/0.25; (2) 0.25/0.50/0.25; (3) 0.25/0.25/0.50.
- Optimistic/pessimistic scenario - the worst (optimistic scenario) and best (pessimistic scenario) value of each country's indicator for each year is eliminated.
- Change of the method of calculating the final index estimate to the geometric mean.

A total of 22 alternatives to the KEVA index were evaluated. In summary, the index is not sensitive to the elimination of indicators, to changes in the index weights, to the artificial improvement or deterioration of the country's performance (optimistic/pessimistic scenario). However, the results of the index are sensitive to changes in the method of calculating the final estimate.

CONCLUSIONS

1. Competitiveness issues are intensively addressed in the scientific literature as well as in political documents of national significance in Lithuania and abroad. The analysis of scientific researches on competitiveness has revealed the diversity of the concept of competitiveness - depending on the research object, purpose or even the researcher's point of view, different descriptions of competitiveness are used, and different factors determining competitiveness are distinguished. However, there is a consensus that only competitiveness at the same level, in the same field or over time can be compared. In this dissertation, industrial competitiveness is understood as the ability of industrial enterprises to profitably sell, increase and sustainably maintain sales of their manufactured products in domestic and export markets.
2. The analysis of the scientific literature on energy efficiency has shown that although the concept of energy efficiency is intuitive, it is difficult to define it clearly. The dissertation defines energy efficiency as the ratio of energy consumed to the value added of produced goods, services or labour, and energy efficiency is expressed in terms of energy intensity.
3. The analysis of the scientific literature has shown that, depending on the objectives of the study and the information available, energy efficiency and its evolution can be assessed by monitoring thermodynamic, physical or economic indicators. Although the most commonly used indicator of energy efficiency is energy intensity and its change, it is also possible to use natural indicators of energy consumption, various relationships of these indicators with other indicators, financial indicators, and index decomposition techniques to monitor changes in energy efficiency in an industry.
4. An analysis of the literature on the relationship between energy efficiency and environmental policy has shown that environmental policy measures affect the competitiveness of energy-intensive industries, while the implementation of energy efficiency measures has an impact on both greenhouse gas emissions and competitive advantages. The dissertation presents an approach to energy efficiency and climate change mitigation, focusing on the impact of these factors on the competitiveness of energy-intensive industries.
5. In order to assess the competitiveness of the industry in terms of energy efficiency, a conceptual model has been developed combining two components.
    a. In the first part, indicators of energy efficiency, climate change mitigation and industrial competitiveness are identified on the basis of scientific literature and statistical analysis. The following indicators are included in the model for assessing competitiveness in terms of energy efficiency: value added generated in the industry, export volumes of the industry, the competitiveness component of the industry in the

country’s exports, the change in the export volumes of the industry, gross investment in machinery and equipment in the industry, the share of the industry's exports in the country's total exports, the amount of final energy consumed in the industry, and the cost of the energy consumed in the industry, final energy consumed by the industry in the previous period, energy intensity of the industry, CO_2 emissions emitted by the industry, CO_2 emissions emitted by the industry in the previous period, CO_2 emissions intensity of the industry, ratio of free and consumed emission allowance units in the industry.

b. The second part of the model proposes an index for assessing the competitiveness of an industry based on the economic, energy consumption and environmental performance of the industry. The competitiveness index used in the work consists of the sub-indices of Exports, Energy Efficiency, and GHG Emissions. In order to avoid subjectivity, based on the analysis of scientific literature and on the practice of the most popular competitiveness indices, a equal-weighted index structure is chosen, where all the weights of the sub-indices and the weights of the indicators are chosen to be equal.

6. An empirical study on the assessment of industrial competitiveness in terms of energy efficiency was carried out in 19 European countries and applied to four energy-intensive industries for the period 2009 to 2019. The empirical study showed that the highest competitiveness (competitiveness index score) across all industries was found in Germany. In addition, all the German industries selected for the study showed an increased competitiveness in the context of the countries studied. The empirical study also shows that German industry, while consuming a bigger amount and more expensive energy, uses it more efficiently and produces higher value-added products and exports more. In parallel, German industry incurs no or marginally higher costs for the purchase of emission allowances. The competitiveness of all the French and Polish industries studied, although not the highest over the whole period, was always above the average of the countries studied. In contrast, four countries - Hungary, Denmark, Sweden and Lithuania - had competitiveness index scores below the. The results of the study show that the most competitive countries maintain their competitive advantage over time vis-à-vis less competitive countries.
7. The regression analysis shows that there is a direct correlation between the competitiveness of an industry and the industry‘s investment, energy costs and greenhouse gas emissions. The results of the regression analysis also showed that the indicators of the competitiveness component, the industry's exports, the industry's share of exports, the industry's investment in the industry, the price of electricity, the cost of primary energy consumed, and the greenhouse

gas emissions emitted can be used to predict the change in the industry's competitiveness ($F(7, 628) = 150.3$; $p < 0.000$; $R^2 = 0.62$).

8. The evaluation of the results of the cluster analysis showed that, according to the selected criteria, all the industries studied can be divided into 6 clusters. The hierarchical classification allowed the countries to be ranked according to the long-term average of the index scores, with the most competitive countries in Cluster I and the least competitive in Cluster VI. Clusters I, VI consist of countries with index scores that are either much higher or much lower than the average, clusters III and V combine countries with a KEVA index score that is marginally higher or lower than the average for the countries studied, and cluster IV combines all countries with a KEVA index score that is close to the average of the countries studied.
9. The results of the cluster analysis also confirmed that all the German industries studied have a significant difference in their KEVA index estimates compared to all the other industries studied in other countries. The uniqueness of the German industry is also demonstrated by the fact that, in all the industries studied, Germany is part of a distinct cluster, of which it is the only one. The cluster analysis has also led to the conclusion that competitiveness is influenced both by the country in which the industry is located and by the industry itself.
10. The results of the analysis of variance confirmed that (1) the competitiveness of the industries in the countries studied differs in a statistically significant way, and about 94 % of the variance of the competitiveness index is due to the differences in the competitiveness of the countries; (2) the interaction between the countries and the industries analysed in the study has an impact on the competitiveness of the industries, and about 87 % of the variance of the competitiveness index is due to the impact of the interaction between the countries and the industries on the competitiveness.
11. To assess the sensitivity of the results of the KEVA index, a rank variance analysis was chosen. The sensitivity analysis of the index tested 22 index alternatives. It can be said that the developed index is not sensitive to the elimination of indicators, to changes in the index weights, to the artificial improvement or deterioration of the country's performance (optimistic/pessimistic scenario). However, the results of the index are sensitive to a change in the method of calculating the estimate.

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Publication of research results

The results of the dissertation research have been presented at international scientific conferences and published in scientific publications. The results of the research have been published in two **scientific publications** and two **scientific conference proceedings**:

- Zuoza A., Pilinkienė V. Causal relations between energy consumption, economic structure and economic growth in EU countries // The 14th International Conference of Young Scientists on energy Issues, Kaunas, Lithuania, May 25-26, 2017. Kaunas: LEI, 2017, ISSN 1822-7554. p.109-117
- Zuoza A., Pilinkienė V. Barriers of industrial energy efficiency // The 15th International Conference of Young Scientists on energy Issues, Kaunas, Lithuania, May 23-25, 2018. Kaunas: LEI, 2018, ISSN 1822-7554. p.234-243
- Zuoza A., Pilinkienė V. Energy consumption, capital expenditures, R&D cost and company profitability: Evidence from paper and allied industry. Energetika, 2019, 65(4), 197–204. https://doi.org/10.6001/energetika.v65i4.4248
- Zuoza A., Pilinkienė V. Energy Efficiency and Carbon Emission Impact on Competitiveness in the European Energy Intensive Industries. Energies 2021, 14(15), 4700; https://doi.org/10.3390/en14154700

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2000-2004	Bachelor's degree in Economics Kaunas University of Technology

Work experience

2008-present	CEO of Agro Baltic GmbH, Rostock, Germany
2017-present	Chairmen of the board of AGT Sp. z o.o., Szczecin, Poland
2006-2008	Export manager, AB Achema, Jonava, Lithuania
2003-2006	Project manager, VšĮ Lietuvos regioninių tyrimų institutas, Kaunas, Lithuania

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