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Green Bonds as an Instrument for Financing Ecological Investments in the V4 Countries

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Abstract: The aim of this paper is to characterise the green bond market in the Visegrad Group of countries (V4) and to identify the determinants and benefits of issuing green bonds. The specific objective is a spatial–temporal analysis of the green bond yield in V4 countries. The following research methods were used in the paper: a source literature analysis and report analysis, statistical data analysis (from international financial markets), and the Dynamic Time Warping method (DTW). DTW comprises a class of algorithms that are used to compare both equal and unequal time series. The DTW method allows the smallest distance between two time series of different lengths to be found while allowing for the transformation over time of both series. As the method is highly efficient, it is used to provide a thorough spatial–temporal analysis of green bonds. The research process confirmed that green bonds are an instrument with potential in the global debt market. Among the most important stimulants for the issuance of green government bonds are capital mobilisation, the development of the green financial market, investor demand, and reputational benefits.

Keywords: green bond; green finance; Visegrad group (V4) countries

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1. Introduction

The idea of environmentally sustainable economic development has long been discussed internationally, uniting governments, international and national institutions, and organisations in joint environmental initiatives. These investments are usually of a long-term nature, and the provision of adequate capital is essential for them to be realised. One of the financial instruments capable of meeting these expectations is so-called green bonds, i.e., debt instruments that exclusively finance projects with environmental benefits and can therefore reduce the negative impact of economic activity on climate change. In practice, the market for so-called green bonds emerged in 2007–2008 with the first issuances by the European Investment Bank and the World Bank. It should be noted, however, that compared to the conventional bond market, the market for this type of bond is still relatively small [1,2] although, since the first such issuance in 2007, their importance has started to grow. Private sector issuers joined the market in 2013 and 2014. In contrast, the first sovereign green bonds were only issued in late 2016. Interestingly, the issuer of these instruments was Poland, which thereby became part of the history of global financial market development [3].

The research subject of this article is the study and evaluation of changes in the green bond market in the Visegrad Group of countries (V4): the Czech Republic, Hungary, Poland, and Slovakia. Green bonds are an important source of long-term financing for environmental investments and act as an alternative to bank loans or share issues.

There are both theoretical and practical reasons for undertaking this subject of research. The current state of knowledge of the green bond market in the V4 countries is incomplete and is not widely described in the literature, being limited primarily to country-specific

literature. It is more common to find studies focusing on the green bond market in the world as a whole [4] in the European Union [5,6] or in individual V4 countries [7,8].

As a result, there are many approaches, definitions, and concepts on the role and importance of the green bond market, but there is no study that shows the situation in the market in the Visegrad Group countries in a comprehensive and integrated manner, simultaneously combining theoretical aspects and research results. The issue of the role and significance of the green bond market in the V4 countries is important not only from a cognitive point of view but also for economic practice. The situation and development of this market are important from the point of view of issuers, individual and institutional investors, business entities, as well as the entire economy. Meanwhile, the results of the research led to the conclusion that green bond yields largely depend on an effective monetary policy that maintains the inflation target at an appropriate level. This state of affairs prompted the examination of the relationship between green bond yields and the level of inflation in the V4 countries.

Consequently, the main objective of this article is to characterise the green bond market in the Visegrad Group of countries (V4) and to identify the determinants of green bond issuance and its benefits. The specific objective is a spatial–temporal analysis of green bond yields in the V4 countries.

The goals include both theoretical–cognitive (related to the study of phenomena, processes, and the detection of relationships, dependencies, and regularities [9] and application objectives. The achievement of the theoretical–cognitive objective in terms of presenting existing knowledge necessitated the identification of various aspects of the current green bond market situation, and required:

- The study of the size and dynamics of the value of green bond issuance in the V4 countries;
- The development of the Dynamic Time Warping (DTW) model—a class of algorithms that are used to compare series with the same number of elements and not with the same number of elements.

The DTW method allows the smallest distance between two time series to be found, allowing for time transformations for both series. The method is efficient and is therefore used for a thorough spatial–temporal analysis of green bonds. The research process confirmed that green bonds are a promising instrument for the global debt market. Among the most important stimulants of government green bond issuance are capital mobilisation, green financial market development, investor demand, and reputational benefits.

With reference to the research subject and the objectives adopted, the following hypothesis was formulated: Inflation is a determinant of the yield of green bonds issued in the V4 countries, but the impact of inflation on yields varies across the V4 countries.

Clearly defining green bonds is not easy. This dilemma does not result from the structure of these debt securities but from the purpose of their issue and the fact that the source literature and the financial markets also include the concept of environmental bonds and climate bonds, which are included as bonds with an ecological profile [10]. While climate bonds focus on financing investments related to adapting the economy to climate change, green bonds and environmental bonds finance projects aimed at environmental protection in the broadest sense [11]. Since counteracting and adapting to climate change falls within the area of environmental protection, green bonds can be understood more broadly than climate bonds, but also, as indicated in the literature on the subject, they can be used as synonyms [12–15]. The latter position, i.e., the identity of green bonds and climate bonds, is shared by both the World Bank (one of the main issuers of these bonds) and the Climate Bonds Initiative (CBI) (an institution that recommends issuance standards and promotes the development of the green bond market segment), which is all the more important, as it is difficult to divide up investment projects that work for environmental protection and at the same time are climate neutral [11]

Green bonds are structured in the same way as traditional investment grade bonds, with the proviso that the money raised through the issue will be used for green investments [7] In the source literature, green bonds are defined in a similar way, always emphasis-

ing the importance of the green and environmental aspects. Green bonds are fixed-income securities that are an integral component of green finance, which finances investments that provide environmental or climate benefits [1]. They are also defined as a commitment by the issuer to exclusively use the money raised to finance or refinance green projects, assets, or business activities in this area [16]. Kaminker and Steward [17] define green bonds as fixed-income securities issued by corporations, international banks and governments to raise capital to finance low-carbon and climate-resilient projects. For the Climate Bond Initiative (2022), the aim of the investment is important, that is, environmental protection and the mitigation of climate change.

The condition for a bond to be considered "green" is that it meets generally applicable standards. The best-known standard for issuing green bonds is the Green Bond Principles—edition 2021, developed by the International Capital Market Association (ICMA). These principles are a global standard for a market that is the largest source of market-based financing dedicated to sustainability and climate transformation available internationally for companies, banks, and countries (ICMA 2022). The principles used by the market are voluntary process guidelines that recommend the transparency and disclosure of all information, as well as promoting integrity in the development of the green bond market by explaining all details of the issuance process. They provide guidance to issuers on triggering issues to finance green projects and, by promoting the availability, accuracy, and integrity of information, help investors assess the environmental impact of their investment. The recommendations included in the text of the principles specifically address four aspects [18]:

- Use of Proceeds—the use of green bond proceeds to fund projects appropriately described in the documentation that qualify as "green" and to provide indisputable environmental benefits.
- Process for Project Evaluation and Selection—the issuer should clearly define the purpose of the capital raised while identifying the clear environmental benefits.
- Management of Proceeds—the funds raised should be retained in a separate sub-account so that they are only used to fund green projects.
- Reporting—the issuer should on an ongoing basis make available and update reports on the level of use of the funds raised, while at the same time indicating which projects have been or are being financed from the funds raised.

Another group of guidelines developed by the Climate Bond Initiative (2022) are detailed conditions for classifying projects as green (climate) by sector. In order for an investment project to qualify for green bond financing, it must specifically relate to investments that identify assets and projects needed to ensure low carbon emissions in the areas of:

- Renewable energy (solar, wind, geothermal, hydro, bioenergy);
- Low-carbon buildings (new residential and commercial buildings and building refurbishment);
- Transport (low-carbon transport, public transport, rail transport, alternative fuels);
- Waste and pollution (recycling, closed-loop economy, energy waste, landfills);
- Industry (cement, steel, glass, chemical, fuel production);
- Agriculture, forestry, fisheries;
- Water (collection, monitoring, treatment, distribution, and flood protection).

The Climate Bonds Initiative has also developed its own climate bond standards and certification system. It includes [19]:

- The Climate Bond Standard, which sets out the requirements that an issuer seeking certification for their issue must meet;
- Climate Bonds Taxonomy—a taxonomy used to assess the climate impact of green bonds for inclusion in a database that is used by various market participants;
- Sector Eligibility Criteria—these provide detailed definitions and guidance for the eligibility of specific projects and assets for green bond financing;

- Guidance and certification documents. With the Climate Bond Standard, bonds can be certified before they are issued, allowing the Climate Bond Certificate label to be used in marketing activities. Once the bonds have been issued and funds allocated, the certificate must be confirmed through a post-issue report containing an independent assessment of post-issue compliance and submitted to the Climate Bonds Standard Board for approval.

The market standards and guidelines listed above provide the organisational and procedural foundations for green bond issuance, but an excess of them may reduce market transparency and consequently discourage issuers and investors from participating. In view of the above, the need for a uniform and EU-binding system of guidelines for green bonds (and sustainable bonds in general) is increasingly becoming an important factor in supporting the further development of these instruments. These challenges have been recognised by the European Commission, which, by introducing and promoting a uniform green bond standard, wants to build Europe's competitive advantage in the global sustainable finance market [20].

On 6 July 2021, the draft Regulation of the European Parliament and of the Council on European green bonds was published [21]. The aim of the draft Regulation is to introduce a standard of high-quality green bonds, which should:

- Make it easier for investors to identify which bonds are high-quality green bonds and have greater credibility;
- Facilitate their issuance by clarifying the definition of green economic activity and reducing the potential risk of issuers losing their reputation in transition sectors;
- Standardise the practice of external auditing and increase trust in external auditors by introducing a voluntary system of registration and supervision.

The key tenets of the European Green Bond Standard (EU GBS) are to be [20]:

- Its voluntary application;
- Its use for financing projects inside and outside the European Union;
- Its application to listed and unlisted instruments by private and public sector issuers;
- Built on existing market practice through Green Bonds Principles and the Climate Bonds Standard;
- Expanded and complemented with aspects aimed at reducing barriers to entry for green bond issuers and investors.

Green bonds can be issued by governments, local authorities, companies, and financial institutions, and the list of types of green bonds will grow longer as work on new bond designs progresses. In general, there are several types of green bonds, as presented in Table 1.

Table 1. Types of green bonds.

Types of Green Bonds	Features
Use of Proceeds from Revenue Bonds or ABS	The debt is secured by revenues from single or multiple investment projects financed by a given debt issue.
Project Bond	A bond is secured by one or more projects for which the investor has direct exposure to project risk, with or without recourse to the bond issuer.
Asset-Backed Security ABS	A bond is secured by one or more specific projects, typically providing recourse to the property backing the bond.
Municipal Bond	A bond issued by a municipality, government, region, or city.
Supranational, sub-sovereign, and agency (SSA) Bond	Bond issued by the World Bank or European Investment Bank. The bonds have characteristics similar to corporate bonds with recourse to the issuer.

Table 1. *Cont.*

Types of Green Bonds	Features
Financial Sector Bond	A type of corporate bond issued by a financial institution to specifically raise capital to finance loans for environmental activities.
Covered Bond	The collateral is used as recourse for the issuer, and if the issuer is unable to repay the debt, the security of the bond is encumbered

Sources: [16,22,23]

2. Literature Review

Recent trends in the global economy (as well as in the Visegrad countries) are drawing attention to the issue of sustainability. In this context, green bonds as a new financing tool have become the subject of much discussion in the literature.

The area under discussion is the reasons for the issue of this type of bond. According to Lyon and Maxwell [24], green bonds can serve as a credible signal of an entity's (government, enterprise) commitment to the environment (the so-called signalling argument). The signal can be valuable because investors often lack sufficient information about an entity's commitment to environmental protection [7]. Issuing green bonds can be a form of greenwashing—the practice of making unsubstantiated or misleading claims about a company's environmental commitment. In this sense, companies issue green bonds to present themselves as environmentally responsible, but without taking tangible action. This results in the issuance of bonds, the income of which is actually used for purposes that have little environmental or social value. Such behaviour can be explained by increasing external pressure to engage in environmental or sustainability issues [25]. Flammer [26], on the other hand, argues that green bond issuers will choose to do what makes the most sense in their area, in addition to being motivated by changing institutional conditions to engage in projects that protect the environment and/or benefit society, rather than just providing them with financial returns. In addition, green bond issuers are credibly signalling their commitment to the environment. As this commitment becomes a reality, the environmental performance of issuers (e.g., companies) increases, as well as their attractiveness to environmentally sensitive investors. Signalling that a company is considering sustainability has several advantages: it increases customer demand, it increases sales and profit margins, it reduces the risk of future environmental liabilities and lawsuits, it reduces production costs through pollution reduction measures, etc. Moreover, improved environmental performance can prompt the government to issue new regulations, resulting in a competitive advantage for those firms that have taken regulatory action and are the first to comply [25].

The source literature focuses largely on two aspects. The first aspect is understanding whether there is a systematic price difference between conventional bonds and similar green bonds, i.e., the green bond premium, while the second focuses on identifying the green bond pricing factors.

Research by Löffler et al. [27] on the difference between the yields of green bonds and conventional bonds shows that green bond yields are lower than those of conventional bonds. This is because investors are more interested in the environmental or social benefits of the project than in other objectives. In addition, they argue that green bonds carry a lower risk than conventional bonds because their issuance involves a more transparent and regular monitoring process [27]. Cheong and Choi [28] on the other hand, identified different results in their review of the literature on green bond pricing. They showed that most studies indicate positive effects on the yield of these bonds, highlighting the fact that investors are interested in projects with social benefits. On the other hand, they also showed the opposite effects, which they explained by the novelty of the instrument and the limited investor base [28]. One of the trends in the source literature points to the existence of a negative premium of green bonds over conventional bonds in recent years, exemplified by studies by Preclaw and Bakshi [29] Ehlers and Packer [1] Baker et al. [30]. Petrova [31] and Sheng at al. [32] However, other studies show no significant difference

in green and conventional bond yields, e.g., Karpf and Mandel [33] Kapraun et al. [34] or even higher green bond yields, for example, Karpf and Mandel [35] and Bachelet et al. [36]. Kapraun et al. [34] however, emphasise that the existence and importance of the green premium vary considerably across currencies and issuer types. It is high and significant for bonds issued by governments or supranational organisations and for bonds denominated in EUR. However, for corporate green bonds, the additional verification of green credentials is required. There are also studies such as that conducted by Antoniuk et al. [37] that have shown that the existence and significance of the green premium depend on unexpected political events related to climate change. They have demonstrated that green bonds significantly outperform conventional bonds in terms of return. They found that unexpected political events, such as the 2015 Paris Agreement, have a positive and significant impact on green bonds and no significant impact on conventional bonds, while, for example, the 2016 US presidential election had a negative impact on bonds overall, but a much larger negative impact on green bonds compared to conventional bonds [37].

The second aspect of the source literature focuses on identifying green bond pricing factors. Wang et al. [38] examined the factors affecting the risk premium of issuance in the green bond market, and their results showed that credit rating, issuance period, and issuance size are three factors that directly affect the risk premium of green bond issuance. Dan and Tiron-Tudor [5], in their examination of the relationship between green bond issuance size and environmental, social, governance, and macroeconomic factors, showed that countries with higher levels of green bond issuance were primarily characterised by good ratings, which increased investor confidence. The ESG risk index, the inflation rate, and the budget balance also influenced the level of issuance. It has also been observed that non-financial performance information becomes important when issuing green bonds, with attention being focused on softer elements. According to Anh Tu et al. [39], financial and infrastructural factors play the most important role in the development of the green bond market. Among them, an effective monetary policy, a controlled inflation rate, political stability ensuring sustainable development, as well as social concern for the environment all play a special role. Besides these, the institutional infrastructure and the legal framework for green bond issuance are important factors influencing the green bond market. It is also emphasised that financial and infrastructural factors are more important for the growth and expansion of the current green bond market than economic and political or social criteria [39].

Another group of articles examines the economic and environmental impact of green bond issuance, focusing on market reaction and economic value implications. Elsayed et al. [40] analysed the interdependence between green bonds and financial markets in the time–frequency domain and found that in the long run, green bonds and financial markets are highly integrated. They proved that the green bond market is a net receiver of externalities from other markets. They also showed that the links between green bonds and financial markets are unstable over time [40]. Zhou and Cui [41] found a positive impact of green bond issuance on share prices, profitability, operating performance, environmental improvement, and corporate social responsibility. Other authors indicate that the size of the economy, trade openness, capital account, and distance from the equator lead to the development of the government bond market, while the control of corruption and the quality of bureaucracy lead to the development of the corporate bond market [42]. Banga [43] finds that green bond market determinants are similar to those for conventional bonds. In contrast, investors' climate consciousness and policymakers' commitment to addressing climate change are key determinants of green bond market development. It is also worth pointing out that the stock market reacts positively to the announcement of a green bond issue, and this effect is stronger in the case of certified bonds [44]. Global awareness of the risks associated with climate change is directing attention towards new financial tools, including green bonds, to finance environmentally friendly projects. In this context, these bonds are becoming a viable financial instrument, the proceeds of which are used exclusively to finance eligible projects. This market is growing rapidly, but there are

some biases, as stakeholders do not always understand the economic benefits, and as a result, green bonds are only seen as an instrument of communication [45].

The source literature identifies both the main benefits and stimulants for the development of the green bond market, i.e., capital mobilisation, the development of the so-called green debt market, the diversification of the investor base, and the improvement of the issuer's image [10]. One of the most important benefits of issuing green bonds for the issuer is to raise capital for low-carbon and climate change-resilient projects. Issuing these bonds helps to lower the cost of financing eco-projects, attracting new bondholders and stimulating capital for sustainable development. An important aspect of expanding green bond financing is public education. Governments should play a key role in raising investors' environmental awareness of green debt and should undertake a range of activities to promote the potential of green bonds (ranging from encouraging public agencies to take an interest in the issue to organising conferences or introducing tax credits for the development of low-carbon assets). In addition, in order to limit excessive freedoms on green issuance, governments may develop national standards and definitions for the bonds in question, as have India, Brazil, and China [10,15]. An important element is that the expansion of green bond offerings contributes to the development of the financial market. For example, 2014 saw the creation of the first ever green bond index, the Solactive Green Bond Index Series, followed by the S&P Green Bond Index, the Barclays MSCI Green Bond Index, and the Bank of America Merrill Lynch Green Bond Index. These indices function as benchmarks for green bond investments and form the basis for the construction of other financial products, for example, ETFs (Lyxor Green Bond UCITS ETF and VanEck Vectors Green Bond ETF). It is worth noting that such financial instruments popularise green investment activity [4].

Another determinant of the issuance of green bonds is increasing investor interest in environmental issues, thus increasing the demand for these instruments. Investors are more aware of the dangers of unrestrained economic expansion and realise that exploiting already limited natural resources reduces the chances of meeting the needs of future generations. Therefore, they realise that it is necessary to support issuers by bearing environmental factors in mind [4]. It is worth noting that an important reason for issuers engaging in environmentalism by issuing green bonds is to improve their image. Issuers use marketing advantages to improve their reputation, which is an intangible asset linked to investor loyalty. In addition, the convergence of stakeholder beliefs with the objectives of the bond issuer results in the building of long-term relationships and provides investors and market influencers with the opportunity to become credible market participants. Issuing green bonds presents the issuer in a better light—as socially and environmentally committed [10].

In the discussion on the issue of ecological bonds, attention should also be paid to the principal benefits and threats resulting from the issuance of green bonds, both for the issuer and for the investor (Table 2).

Table 2. Benefits and threats of green bond issue for issuers and investors.

	Advantages	Disadvantages
Issuers	• Presentation and implementation of the issuer's approach to the issue of ESG bonds (Environmental, Social, Governance) are factors related to environmental protection, society and corporate governance that affect the long-term value of the entity. These criteria, in line with the conscious and sustainable allocation of resources, should be appropriate; • Used in making investment decisions; • Improving the diversification of the investor base of green bonds; • Buy-and-hold green bond investors may contribute to reducing volatility in the secondary market; • Significant investor demand for bonds can lead to oversubscription and an increase in issuance; • Reputation improvement; • Increased credibility of the sustainable development strategy; • Access to the "economies of scale", as most of the emission costs are related to the emission process.	• Reputational risk, should the green credentials of the bonds be questioned; • Transaction costs associated with administration, certification, reporting, verification, and monitoring. Investors can claim penalties for a so-called "green default", whereby the bond is repaid in full if the issuer breaches the agreed green clauses.
Investors	• Investors can offset risk-adjusted financial returns with environmental benefits; • Meets environmental, social, and governance (ESG) requirements; • Better risk assessment in an otherwise opaque fixed income market through the use of income reporting; • Potential use of pure-play, project and ABS to actively hedge climate policy risk in a portfolio including green assets; • Recognised by the United Nations Framework Convention on Climate Change (UNFCCC) as a non-state actor taking "climate action"; • Engagement and private dialogue with issuers on ESG in relation to green bond issuance, facilitates issuer credit assessment; • Traceability of issue proceeds and reporting leads to improved internal governance structures.	• Small and emerging (and potentially less liquid) market, small size of bond issues, • Lack of harmonised standards can cause confusion and increase reputational risk in the event of questioning the ecological integrity of the bond; • Limited possibilities of legal enforcement of ecological integrity; • Lack of standardisation can lead to complications in the research; • The need for additional due diligence may not always be met.

Source: Own study [46,47].

Table 3. Barriers and solutions in the green bond market.

Barriers	Solutions
General bond market challenges	Increasing green bond issuance and investment activity by governments, local authorities, and development/investment banks.
Difficulties in accessing local markets for foreign investors	Promoting international cooperation and cross-border flows.
Lack of domestic investors in green bonds	Promoting the integrity of green bonds and raising awareness of their benefits.
Higher risks associated with green bonds	Ensuring credit enhancement, use of tax incentives, implementation of risk mitigation instruments, e.g., securitisation options.

Table 3. *Cont.*

Barriers	Solutions
Lack of awareness of the benefits of green bonds, lack of existing international/local guidelines and standards for project eligibility, deficit of harmonised global standards,	Developing a definition and standardisation of the green bond framework.
Lack of a labelled green bond, greenwashing risk,	Labelling of eligible bonds.
Lack of bankable projects	Strengthening the roles of development finance and public institutions.
Compliance costs	Reducing issuance, certification, reporting, and other administrative costs, use of tax incentives by the Ministry of Finance.
Lack of ratings, indices, and quotations	Development of indices, ratings, and exchange lists.
Lack of information on the impact of green bond projects, lack of mandatory disclosures by issuers.	Regular reporting on environmental impacts.

Source: [5,48].

The green market has grown rapidly but is a relatively small part of the financial market compared to conventional bonds, so Tolliver et al. [48], and Dan and Tiron-Tudor, [5], attempted to identify the main barriers to the development of green bonds and provide potential solutions, which are detailed in Table 3.

The development of the green bond market varies around the world. In many countries, green bonds have not yet been issued. Our research was directed at the Visegrad countries.

3. Materials and Methods

3.1. Green Bond Issuance in V4 Countries

The start of green bond issuance in the V4 countries dates back to 2016 (in Poland). Since then, green bonds have been issued in all V4 countries, with both the number of issues and the value of issues varying. The largest number of issues was carried out in Poland (9 issues) and Hungary (8 issues), followed by the Czech Republic (7 issues), and finally, Slovakia, where only one issue was carried out [49]. The currency of the green bond issues also differed in each country. In US dollar terms, Poland raised the most funds through green bond issues to the value of USD 5893.81 million, with the Czech Republic raising USD 5582.61 million. In contrast, Hungary's issuance amounted to USD 3320.73 million and Slovakia's to only USD 361.38 million [49]. Green bond issuance across countries also varied by sector. Poland and Hungary were dominated by the government sector, while the Czech Republic and Slovakia were dominated by the corporate sector, mainly non-financial.

The issue of green bonds in Poland took place both in the state sector and in non-financial and financial enterprises. The value of the funds obtained, converted into US dollars, was as follows:

- USD 3069.18 million for the state sector;
- USD 862.67 million for the non-financial enterprise sector;
- USD 720.20 million for the financial enterprise sector.

Since 2016, the Polish government has carried out four euro-denominated green bond issues. The first issue of government green bonds took place on 19 December 2016. These were 5-year bonds in which the yield was set at 0.5%. The Polish government raised €750 million ($791.89 million) through the bond issue. Another green bond issue by the Polish government (worth €1 billion, or $1243 million) took place on 7 February 2018. This issue matures on 7 August 2026 and has a coupon rate of 1.13%. The next largest green bond issue to date, conducted on 7 March 2019, enabled the Polish government to raise 50% more capital (USD 1707.06 million) at a cost 0.13% lower than the previous issue (1%). The maturity date of these bonds is 7 March 2029. In contrast, the longest tenor (i.e., the period from the bond issue to the scheduled redemption date) of the green bonds issued by the Polish government is 30 years and relates to the issue conducted on 7 March 2019. As a

result of this issue, the Polish government raised €500 million, but with the highest cost of capital (2%) resulting from the coupon.

In addition to the government sector, the main issuers of green bonds in Poland have been non-financial companies, including PKN Orlen and Cyfrowy Polsat. PKN Orlen is a listed company active in energy and mobility based on advanced and clean technologies. The company's main focus is on renewable energy and modern petrochemicals, as well as the search for innovative solutions in the areas of new mobility, hydrogen energy, and recycling. The company's main objective is to achieve carbon neutrality in 2050. A natural consequence of the mission undertaken at PKN Orlen is to raise funds by issuing green bonds. PKN Orlen carried out its first and so far only green bond issue (denominated in euro) on 21 May 2021, from which it raised €500 million (USD 607.30 million). The bond yield was set at 1.13%, with a maturity date of 27 May 2028.

Another non-financial company that has issued green bonds in Poland is Cyfrowy Polsat. The company's core business focuses on the provision of integrated media and telecommunications services in Poland, including satellite, terrestrial and internet television services, mobile and fixed telephony services, data transmission services, and broadband internet access, as well as wholesale services in the inter-operator telecommunications, television, and advertising markets. In December 2021, the company adopted a new programme called Strategy 2023+, which involves expanding its existing operations into a new area—clean energy production. One year prior to the adoption of the new strategy, Cyfrowy Polsat issued green bonds (denominated in the Polish zloty) with a nominal value of PLN 1 billion and with a maturity date of 12 February 2027. The yield on the bonds was determined based on 6m WIBOR plus 165 bps.

A similar yield calculation is represented by green bonds issued by financial companies in Poland. Among green bond issuers in the financial sector, two banks should be singled out: mBank and PKO Bank Polski. mBank was the first fully online bank in Poland. It is currently focusing on implementing innovative solutions, especially within online and mobile banking. In addition, mBank focuses on activities in five strategic segments, which include retail banking, the e-commerce segment, corporate banking, technology, security and data, and employees and organisational culture. mBank's first and so far only green bond issue took place on 20 September 2021, with a maturity date of 21 September 2027. The bond's yield is derived from the 3m EURIBOR interest rate, plus 1.25%. As a result of this issue, mBank raised €500 million ($590.65 million).

The last financial company to issue green bonds in Poland is PKO BP Bank. PKO BP is one of the largest and at the same time oldest banks operating in the Polish market. Its activities are based on the idea of sustainable development. PKO BP Bank has implemented a strategy aimed at protecting the environment, as well as a strategy assuming a positive impact on the social environment. In terms of environmental protection, the bank has taken measures to simplify and streamline processes by reducing paper documentation (optimising paper consumption) and by reducing energy consumption. In addition, the bank has implemented new procedures related to space optimisation and efficient waste management. Furthermore, as part of its cooperation with the social environment, PKO BP Bank has launched sponsorship and charity activities.

PKO BP Bank carried out two green bond issues. The first issue took place on 10 June 2019, maturing on 30 September 2024, with the bank raising PLN 250m (USD 65.70 million). The bond yield was set at 3m WIBOR, plus 0.6%. PKO BP's second green bond issue took place on 27 November 2019 and matures on 2 December 2024. The cost per interest payment (coupon) was set at 3m WIBOR, plus 51 bps. The execution of the issue enabled the bank to raise PLN 250m (USD 63.85 million).

The second country in the V4 countries in terms of green bonds issued is the Czech Republic. In the Czech Republic, cash was raised exclusively for the corporate sector, with a significant portion for the non-financial sector (USD 4989.05 million), while only USD 593.56 million was raised for the financial sector.

The main issuer of green bonds in the Czech Republic is CTP Group N.V., which operates in the logistics and industrial real estate sector in Central and Eastern Europe. Its structure includes two economically related companies: CTP Property B.V. and CTP Invest spol., s r.o. CTP Property B.V. is involved in property management, while CTP Invest spol., s r.o. is a commercial property developer and asset manager. The portfolio of CTP Invest spol., s r.o. consists of 96 premium industrial business parks with a total leasable area of more than 5.5 million square metres. The company's portfolio includes both industrial parks comprising warehouse space and other space necessary for business development, as well as business parks. The business parks focus on office space, office services, and shops located in the city centres of Central and Eastern Europe.

CTP Group N.V.'s activities are geared towards sustainability and take into account the impact on the environment and the surroundings in which it operates. The entire portfolio of the CTP N.V. Group is BREEAM-certified (Building Research Establishment Environmental Assessment Method), confirming the implementation of the sustainability concept for infrastructure and buildings. Consequently, the company's financing is also based on the concept of sustainability, as the company has been raising cash through the issue of green bonds, denominated in euros, for the past three years. In 2020, CTP Group N.V. issued 2 series of green bonds with a total issue value of €1050 million (USD 1234.38 million), i.e., €650 million (USD 757.80 million) for the 5-year bond and €400 million (USD 476.58 million) for the 3-year bond. The yield on the €650 million issue value bond was set at 2.1250% and its maturity date is October 2025. In contrast, the yield on the bond with an issue value of €400 million was set at 0.0625%, and its maturity date falls in November 2025.

In 2021, CTP Group N.V. continued to issue green bonds and issued 3 series of bonds. The first issue took place on 18 February 2021. The issue value of the bonds issued with a maturity date of 18 February 2027 was EUR 500 million (USD 603 million) and their yield was set at 0.75%. The next green bond issue took place on 21 June 2021 and was divided into two equal tranches with a nominal value of €500 million (USD 593.10 million) each. The different tranches differed in maturity and interest rate level. The maturity of the first tranche (with a yield of 0.5%) was set as 21 June 2025, while the maturity of the second tranche (with a yield of 1.25%) was set as 21 June 2029. The tenor of the bonds for this issue was 4 and 8 years. A similar procedure also applied to the next green bond issue, which took place on 27 September 2021. The tenor of the issue was €1 billion (USD 1171.80 million) and was also divided into two tranches with issue values of €500 million. This time, the tenor of the bonds issued was the longest, at five and 10 years. The yield on the five-year green bond was set at 0.625% while the yield on the 10-year bond was set at 1.50%.

The procedure for financing CTP N.V.'s operations with green bonds was also maintained in 2022. The most recent green bond issue, with a maturity date of 20 January 2026, took place on 6 January 2022. During this issue, the CTP N.V. group raised EUR 700 million (USD 793.67 million) and the cost of this issue, resulting from the coupon, was set at 0.875%.

In addition to CTP N.V., another issuer of green bonds in the Czech Republic was Ceska Sporitelna AS, part of the Erste Group, which operates in Central Europe. Ceska Sporitelna AS is one of the oldest banks in the Czech market, offering banking and other financial market services to individuals, small and medium-sized enterprises, and large corporations, as well as cities and municipalities. The bank's activities are guided by the principles of sustainable development. The bank adapts its business activities to the environment in which it operates. Above all, it supports the development of local communities, strives to improve education, supports the elderly and people with intellectual disabilities by adapting its services to people with different types of disabilities, and prevents the spread of drug addiction by taking preventive measures. The first and so far only green bond issue was carried out by Ceska Sporitelna AS Bank on 13 September 2021, through which it raised €500 million (USD 593.56 million). The maturity date of this issue was set for 13 September 2028 and the bond yield was set at 0.50%.

Hungary is the third country in the V4 countries in terms of green bond issuance. Green bond issuance in Hungary has taken place both in the state sector and in non-financial and financial companies. The value of funds raised, in US dollar terms, was as follows:

- USD 2858.33 million for the state sector;
- USD 300 million for the financial enterprise sector;
- USD 162.40 million for the non-financial corporate sector.

Since 2020, the Hungarian government has carried out six green bond issues, denominated in both Hungarian forints and the euro, US dollars, Japanese yen, and Chinese yuan. Hungary's first government green bond issue took place on 5 June 2020. The tenor of this issue is 15 years and the yield was set at 1.75%. Through the issue, the Hungarian government raised €1500 million (USD 1643.10 million). Another issue was denominated in Japanese yen and took place on 18 September 2020. The value of the issue was 40 million Japanese yen (USD 376.79 million). The issue was divided into three tranches, differentiated by value, tenor, and interest rate (Table 4).

Table 4. Hungarian government green bond issue of 18 September 2020.

Yen Value (in Millions)	Dollar Value (in Millions)	Pricing Date	Settlement Date	Maturity Date	Tenor	Coupon
20,000	188.40	11 September 2020	18 September 2020	18 September 2025	5	0.74%
15,500	146	11 September 2020	18 September 2020	17 September 2027	7	1.03%
4500	42.39	11 September 2020	18 September 2020	18 September 2030	10	1.29%

Source: [49].

Two more green bond issues were carried out by the Hungarian government in 2021. The first issue, through which the government raised 30 million Hungarian forints (USD 162 million), took place on 22 April 2021. The maturity date of the bond was set for 28 April 2051 (the tenor is 30 years). The bond yield on this issue is 4%. In the same year, the Hungarian government also raised USD 157 million through another green bond issue. The issue took place on 14 December 2021 and was denominated in Chinese yuan. The tenor was set at three years and the yield was 3.28%.

A few weeks later (26 January 2022), the Hungarian government conducted another green bond issue with maturity set for 27 May 2032. The yield on the bonds issued was 4.50%. As a result of the issue, the government raised 20,799.98 million Hungarian forints (USD 66.87 million).

Hungary's most recent government green bond issue took place on 25 February 2022 for a total of 59.30 million Japanese yen (USD 514.99 million). Like the previous issue denominated in Japanese yen, the current issue was also divided into three tranches, differentiated in terms of value, tenor, and interest rate (Table 5).

Table 5. Hungarian government green bond issue of 25 February 2022.

Yen Value (in Million)	Dollar Value (in Million)	Pricing Date	Settlement Date	Maturity Date	Tenor	Coupon
46,800	406.4339	18 February 2022	25 February 2022	25 February 2027	5	0.73%
4700	40.81708	18 February 2022	22 February 2022	22 February 2029	7	0.91%
7800	67.73899	18 February 2022	25 February 2022	25 February 2032	10	1.15%

Source: [49].

In addition to the government sector, two companies from the corporate sector have also issued green bonds in Hungary. The first issue was carried out by Futureal, a group focusing on the real estate market in Hungary, Poland and the UK. Futureal is a group comprising three companies:

- Futureal—which develops retail properties;

- Cordia—which is a developer of residential properties;
- HelloParks—which develops industrial and logistics facilities.

In addition to its core business, the Futureal Group is also active in such areas as fund management, investment in public and private bonds, and factoring. The company's mission is to implement the principles of sustainable development, which it does by:

- Minimising paper consumption through the use of technological improvements;
- Creating a green environment;
- Encouraging healthy eating;
- Selective waste collection;
- Providing filtered, clean water throughout offices;
- Providing electric car chargers, bicycle storage, and changing facilities to promote environmentally friendly transport.

Futureal Group's first and so far only green bond issue raised 50 million Hungarian forints (USD 162.40 million). The bond matures on 23 March 2031 and has a yield of 4%.

The second company to issue green bonds on the Hungarian market is the Bank of China (Hungarian Branch). The bank was opened in December 2014 and has been an active participant in the Hungarian market since then. The Bank of China (Hungarian Branch) issued a green bond (denominated in US dollars) on 16 February 2022. The tenor of the bond was 2 years and the bond yield was set at 1.62%. With this issue, the Bank of China (Hungarian Branch) raised USD 300 million.

The smallest green bond issuance in the V4 countries was recorded in Slovakia, where only one issue took place. The issuer of the bond is Tatra Banka, a leader in financial innovation in the Slovak market. The bank's strategy focuses on customer value-oriented innovation. From the green bond issue conducted on 23 April 2021 (maturing on 23 April 2028), the bank raised EUR 300 million (USD 361.38 million). The yield of the bond was 0.5%.

3.2. Method

The article uses a proprietary algorithm based on multi-way analysis and dynamic programming to provide a detailed analysis of the yield on bonds in the Visegrad group. Dynamic time warping was selected from among dynamic programming methods, and hereinafter in the article is abbreviated as the DTW measurement, while from multi-way analysis methods the Daubechies wavelet was selected. The dynamic time warping in the model is used to measure the degree of similarity of changes between the tested time series, and more specifically between the series representing the current yield of a given bond and selected indicators. The DTW algorithm was used in the model because it is extremely effective in measuring the similarity of signals in the time domain. It minimises the effects of signals being shifted and distorted by the "flexible" transformation of the time signal, which allows similar shapes to be found with different phases [50,51]. The wavelet analysis in the model is used to conduct the wavelet decomposition of the analysed time series, and to investigate their similarity in specific trends. Brief characteristics of dynamic time warping and wavelet analysis are presented below.

3.3. Theoretical Background to the Method

3.3.1. Dynamic Time Warping (DTW)

A standard application of the dynamic time warping algorithm is to use its properties to match two waveforms that are out of sync with each other or differ in the speed of the waveform. In fact, any data that can be linearised can then be analysed using the DTW. The most frequently used distance measurement in the DTW algorithm is the Euclidean measure, although it is possible to use virtually any distance measure [52,53]. Simply put, the way the DTW algorithm works can be described as follows:

- We introduce the time series X, Y to the algorithm. The series X has the length N. The series Y has the length M.

- The algorithm creates a grid with the dimensions N x M, where, in each of its fields, the distance between the samples of signals with numbers n and m is calculated, where n = 1, 2,..., N and m = 1, 2,..., M.
- The algorithm searches for path W connecting the points (1, 1) and (N, M) in such a way that the cost of the transition between these points is as low as possible. This path must meet the following conditions:
  - Border;
  - Monotonicity;
  - Stride length.

The monotonicity condition ensures that the waveforms are properly timed, which means that none of the waveforms will go back in time in the matching process.

The stride length condition means that successive points on the fitting path cannot jump too far on the fitted waveforms. This condition ensures that no elements of the X and Y waveforms are omitted.

- In each step, the next point on the path must be specified so that it is adjacent to the previous point, and indices n and m cannot decline. The selected path is called the optimal alignment path.

Matching two signals to each other using the DTW method allows the distance between them to be determined. In the case in question, it is calculated as the sum of the values of all fields through which the path passes. A highly detailed description of the algorithm is presented in Hadaś-Dyduch [54,55].

3.3.2. Wavelet Analysis

The functions called wavelets can be said to have arisen in response to the need to create a mathematical apparatus that would allow the study of the properties of signals in the vicinity of selected time moments in a way that was improved in comparison to the windowed Fourier transform (more, among others, in Hadaś-Dyduch, [54–56], Rakowski [57]). Before starting an adventure with wavelet analysis, it is important to know that the fundamental feature of a wavelet is the lack of a constant component. This property means that the wavelet must have oscillations. The wavelet should be different from zero only over a finite interval of time, or fade very quickly, e.g., exponentially, outside of this interval.

The wavelet transform consists of calculating the wavelet transform $Wf(t,s)$, which is the scalar product of the signal $f(t)$ and the scaled and shifted wavelet:

$$Wf(t,s) = \langle f(\tau),\ \psi_{t,s}(\tau) \rangle \tag{1}$$

where:

$$\psi_{t,s}(\tau) = \frac{1}{\sqrt{s}} \psi\left(\frac{\tau - t}{s}\right) \tag{2}$$

$$\int_{-\infty}^{+\infty} \psi(t)dt = 0 \tag{3}$$

The wavelet transform of a function of one variable, according to the cited formulas, is a function of two variables: time and scale. It is a highly redundant and computationally expensive representation. It is natural to try to discretise the time-scale plane in such a way as to reduce the computational effort and maintain the reversibility of the wavelet transform. The general method of discretisation is the use of scaled and shifted wavelets according to the formula [58]:

$$\psi_{n,j}(\tau) = \frac{1}{\sqrt{a^j}} \psi\left(\frac{\tau - na^j b}{a^j}\right) \tag{4}$$

where $a > 0,\ b > 0$ are time-scale plane discretisation parameters.

However, to calculate the discrete wavelet representation of the signal, digital filters h and g are needed. In the case of orthogonal transformations, one low-pass filter h is sufficient, since it serves as a basis, in a simple way, for the creation of a high-pass filter g. The wavelet is not directly used in discrete wavelet transformations, but its properties determine the values of the set of numerical coefficients constituting the wavelet representation of the signal. The selection of the wavelet determines the selection of associated digital filters appearing in the transformation patterns [58].

There are many types of wavelets. Each of the wavelets has its advantages and disadvantages. Details in this respect are described, among others, in the monograph by Hadaś-Dyduch [55]. One of the more interesting wavelets is the Daubechies wavelet. This is an example of a compact carrier wavelet. Details of this family of wavelets are described, inter alia, in Daubechies [59]; Antonini, Barlaud, Mathieu, and Daubechies [60]; and Hadaś-Dyduch [56].

The scaling functions and wavelets associated with orthogonal filters with compact carriers do not have analytical formulas allowing their values to be calculated. Daubechies provided an algorithm called the cascade algorithm for computing with any degree of precision the approximate value of the scaling function based on the low-pass filter h. Details of this algorithm are described by Daubechies in her paper published in 1992. The scaling function corresponding to Daubechies' Grade 2 filter, calculated by the cascade algorithm in MATLAB software, is shown in the figure below (Figure 1).

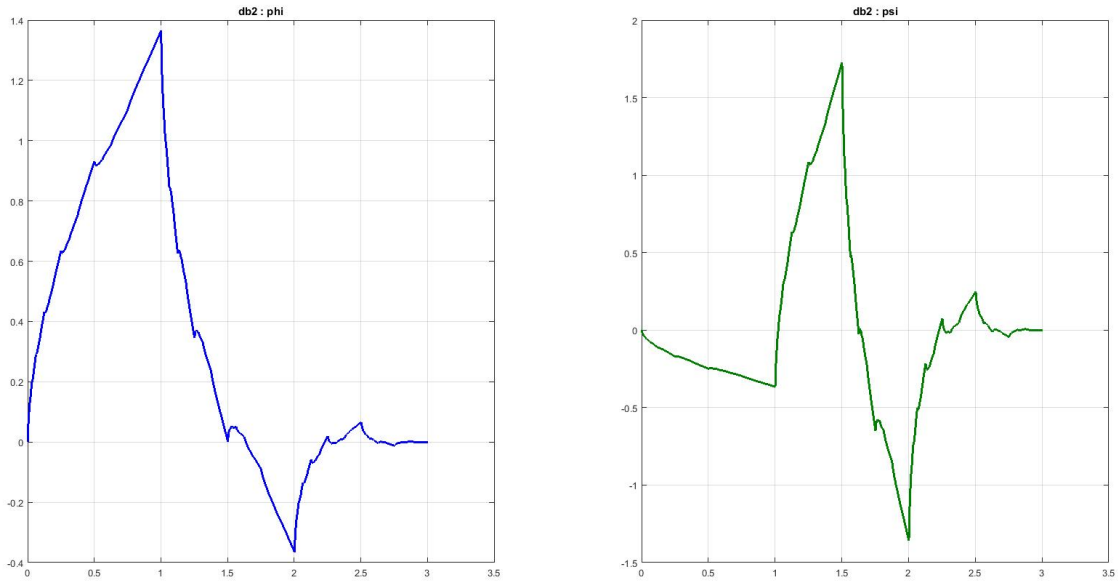


Figure 1. Scaling function Daubechies 2 (**left**) and wavelet Daubechies 2 (**right**).

The Daubechies wavelet generated in the figures above is calculated from the following wavelet equation:

$$\psi(t) = \sqrt{2} \sum_{n=-2}^{1} (-1)^n h[1-n] \phi(2t-n) \tag{5}$$

where:

$\phi(t)$—scaling function of the wavelet $\psi(t)$

$h[1-n]$—filters of Daubechies:

$$h[0] = \frac{1+\sqrt{3}}{4\sqrt{2}}$$

$$h[1] = \frac{3+\sqrt{3}}{4\sqrt{2}}$$

$$h[2] = \frac{3-\sqrt{3}}{4\sqrt{2}}$$

$$h[3] = \frac{1-\sqrt{3}}{4\sqrt{2}}$$

A detailed description of the Daubechies wavelet is presented, among others, in Daubechies, [61]; Hadaś-Dyduch [55,56].

3.3.3. Research Model

In this article, a modification of the original WDTW algorithm was used to provide a detailed analysis of the yield on bonds in the Visegrad group. This algorithm is based on wavelet analysis and dynamic time warping. As mentioned above, the DTW measurement in the proprietary model is used to measure the degree of the similarity of changes between the tested time series, and more specifically between the series representing the current yield of a given bond and selected indicators. Meanwhile, the wavelet in the original WDTW model is used to make a wavelet decomposition of the analysed time series and to investigate their similarity in specific trends. The study included 18 bonds with different investment durations. Moreover, the stock exchange quotations of these bonds were used. A total of 3245 observations were used: Czech Republic—1283 observations, Hungary—342 observations, Poland—1376 observations, and Slovakia—244 observations.

The proprietary model is described below in a few principal steps.

STEP 1

We introduced the following one-dimensional time series into the model:

- P—bond market price at the session closing price; the series has n observations;
- C—the number of annual coupon payments determined according to the bond coupon; the series has n observations;
- $X_1, X_2, \ldots, X_n$—Indicators. Series of any dimension.

STEP 2

We then calculated the current yield on the bond for its holder as the quotient of the market price of the bond according to the session closing price and the coupon payments specified in the bond prospectus. We obtained a one-dimensional series Y that has n observations.

STEP 3

We applied the DTW algorithm to determine the degree of similarity of changes between the series presenting the current yield of a given bond and the indicators selected for the research: $X_1, X_2, \ldots, X_n$.

STEP 4

Equal amount of data in the series (this step is not required). For series Y and series $X_1, X_2, \ldots, X_n$, we brought about equality with appropriate statistical methods. After this step, $Y, X_1, X_2, \ldots, X_n$ had the same number of elements and related to the same research period.

STEP 5

Extending the time series. We extended the data using appropriate methods so that the number of each series is a multiple of the number 2. The literature provides various methods for extending a finite series, e.g., zero padding, assumption of periodicity, mirroring at the end of the signal, and the like. Each method has its advantages and disadvantages. The degree of highlighting the advantages and disadvantages of the series extension methods depends on many factors, one of them being the specificity of the series being tested.

STEP 6

Wavelet decomposition of each series at the first resolution level. Based on the algorithms of the discrete wavelet transform, we determined the coefficients for the short-term relationship. We received the so-called details and approximation.

STEP 7

Using a dynamic wavelet transform, we determined the distance (describing the degree of similarity) between the appropriate coefficients of the Y series and the series X_1, $X_2, \ldots,$ X_n. We denote the distance as WDTW.

STEP 8

In the next steps, we used a dynamic wavelet transform to determine the distance between the coefficients on the first level of decomposition, then on the second level of decomposition, etc. The maximum number of steps in the algorithm depends on the length of the series being tested. In the case of series of different lengths, the number of maximum steps depends on the number of elements of the shortest series included in the test.

4. Results

We introduced the following indicators into the proprietary model described above, depending on the country:

- P—The market price of the bond at the session closing price;
- C—Annual coupon payments determined according to the bond coupon;
- X_1—Inflation;
- X_2—Inflation moved one period ahead;
- X_3—Non-financial corporations. Loans and advances. Credit unions;
- X_4—Non-financial corporations. Loans and advances. Banks;
- X_5—Non-financial corporations. Debt securities. Credit unions;
- X_6—Non-financial corporations. Debt securities. Banks;
- X_7—Non-financial corporations. Deposits. Credit unions;
- X_8—Non-financial corporations. Deposits. Banks;
- X_9—Bank Overdrafts;
- X_{10}—Loans up to EUR 1 million by initial rate fixation. Floating rate and up to 1 year;
- X_{11}—Loans up to EUR 1 million by initial rate fixation. Over 1 and up to 5 years;
- X_{12}—Loans up to EUR 1 million by initial rate fixation. Over 5 years;
- X_{13}—Loans over EUR 1 million by initial rate fixation. Floating rate and up to 1 year;
- X_{14}—Loans over EUR 1 million by initial rate fixation. Over 5 years;
- X_{15}—Loans for individual entrepreneurs. Variable and fixed rate up to 3 months inclusive;
- X_{16}—Loans for individual entrepreneurs—total;
- X_{17}—Deposits with a maturity of up to and including 1 month;
- X_{18}—Deposits with a maturity of over 1 month up to and including 3 months;
- X_{19}—Deposits with a maturity of over 3 months up to and including 6 months;
- X_{20}—Deposits with a maturity of over 6 months up to 1 year inclusive;
- X_{21}—Deposits with a maturity of over 1 year.

The analysis of the results obtained from the study was carried out through the prism of the countries belonging to the Visegrad group.

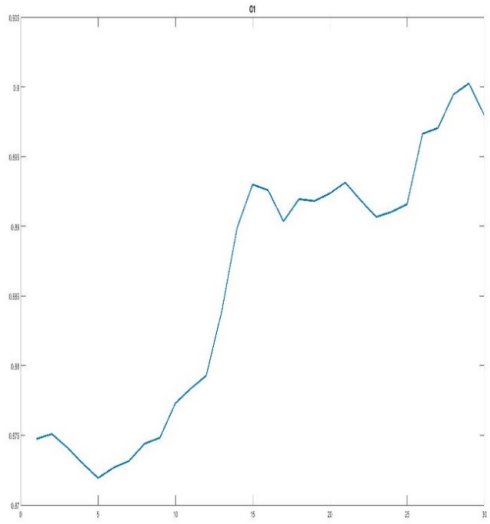
4.1. The Czech Republic

The analysis covers nine green bonds. Basic information on these bonds is presented in Table 6 below.

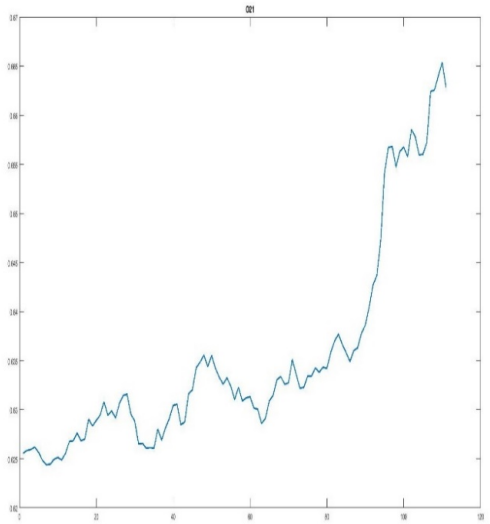
The first step in the analysis is to determine the current rate of yield on green bonds. The evolution of this indicator, understood as the quotient of the number of annual coupon payments determined in the study according to the bond coupon, and the market price of the bond at the session closing price, is presented in Figure 2 below.

Table 6. Brief characteristics of the bonds included in the model analysis.

Name	Pricing Date Swap_Vert	Settlement Date Swap_Vert	Maturity Date Swap_Vert	Coupon
O1	6 January 2022	20 January 2022	20 January 2026	0.875%
O2.1	21 September 2021	27 September 2021	27 September 2026	0.625%
O2.2	21 September 2021	27 September 2021	27 September 2031	1.5%
O3	06 September 2021	13 September 2021	13 September 2028	0.5%
O4.1	14 June 2021	21 June 2021	21 June 2025	0.5%
O4.2	14 June 2021	21 June 2021	21 June 2029	1.25%
O5	11 February 2021	18 February 2021	18 February 2027	0.75%
O6	25 November 2020	27 November 2020	27 November 2023	0.0625%
O7	17 September 2020	25 September 2020	01 October 2025	2.1250%



(**a**)



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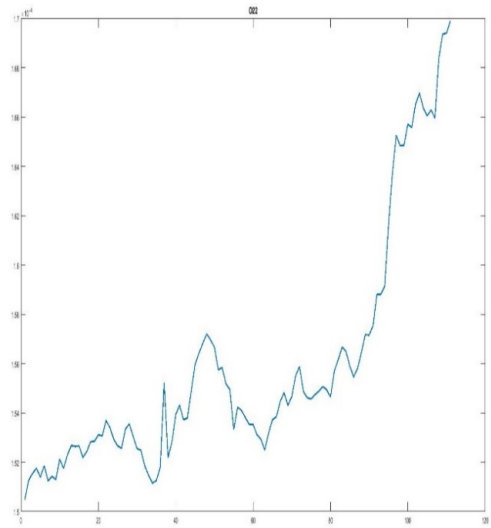

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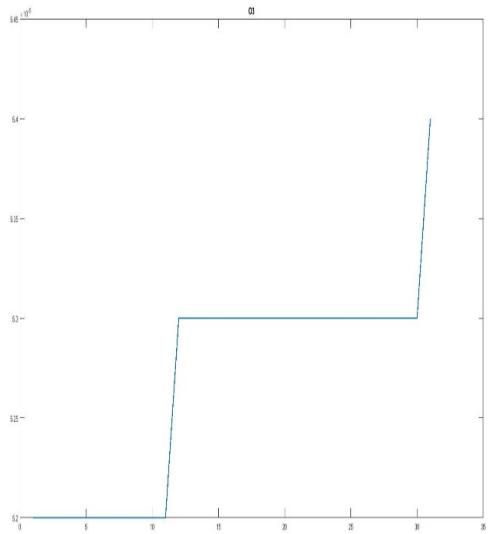
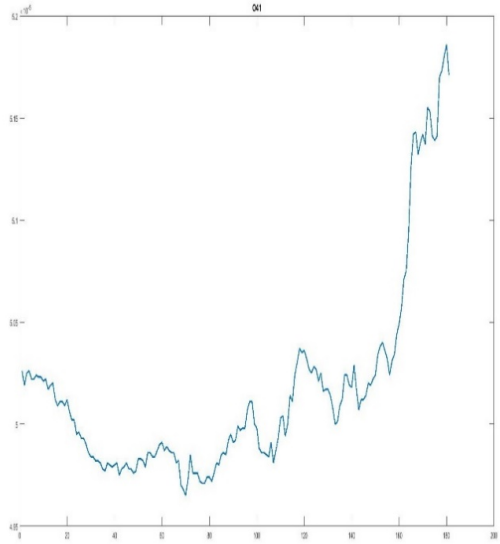


(**d**)

Figure 2. *Cont*.



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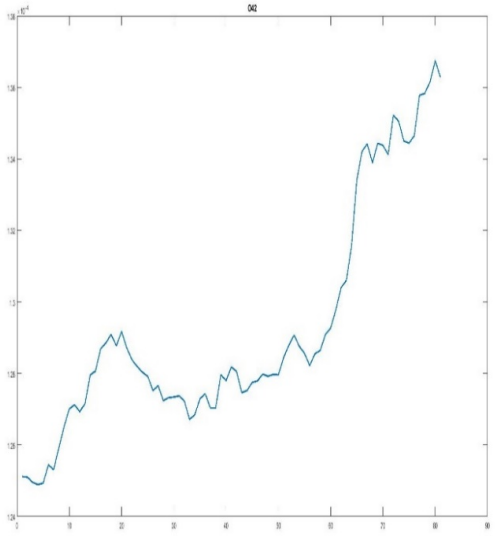

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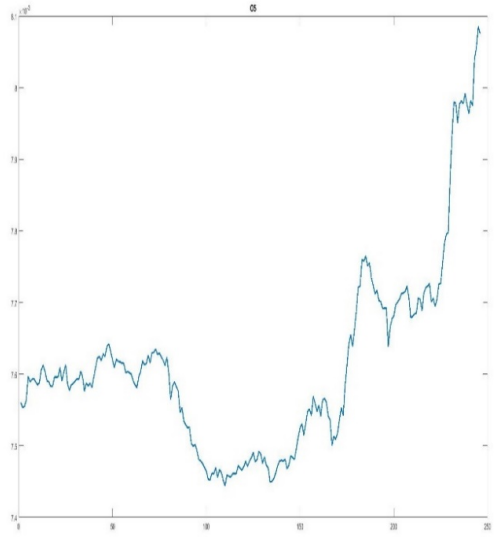
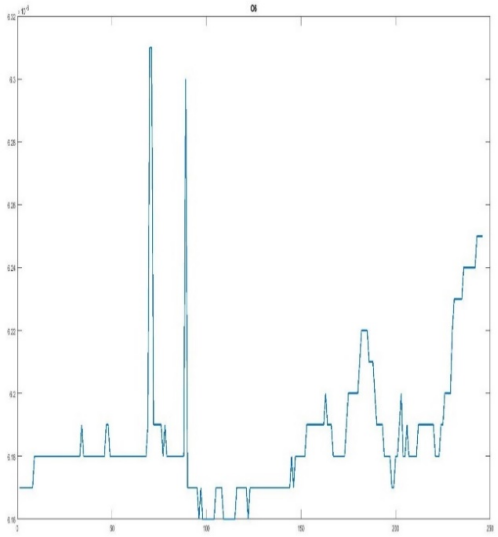
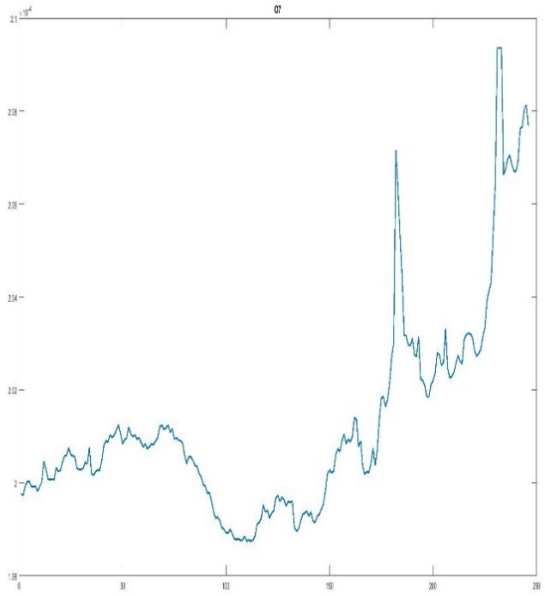


(**g**)



(**h**)

Figure 2. *Cont.*



(**i**)

Figure 2. The current rate of income (in %) for individually analysed green bonds issued in the Czech Republic. (**a**): The current rate of income (in %) for O1 green bonds issued in the Czech Republic; (**b**): The current rate of income (in %) for O2.1 green bonds issued in the Czech Republic; (**c**): The current rate of income (in %) for O2.2 green bonds issued in the Czech Republic; (**d**): The current rate of income (in %) for O3 green bonds issued in the Czech Republic; (**e**): The current rate of income (in %) for O4.1 green bonds issued in the Czech Republic; (**f**): The current rate of income (in %) for O4.2 green bonds issued in the Czech Republic; (**g**): The current rate of income (in %) for O5 green bonds issued in the Czech Republic; (**h**): The current rate of income (in %) for O6 green bonds issued in the Czech Republic; (**i**): The current rate of income (in %) for O7 green bonds issued in the Czech Republic.

The proposed ratio of the current rate of income for the analysed group of green bonds reaches a minimum value of 0.001% (bond O6), and a maximum value of 0.9% (bond O1). The average value of this ratio, depending on the bond, ranges from 0.005% to 0.886% (Table 7).

Table 7. Descriptive statistics for the current rate of income for individual (analysed) green bonds issued in the Czech Republic.

Bonds	Average	Minimum	Maximum	Std.Dev.	Kurtosis
O1	0.8860	0.8720	0.9000	0.0096	−1.5422
O21	0.6350	0.6240	0.6650	0.0108	0.9374
O22	0.0160	0.0150	0.0170	0.0005	1.2112
O3	0.0050	0.0050	0.0050	0.0001	−1.5788
O41	0.0050	0.0050	0.0050	0.0000	3.1660
O42	0.0130	0.0120	0.0140	0.0003	−0.2073
O5	0.0080	0.0070	0.0080	0.0001	2.2025
O6	0.0010	0.0010	0.0010	0.0000	9.7784
O7	0.0200	0.0200	0.0210	0.0002	2.5987

Source: Own calculations.

The estimated ratio of the current rate of income in the case of two analysed bonds is characterised by left-hand asymmetry, and in the remaining bonds by right-handed asymmetry (details in the two figures below, Figures 3 and 4).

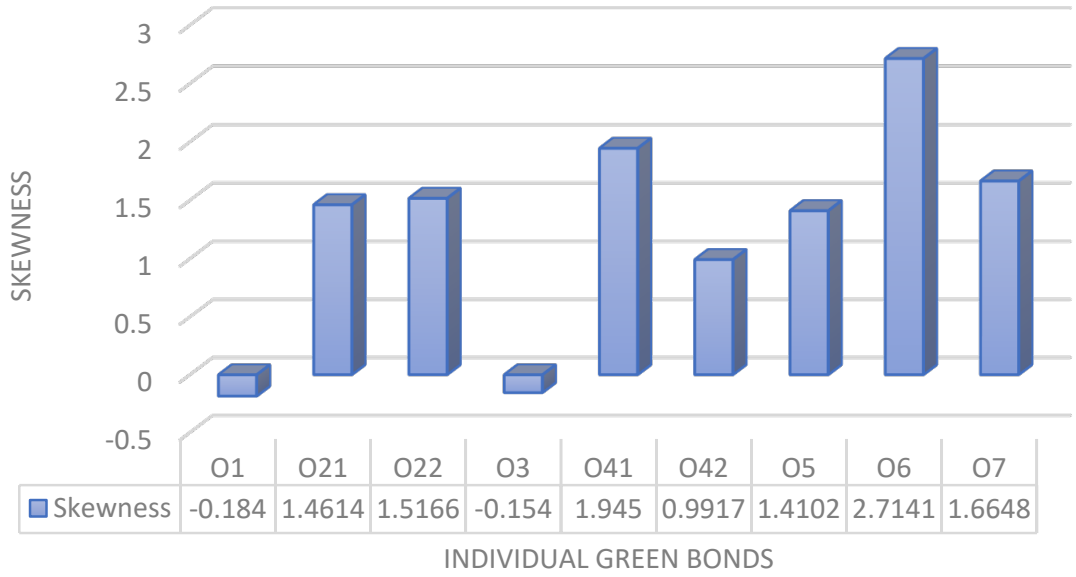
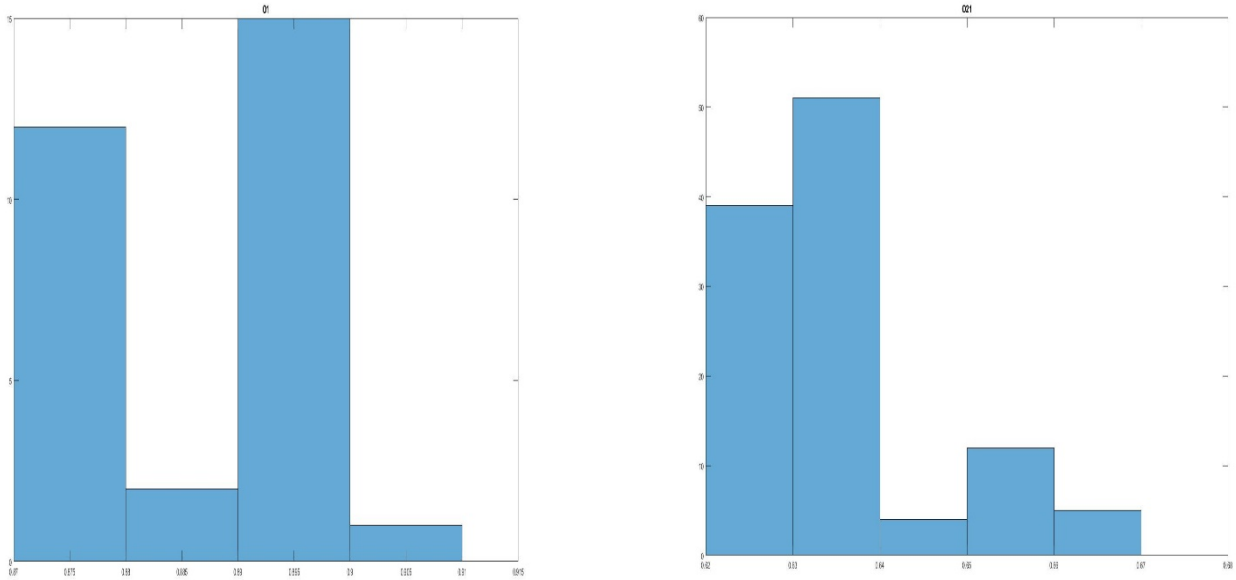
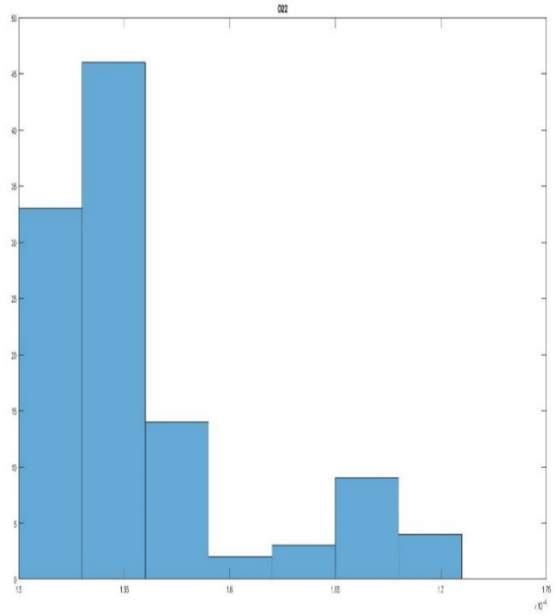


Figure 3. Classical asymmetry coefficient for the current yield index for individual analysed green bonds issued in the Czech Republic. Source: Own calculations.

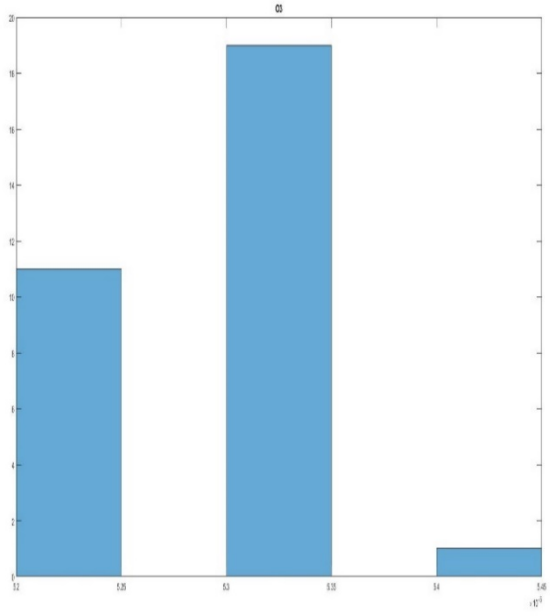


(**a**) (**b**)

Figure 4. *Cont.*



(**c**)



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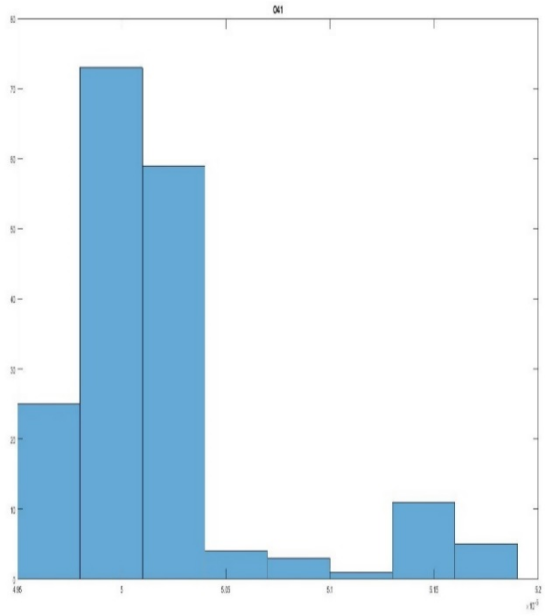

(**e**)

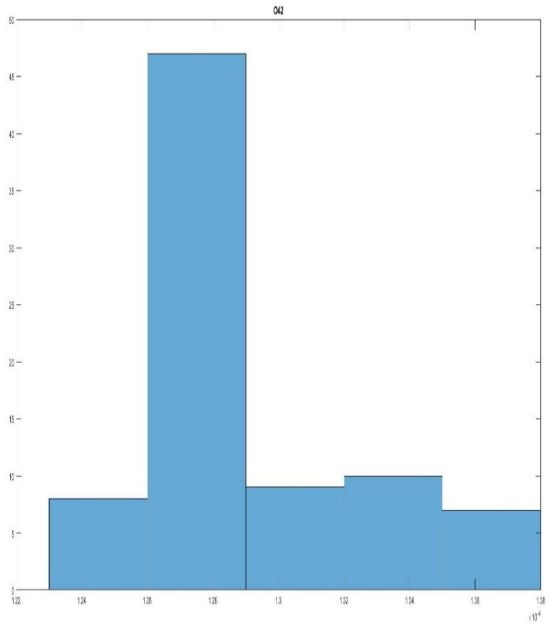

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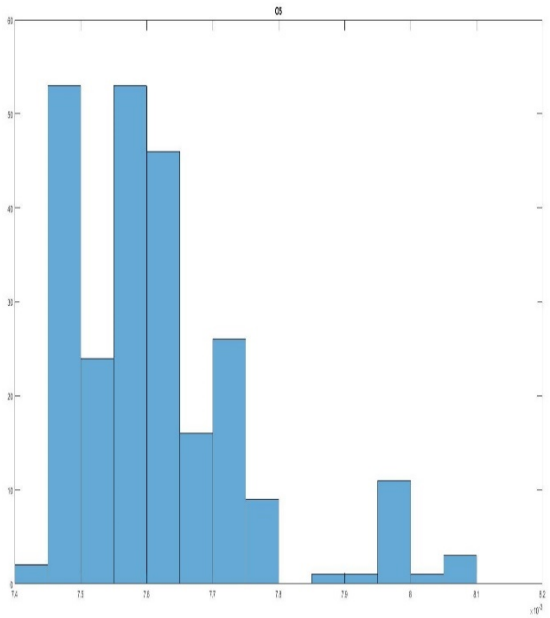
Figure 4. *Cont.*



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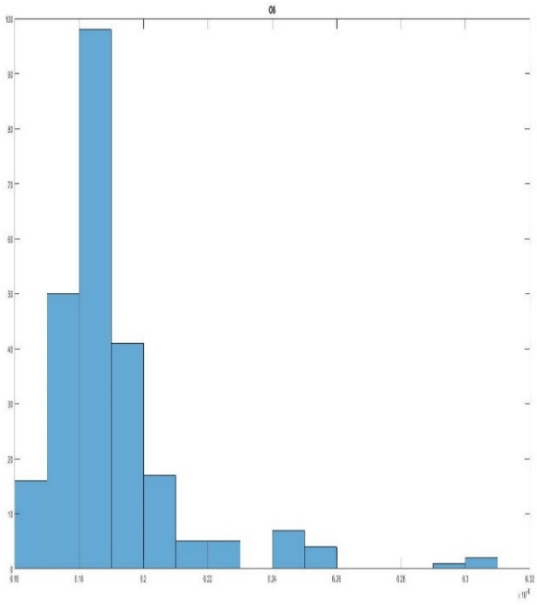
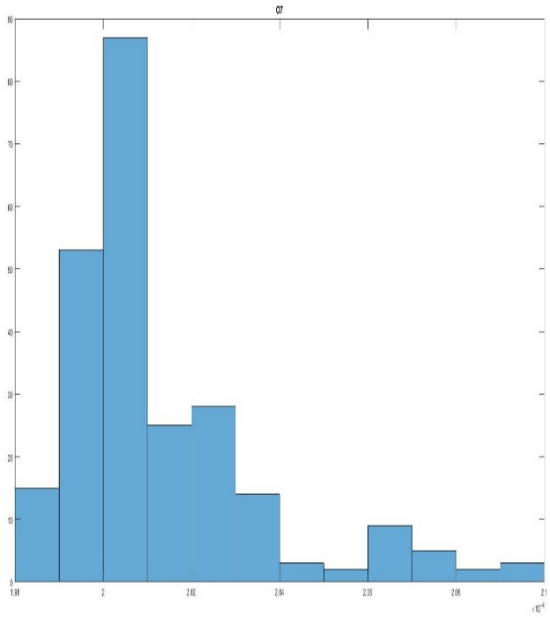


(**h**)

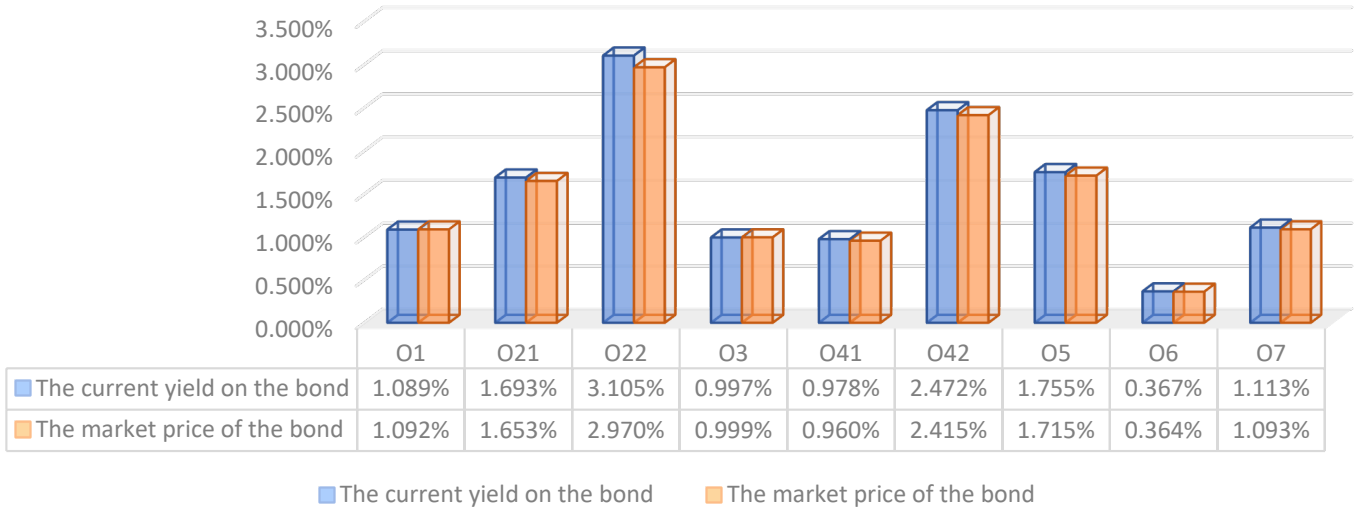


(**i**)

Figure 4. Histograms showing the current rate of income (in %) for individual analysed green bonds issued in the Czech Republic. Source: Own calculations. (**a**): Histograms showing the current rate of income (in %) for O1 green bonds issued in the Czech Republic; (**b**): Histograms showing the current rate of income (in %) for O2.1 green bonds issued in the Czech Republic; (**c**): Histograms showing the current rate of income (in %) for O2.2 green bonds issued in the Czech Republic; (**d**): Histograms showing the current rate of income (in %) for O3 green bonds issued in the Czech Republic; (**e**): Histograms showing the current rate of income (in %) for O4.1 green bonds issued in the Czech Republic; (**f**): Histograms showing the current rate of income (in %) for O4.2 green bonds

issued in the Czech Republic; (**g**): Histograms showing the current rate of income (in %) for O5 green bonds issued in the Czech Republic; (**h**): Histograms showing the current rate of income (in %) for O6 green bonds issued in the Czech Republic; (**i**): Histograms showing the current rate of income (in %) for O7 green bonds issued in the Czech Republic.

The volatility of the current rate of income ratio for all analysed bonds is low, ranging from 0.37% to 3.11% (Figure 5).

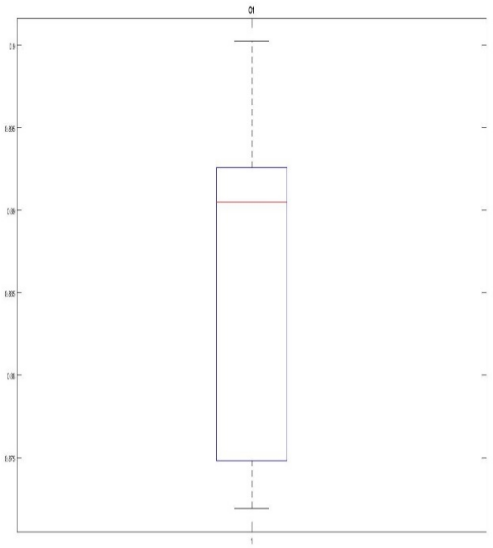


	O1	O21	O22	O3	O41	O42	O5	O6	O7
The current yield on the bond	1.089%	1.693%	3.105%	0.997%	0.978%	2.472%	1.755%	0.367%	1.113%
The market price of the bond	1.092%	1.653%	2.970%	0.999%	0.960%	2.415%	1.715%	0.364%	1.093%

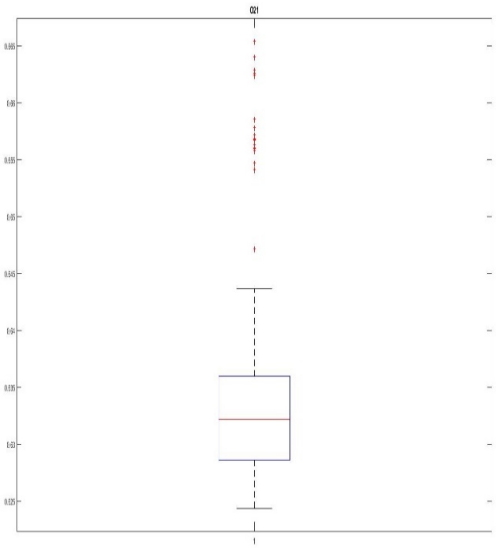
Figure 5. Comparison of the volatility of the estimated ratio of the current bond rate with the market price of bonds for individual analysed green bonds issued in the Czech Republic. Source: Own calcu-lations.

Analysing the yield on bonds through the prism of the current market rate indicator and quantiles, we note that for the O1 bonds, in the case of 50% of the quotations, the value of the current market rate indicator was at least 0.891%; in the case of O21 bonds, the value of the current market rate indicator was at least 0.632%; for O22 bonds the value of this ratio was not lower than 0.015%; for O3 bonds it was not less than 0.005%; for O41 bonds—0.005%; O42 bonds—0.013%; O5 bonds—0.008%; O6 bonds—0.001%; and for O7 bonds—0.02% (Figure 6).

As indicated in the algorithm, we determined the dependence of the current rate of income indicator on other indicators included in the analysis. The calculated measurement of similarity (dependence) was normalised to the range from 0 to 1. Value 0 means 100% similarity between two series, and value 1 means 0% similarity between two analysed series. The following conclusions for the Czech Republic can be drawn from the research (according to the indicated original WDTW algorithm).



(**a**)



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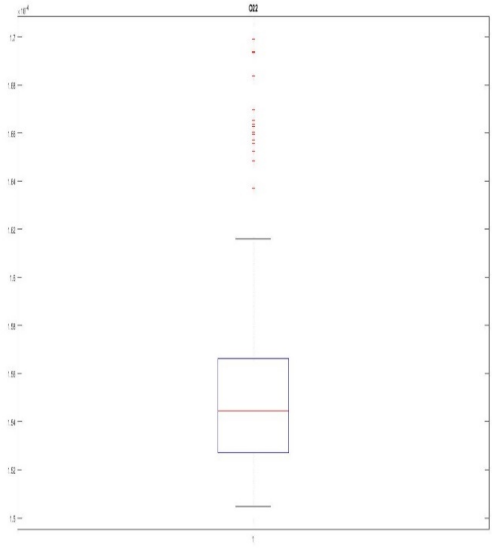

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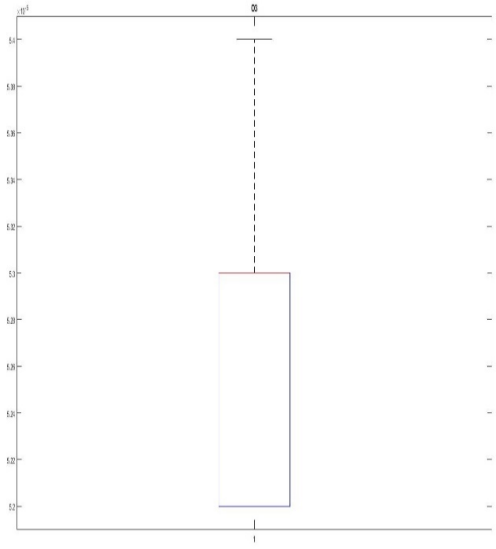
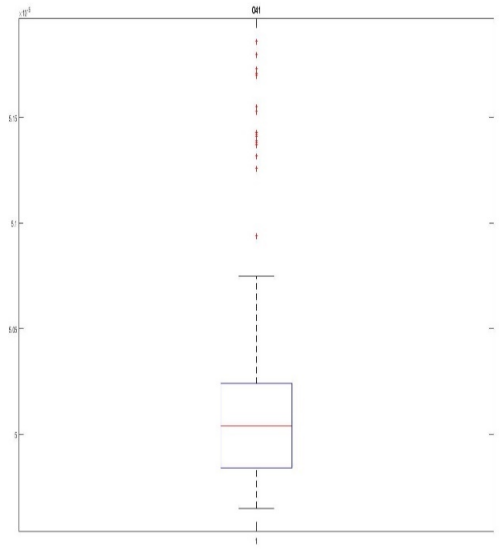


(**d**)

Figure 6. *Cont*.



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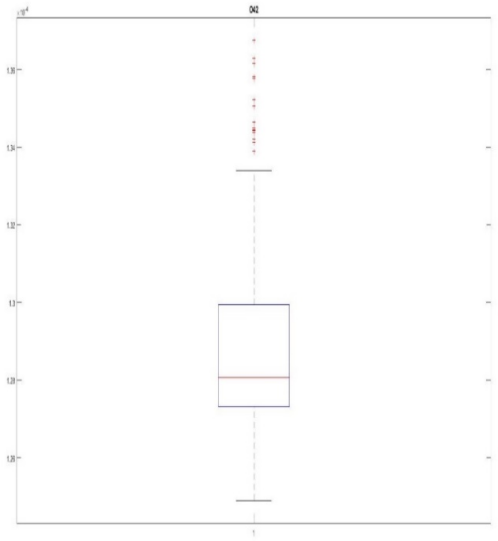

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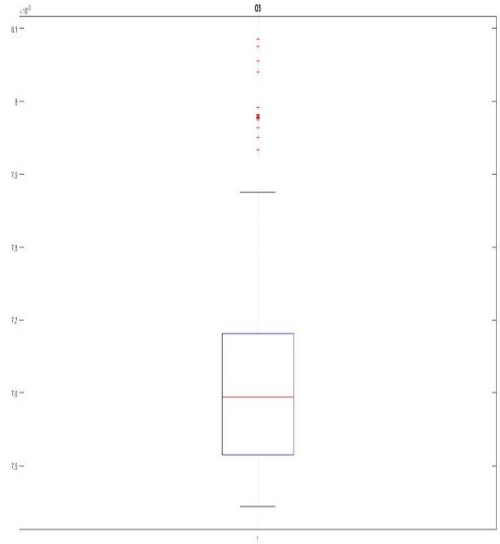

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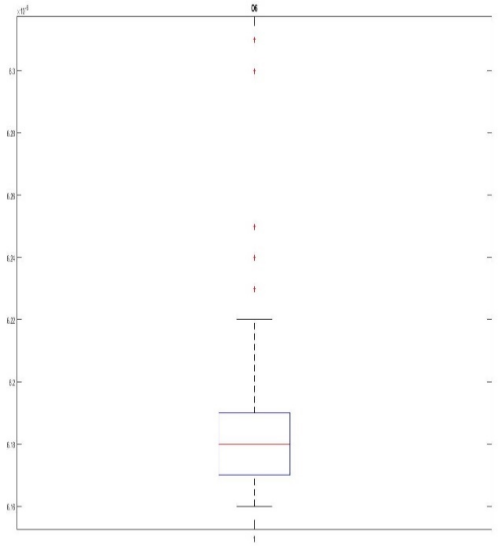

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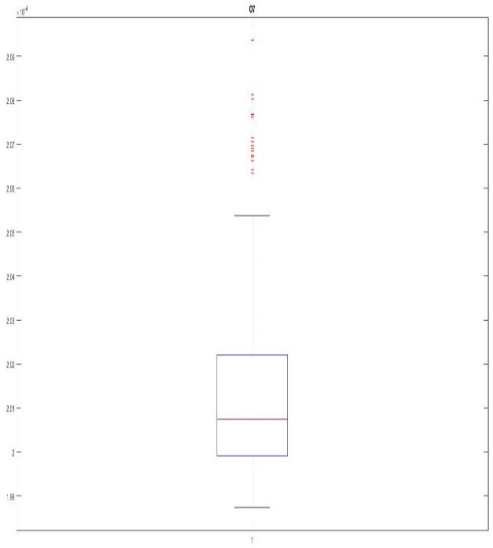
Figure 6. *Cont.*



(**i**)

Figure 6. Quartile analysis. The current rate of income (in %) for the analysed green bonds issued in the Czech Republic. Source: Own calculations. (**a**): Quartile analysis for O1 green bonds issued in the Czech Republic; (**b**): Quartile analysis for O2.1 green bonds issued in the Czech Republic; (**c**): Quartile analysis for O2.2 green bonds issued in the Czech Republic; (**d**): Quartile analysis for O3 green bonds issued in the Czech Republic; (**e**): Quartile analysis for O4.1 green bonds issued in the Czech Republic; (**f**): Quartile analysis for O4.2 green bonds issued in the Czech Republic; (**g**): Quartile analysis for O5 green bonds issued in the Czech Republic; (**h**): Quartile analysis for O6 green bonds issued in the Czech Republic; (**i**): Quartile analysis for O7 green bonds issued in the Czech Republic.

CONCLUSION 1

The yield of all analysed Czech green bonds is strongly related to inflation, both in the short-term and in the long-term trend. The determined ratio of WDTW dependence for all green bonds issued in the Czech Republic (short-term tendency) fluctuates around zero (details in Figure 7 below).

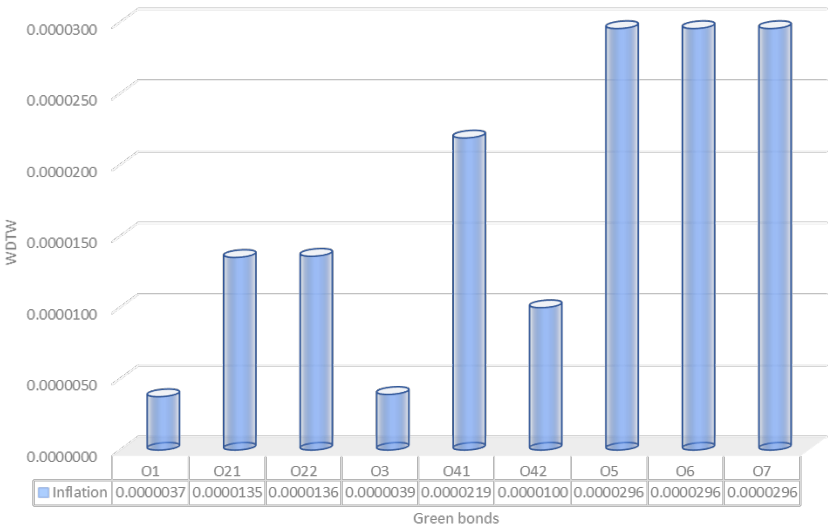


Figure 7. WDTW (short-term trend) between the current rate of income and inflation for the analysed green bonds issued in the Czech Republic. Source: Own calculations.

CONCLUSION 2

The yield of all analysed Czech green bonds, both in the short-term and in the long-term trend, is strongly related not only to the current value of inflation but also to inflation lagging by one period. The ROI dependency ratio (short-term tendency) determined for the dependence and lagging inflation fluctuates around zero (details in Figure 8 below).

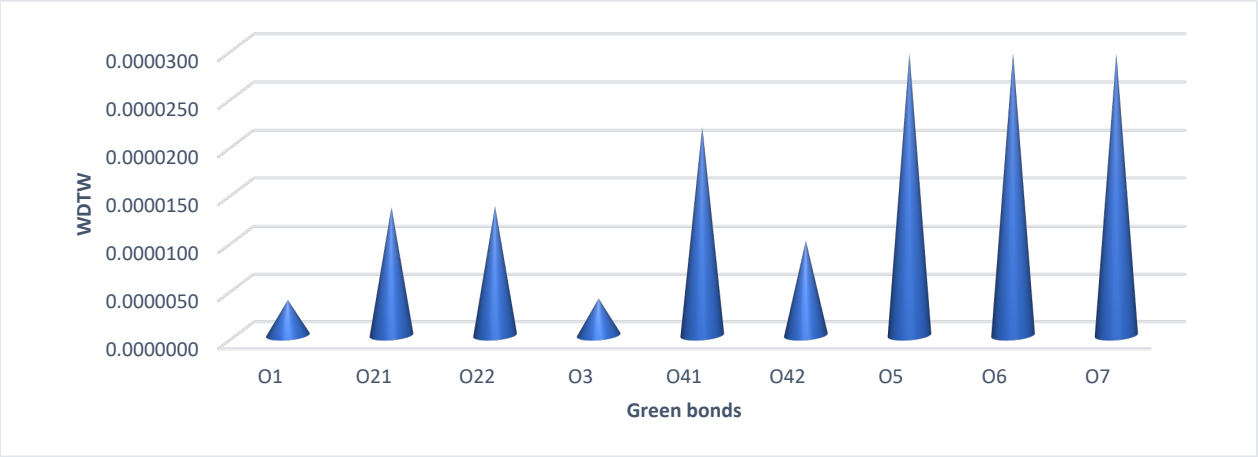


Figure 8. WDTW (short-term trend) between the current rate of income and inflation lagging by one period for the analysed green bonds issued in the Czech Republic. Source: Own calculations.

CONCLUSION 3

The ratio of the current rate of yield on bonds is most dependent on current inflation and inflation lagged by one period in the case of O1 bonds, i.e., bonds with the following parameters:

- Issuer swap vert: CTP;
- Category swap vert: Green bond;
- Value (M) swap vert: 700m euro;
- Currency swap vert: EURO;
- Dollar Value (M) swap vert: 793.67m;
- Pricing Date swap_vert: 6 January 2022;
- Settlement Date swap_vert: 20 January 2022;
- Maturity Date swap_vert: 20 January 2026;
- Coupon: 0.875%.

The ratio of the current yield on bonds is the least dependent on current inflation and inflation lagged by one period in the case of O5, O6, and O7 bonds. The parameters of these bonds are presented in Table 8 below.

Table 8. Characteristics of bonds O5, O6, and O7.

Green Bonds	O5	O6	O7
Issuer swap_vert	CTP	CTP	CTP
Category swap_vert	Green bond	Green bond	Green bond
Value (M) swap_vert	500	400	650
Currency swap_vert	EUR	EUR	EUR
Dollar Value (M) swap_vert	603	476.58	757.8
Pricing Date swap_vert	11 February 2021	25 November 2020	17 September 2020
Settlement Date swap_vert	18 February 2021	27 November 2020	25 September 2020
Maturity Date swap_vert	18 February 2027	27 November 2023	1 October 2025
Coupon	0.75%	0.0625%	2.1250%

Source: Own calculations.

CONCLUSION 4

The yield on some of the Czech green bonds analysed is linked to loans. In the case of the loan "Non-financial corporations. Loans and advances. Credit unions", the greatest relationship with this type of loan was noted in the case of O42 bonds (Figure 9), i.e., bonds with the following parameters:

- Issuer swap vert: CTP;
- Category swap vert: Green bond;
- Value (M) swap vert: 1m euro;
- Currency swap vert: EURO;
- Dollar Value (M) swap vert: 1186.2m;
- Pricing Date swap_vert: 14 June 2021;
- Settlement Date swap_vert: 21 June 2021;
- Maturity Date swap_vert: 21 June 2021;
- Coupon: 1.25%.

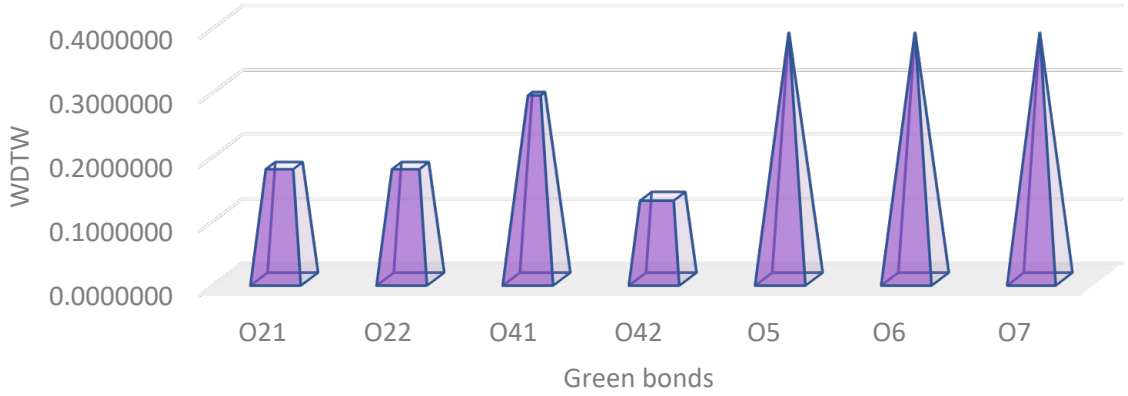


Figure 9. WDTW (short-term trend) between the current rate of income ratio and the "Non-financial corporations. Loans and advances. Credit unions". Source: Own calculations.

CONCLUSION 5

In the case of the loan "Non-financial corporations. Loans and advances. Banks", No link was noted for bonds O5, O6, or O7 (Figure 10). The greatest correlation with this type of loan was noted in the case of O42 bonds. Thus, it can be concluded that the loan "Non-financial corporations. Loans and advances. Banks" does not affect the profitability of O5, O6, or O7 bonds, both in the short-term and long-term trends.

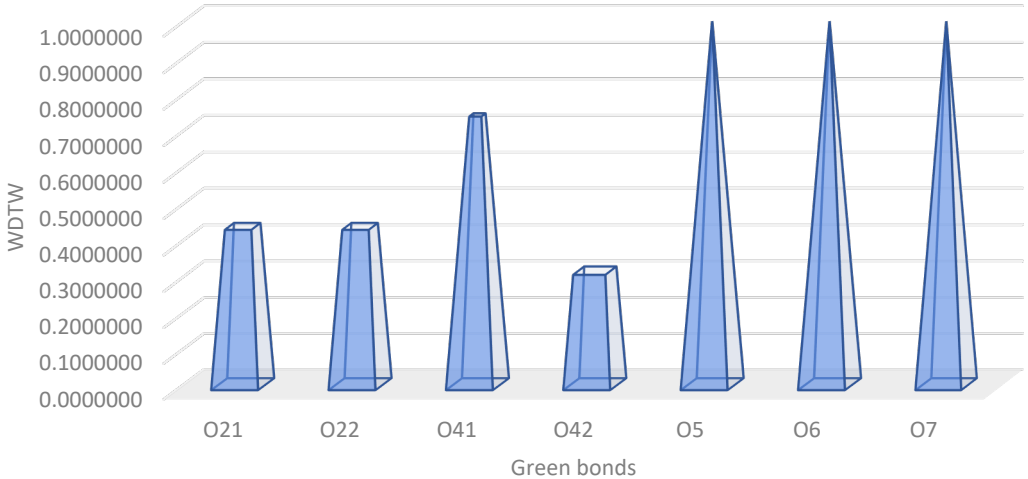


Figure 10. WDTW (short-term trend) between the current rate of income ratio and the type of loan "Non-financial corporations. Loans and advances. Banks". Source: Own calculations.

CONCLUSION 6

The analysis shows that the analysed loans have an impact on the bond yield, but not on all types of these bonds. The loan "Non-financial corporations. Debt securities. Credit unions" is related to all analysed bonds to a greater extent than the loans "Non-financial corporations. Debt securities. Banks", "Non-financial corporations. Deposits. Credit unions", and "Non-financial corporations. Deposits. Banks" (Table 9). Meanwhile, the credits "Non-financial corporations. Deposits. Credit unions" and "Non-financial corporations. Deposits. Banks" have little influence on the yield of the analysed Czech green bonds.

Table 9. Values of the WDTW measurement (short-term trend).

	Non-Financial Corporations. Loans and Advances. Credit Unions.	Non-Financial Corporations. Loans and Advances. Banks.	Non-Financial Corporations. Debt Securities. Credit Unions.	Non-Financial Corporations. Debt Securities. Banks.	Non-Financial Corporations. Deposits. Credit Unions.	Non-Financial Corporations. Deposits. Banks
O21	0.1765044	0.4368544	0.0049771	0.0262464	0.1855359	0.3815165
O22	0.1765044	0.4368544	0.0049771	0.0262464	0.1855359	0.3815165
O41	0.2883751	0.7424422	0.0083355	0.0472440	0.2947408	0.6203909
O42	0.1288191	0.3155270	0.0035462	0.0190948	0.1354491	0.2833768
O5	0.3847798	1.0000000	0.0116513	0.0587942	0.4003723	0.8408462
O6	0.3847798	1.0000000	0.0116513	0.0587942	0.4003723	0.8408462
O7	0.3847798	1.0000000	0.0116513	0.0587942	0.4003723	0.8408462

Source: Own calculations.

4.2. Hungary

Only two bonds were selected for the analysis. Their characteristics are presented in Table 10.

Table 10. Brief characteristics of the bonds included in the model analysis.

Name	Dollar Value (M) Swap Vert	Pricing Date Swap Vert	Settlement Date Swap Vert	Maturity Date Swap Vert	Coupon
01	99.58	22 April 2021	22 April 2021	28 April 2051	4%
02	1.643,1	03 June 2020	05 June 2020	05 June 2035	1.75%

Source: Boerse Frankfurt.

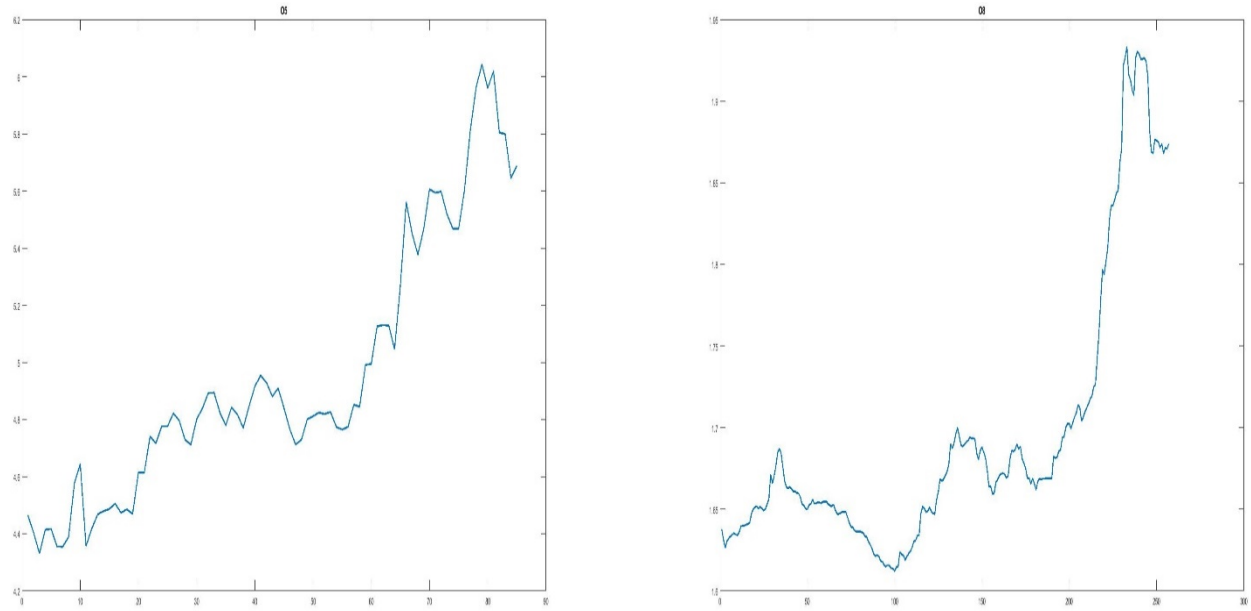
Determining the current rate of return on green bonds (Figure 11) (In the analyses of the proprietary model, only two green bonds were taken into account. For the remaining bonds, no relevant data was obtained for analysis):

The proposed ratio of the current rate of income for the analysed group of green bonds reaches a minimum value of 1.612% (bond O1) and a maximum value of 6.043% (bond O2). The average value of this ratio for O1 bonds is 1.695%, and for O2 bonds it is 4.952% (Table 11).

Table 11. Descriptive statistics for the current rate of income for individual analysed green bonds issued in Hungary (in %).

Bond	Avarage	Minimum	Maximum	Std. Dev.	Kurtosis
01	1.695	1.612	1.934	0.084	1.671
02	4.952	4.331	6.043	0.455	–0.306

Source: Own calculations.



(**a**) (**b**)

Figure 11. The current rate of income (in %) for the individual analysed green bonds issued in Hungary. Source: Own calculations. (**a**): The current rate of income (in %) for O1 green bonds issued in Hungary; (**b**): he current rate of income (in %) for O2 green bonds issued in Hungary.

The volatility of the current rate of income ratio for both analysed bonds is low. For O1 it is 4.94%, and for O2 it is 9.19%. The estimated ratio of the current yield in the case of both analysed bonds is characterised by right-hand asymmetry. The classic coefficient of asymmetry for O1 is 1.697% and for O2 it is 0.891%, therefore, the O1 bond is characterised by a much greater right-hand asymmetry than the O2 bond (details in Figure 12 below).

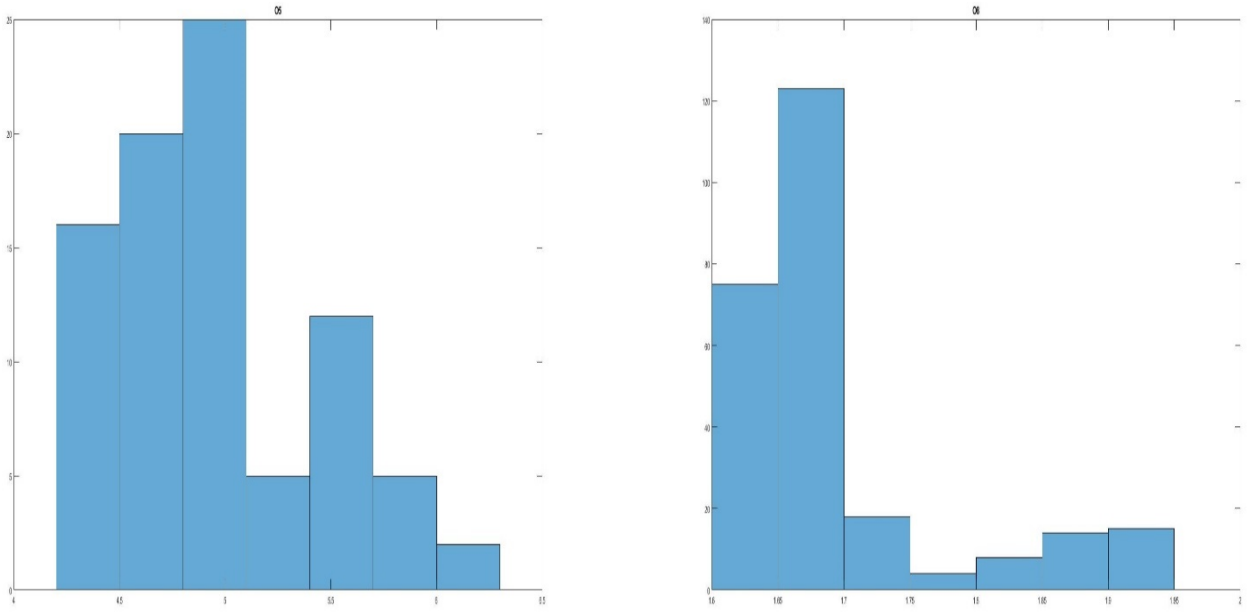


Figure 12. Histograms showing the current rate of income (in %) for each analysed green bond issued in Hungary. O1 (**left**), O2 (**right**). Source: Own calculations.

Analysing the yield on bonds through the prism of the current market rate indicator and quantiles, we note that for O1 bonds, in the case of 50% of quotations, the value of the current market rate indicator was not lower than 1.668%, and in the case of O2 bonds, the value of the current market rate indicator was not less than 4.823%.

The quantile analysis also shows that (Figure 13):

- For O1 bonds, in the case of 25% of quotations, the value of the current market rate ratio was not lower than 1.65%, and in the case of 75% of quotations, not more than 1.65%.
- For O2 bonds, in the case of 25% of quotations, the value of the current market rate indicator was not lower than 4.711%, and in the case of 75% of quotations, not more than 4.711%.
- For O1 bonds, in the case of 75% of quotations, the value of the current market rate ratio was not lower than 1.69%, and for 25% of quotations, not more than 1.69%.
- For O2 bonds, in the case of 25% of quotations, the value of the current market rate indicator was not lower than 5.13% and in the case of 75% of quotations, not more than 5.13%.

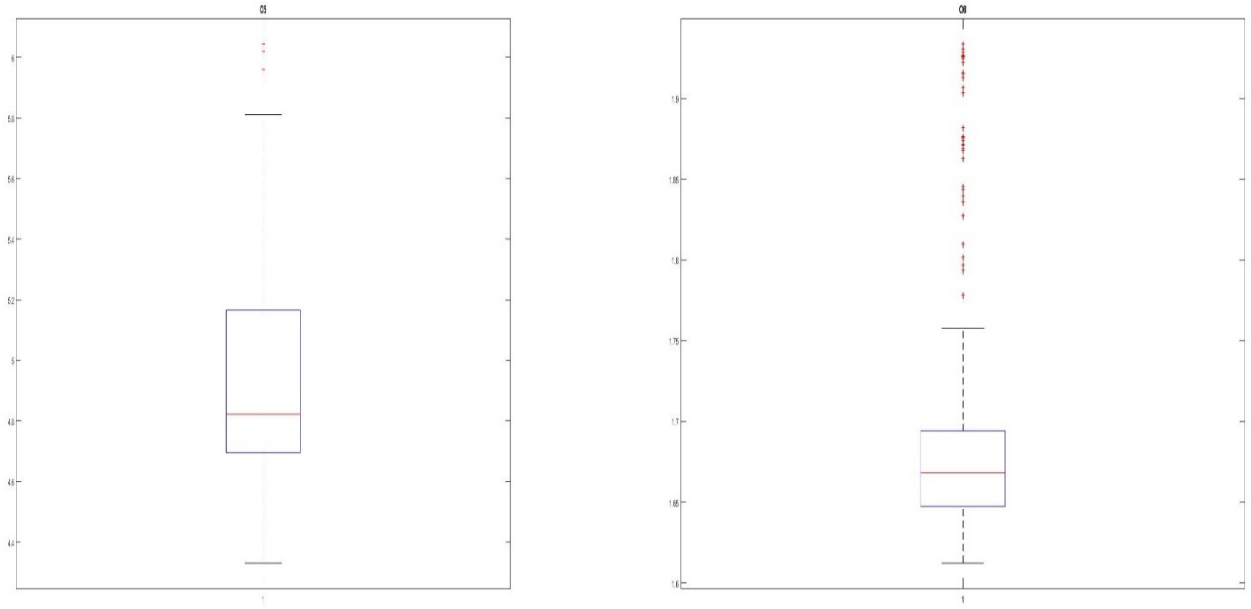


Figure 13. Quantile analysis. The current rate of income (in %) for the analysed green bonds issued in Hungary. O1 (**left**), O2 (**right**). Source: Own calculations.

As indicated in the algorithm, we determined the dependence of the current rate of income indicator on other indicators included in the analysis. The calculated measurement of similarity (dependence) was normalised to the range from 0 to 1. Value 0 means 100% similarity between two series, and value 1 means 0% similarity between two analysed series.

The following conclusions can be drawn from the research (according to the indicated original WDTW algorithm).

CONCLUSION 1

The yield on Hungary's first green bond (O1) is not related to inflation in the country in both the short and the long term. In each case, the WDTW ratio is very high. For example, for the short-term trend, it is 0.96 (on a scale from 0 to 1), which indicates that the yield on O1 bonds is not affected by inflation.

CONCLUSION 2

The yield on Hungary's O1 green bond is also not linked to lagging inflation by one period in both the short-term and long-term trends. With the current rate of income and lagged inflation for the relationship, the WDTW dependency ratio fluctuates around 1 (on a scale from 0 to 1, where 1 means "no dependence").

CONCLUSION 3

The yield on the second Hungarian green bond (O2) is not related to inflation in the country both in the short-term and long-term tendencies. The WDTW index fluctuates around the value of 1 (on a scale from 0 to 1), which indicates that the yield on O1 bonds is not influenced by inflation.

CONCLUSION 4

The yield on Hungary's O2 green bond is also not related to lagging inflation by one period in both the short-term and long-term trends. The WDTW index fluctuates around the value of 1 (on a scale from 0 to 1). The current income rate and lagging inflation rate for the relationship between the WDTW (short-term tendency) is 0.98 (on a scale from 0 to 1, where 1 means "no dependence").

4.3. Slovakia

The analysis covers only one green bond (Table 12), a short description of which is presented below.

Table 12. Brief characteristics of the bond included in the model analysis.

Dollar Value (M) Swap_Vert	Pricing Date Swap_Vert	Settlement Date Swap_Vert	Maturity Date Swap_Vert	Coupon
361.38	21 April 2021	23 April 2021	23 April 2028	0.5

Determining the current rate of return on the green bond (Figure 14):

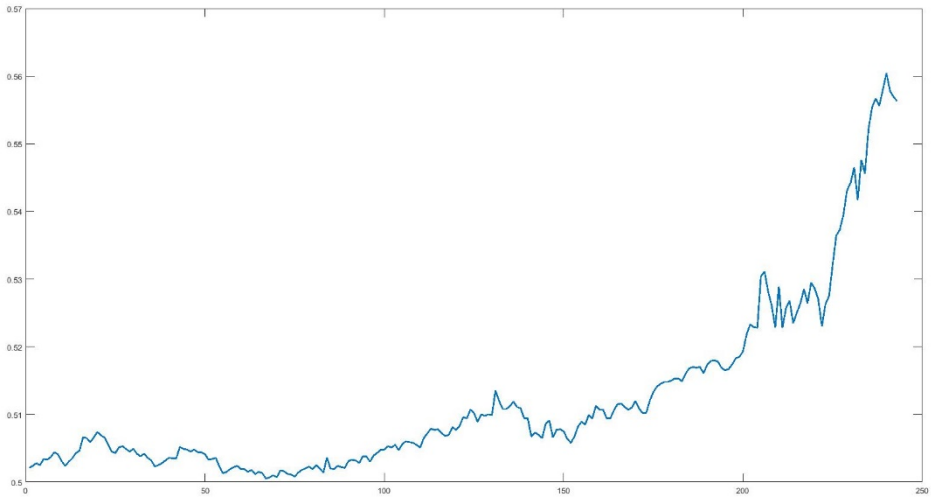


Figure 14. The current rate of income (in %) for the green bond issued in Slovakia. Source: Own calculations.

The proposed ratio of the current rate of income for the analysed Slovak green bond reaches a minimum value of 0.5005% and a maximum value of 0.56% (the difference understood as the difference between the maximum and minimum value is 0.06 (%)). The average value of this ratio is 0.512% with an error of 0.0008%. The deviation from the mean is ±0.013%. The index is characterised by low volatility (the coefficient of variation is 2.5%).

The series presenting an indicator of the current yield on the Slovak green bond is characterised by strong right-hand asymmetry, which is clearly visible in the histogram below—Figure 15 (the asymmetry coefficient is 1.95%, kurtosis is 3.46%).

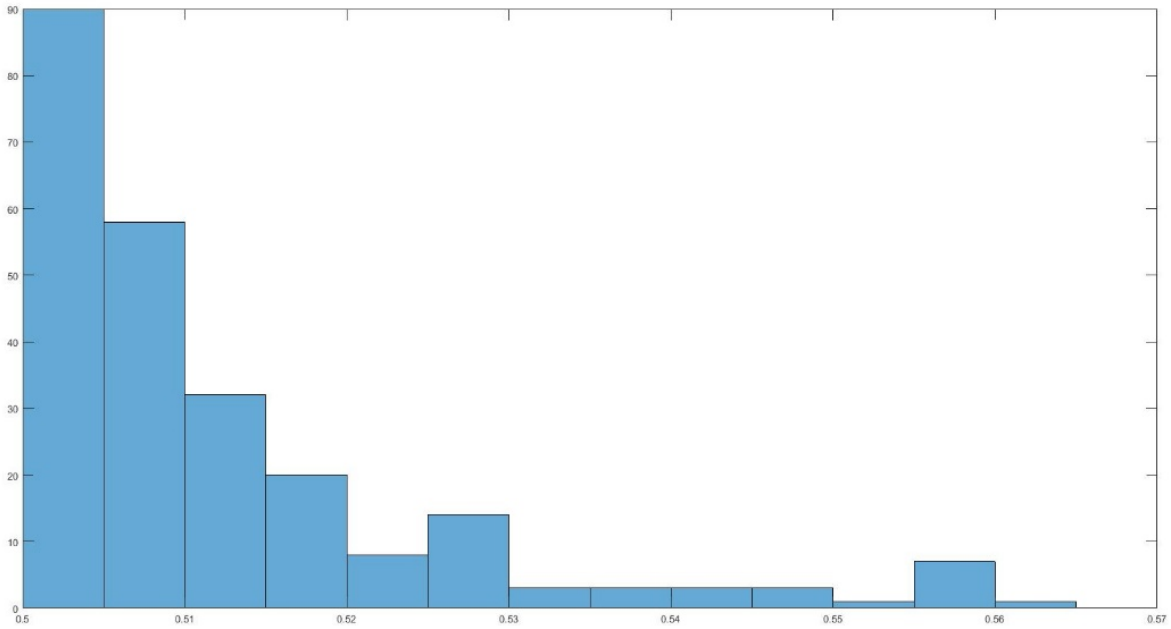


Figure 15. Histograms showing the current rate of income (in %) for the green bond issued in Slovakia. Source: Own calculations.

In the case of 50% of quotations, the value of the current market rate indicator was not lower than 0.50733% (Figure 16).

In the case of 25% of quotations, the value of the current market rate of the green bond issued in Slovakia was at most 0.50363% and in the case of 75% of quotations at least 0.50363%.

In the case of 75% of the quotations, the value of the current market rate ratio of the green bond issued in Slovakia was at most 0.51586% and in the case of 25% of the quotations at least 0.51586%.

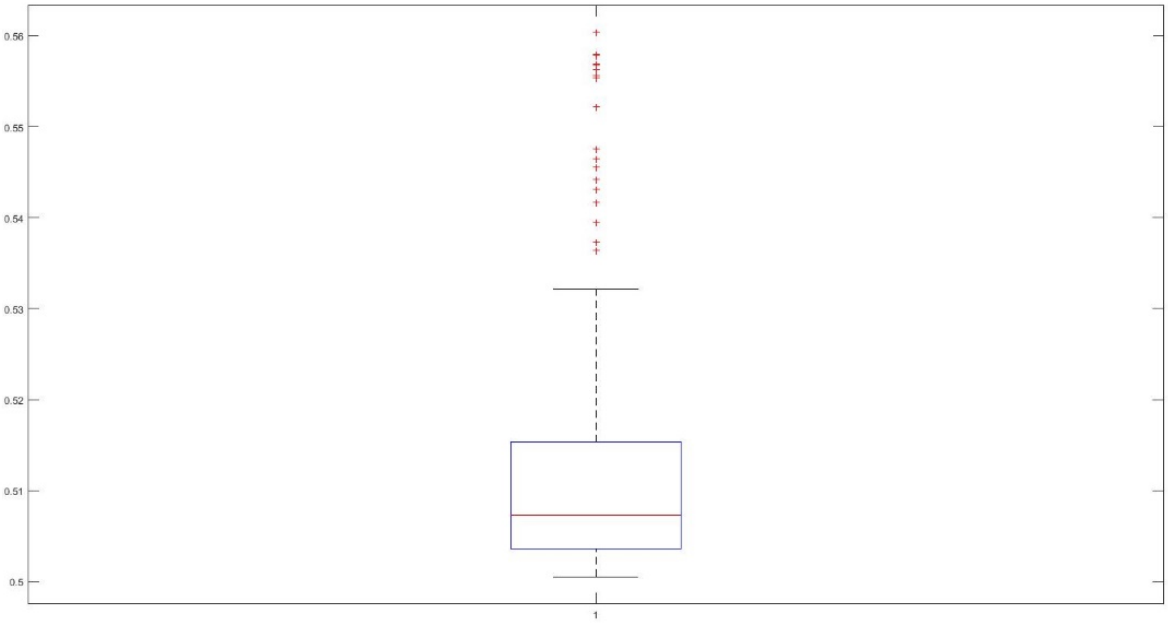


Figure 16. Quantile analysis. The current rate of income (in %) for the analysed green bond issued in Slovakia. Source: Own calculations.

The research (according to the indicated original WDTW algorithm) shows the following most important conclusions.

CONCLUSION 1

The yield of the analysed green bond issued in Slovakia is not related to inflation, both in the short-term and long-term trends. The determined index of WDTW dependence oscillates around the value of 1 in each case.

CONCLUSION 2

The yield of the analysed green bond issued in Slovakia is not related to inflation lagging by one period, in both the short-term and long-term trends. The determined index of WDTW dependence fluctuates around the value of 1.

CONCLUSION 3

The profitability of the analysed green bond issued in Slovakia is strongly related to loans both in the long and short term.

Bond yield is the strongest related to loans over EUR 1 million by initial rate fixation (floating rate and up to 1 year). WDTW index = 0.012.

There is also a significant link with bond yields:

- Loans over EUR 1 million by initial rate fixation over 1 and up to 5 years: WDTW (short trend) = 0.031.
- Loans over EUR 1 million by initial rate fixation over 5 years. WDTW (short-term trend) = 0.034.
- Loans over EUR 1 million by initial rate fixation, floating rate and up to 1 year. WDTW (short-term trend) = 0.018.
- Bank overdrafts. WDTW (short-term trend) = 0.017.
- Loans over EUR 1 million by initial rate fixation, Over 5 years. WDTW (short-term trend) = 0.019.

4.4. Poland

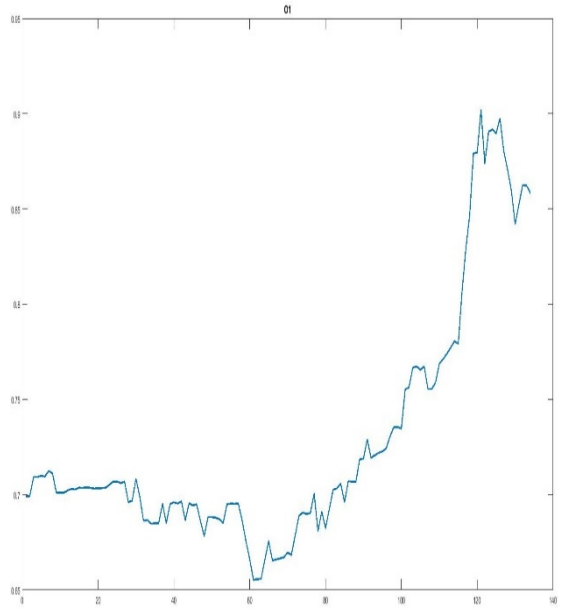
The analysis covers six green bonds. A brief description of these bonds along with the symbols used are presented below (Table 13).

Table 13. Brief characteristics of the bonds included in the model analysis.

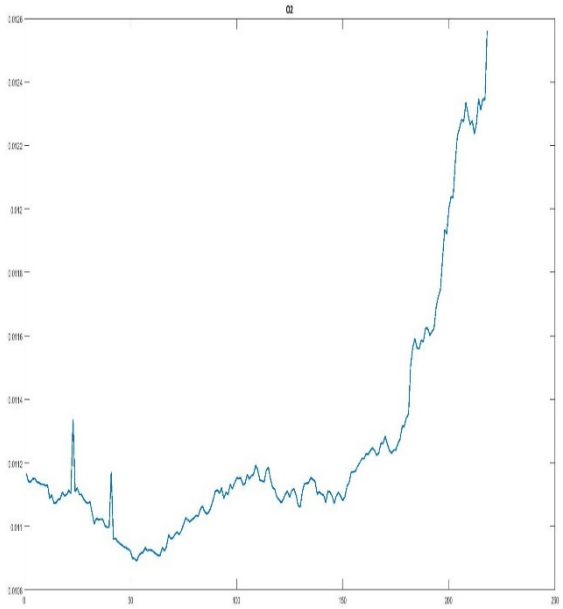
Name	Issuer Swap Vert	Pricing Date Swap Vert	Settlement Date Swap Vert	Maturity Date Swap Vert	Coupon
01	mBank	16 September 2021	20 September 2021	21 September 2027	3-month EURIBOR + 1.25%
02	PKN Orlen	13 May 2021	21 May 2021	27 May 2028	1.125%
04	PKO BP	27 November 2019	27 November 2019	02 December 2024	3M WIBOR +51 bps
05	PKO BP	05 June 2019	10 June 2019	30 September 2024	3M WIBOR + 0.6%
06	Republic of Poland	28 February 2019	07 Marc 2019	08 Marc 2049	2%
08	Republic of Poland	31 January 2018	07 February 2018	07 August 2026	1.13%

Source: Boerse Frankfurt.

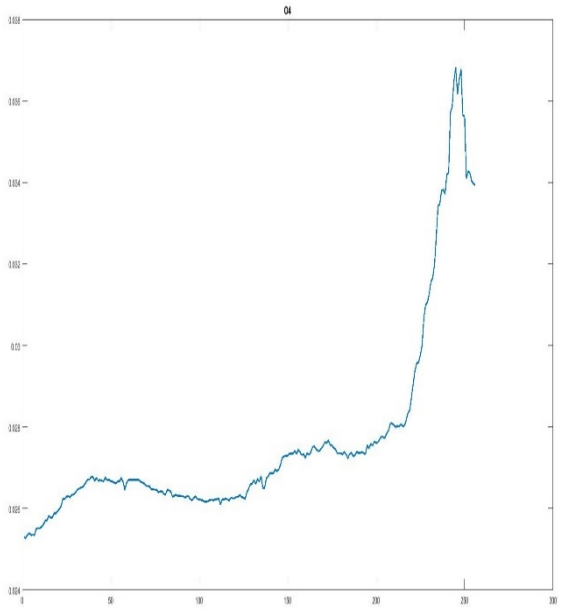
Determining the current rate of return on the green bonds (Figure 17):



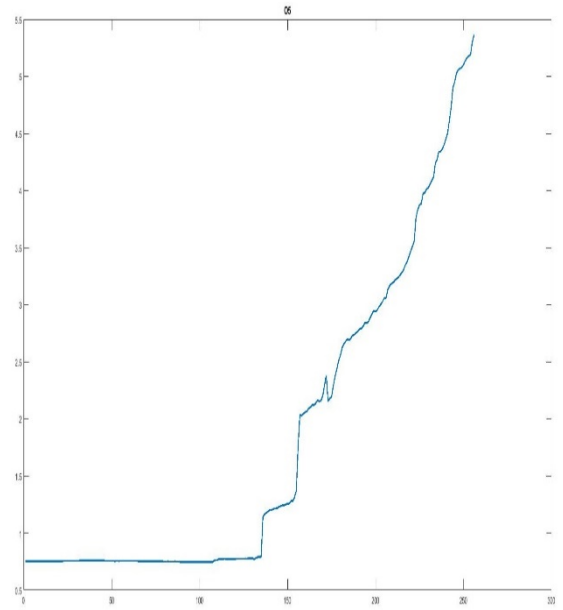
(**a**)



(**b**)

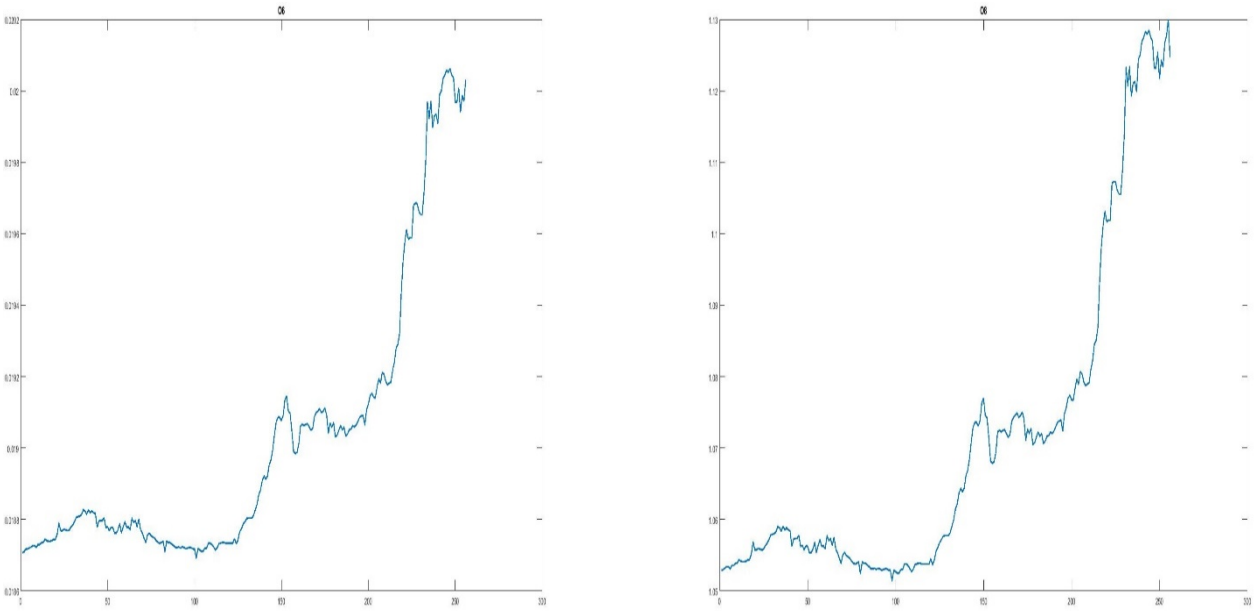


(**c**)



(**d**)

Figure 17. *Cont*.



(**e**) (**f**)

Figure 17. The current rate of income (in %) for the individual analysed green bonds issued in Poland. Source: Own calculations. (**a**): The current rate of income (in %) for O1 green bonds issued in Poland; (**b**): The current rate of income (in %) for O2 green bonds issued in Poland; (**c**): The current rate of income (in %) for O4 green bonds issued in Poland; (**d**): The current rate of income (in %) for O5 green bonds issued in Poland; (**e**): The current rate of income (in %) for O6 green bonds issued in Poland; (**f**): The current rate of income (in %) for O8 green bonds issued in Poland.

The proposed ratio of the current rate of income for the analysed group of green bonds reaches a minimum value of 0.011% (O2 bond), and a maximum value of 5.366% (O1 bond). The average value of this ratio, depending on the bond, ranges from 0.011% to 1.006% (Table 14).

Table 14. Descriptive statistics for the current rate of income for individual analysed green bonds issued in Poland (in %).

Bonds	Average	Minimum	Maximum	Std.Dev.	Kurtosis
O1	0.728	0.655	0.902	0.063	1.150
O2	0.011	0.011	0.013	0.000	3.088
O4	0.028	0.025	0.037	0.002	4.303
O5	1.806	0.744	5.366	1.382	−0.191
O6	0.019	0.019	0.020	0.000	1.228
O8	1.071	1.051	1.130	0.022	0.941

Source: Own calculations.

The estimated ratio of the current rate of income in the case of two analysed bonds is characterised by left-hand asymmetry and in the remaining ones by right-hand asymmetry (details in the two figures below, Figures 18 and 19).

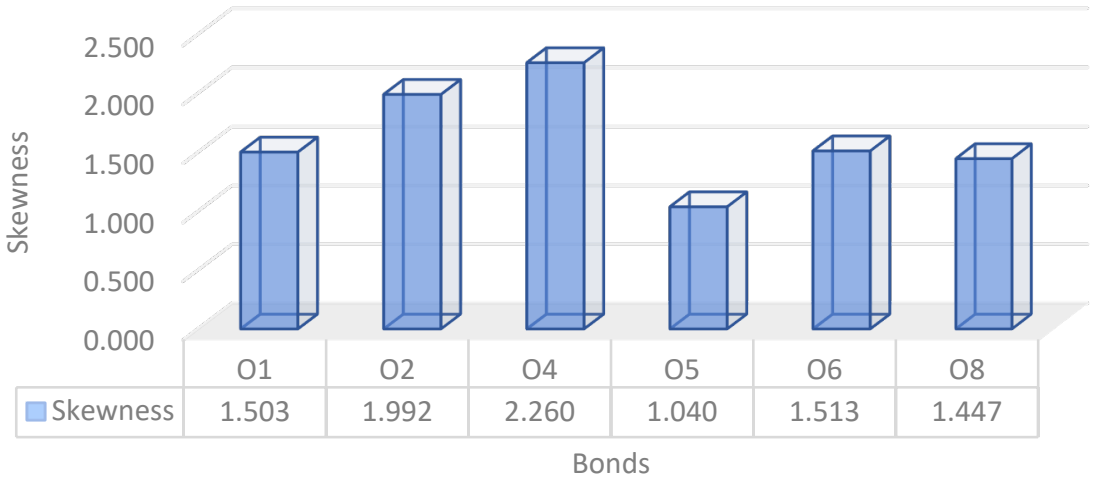
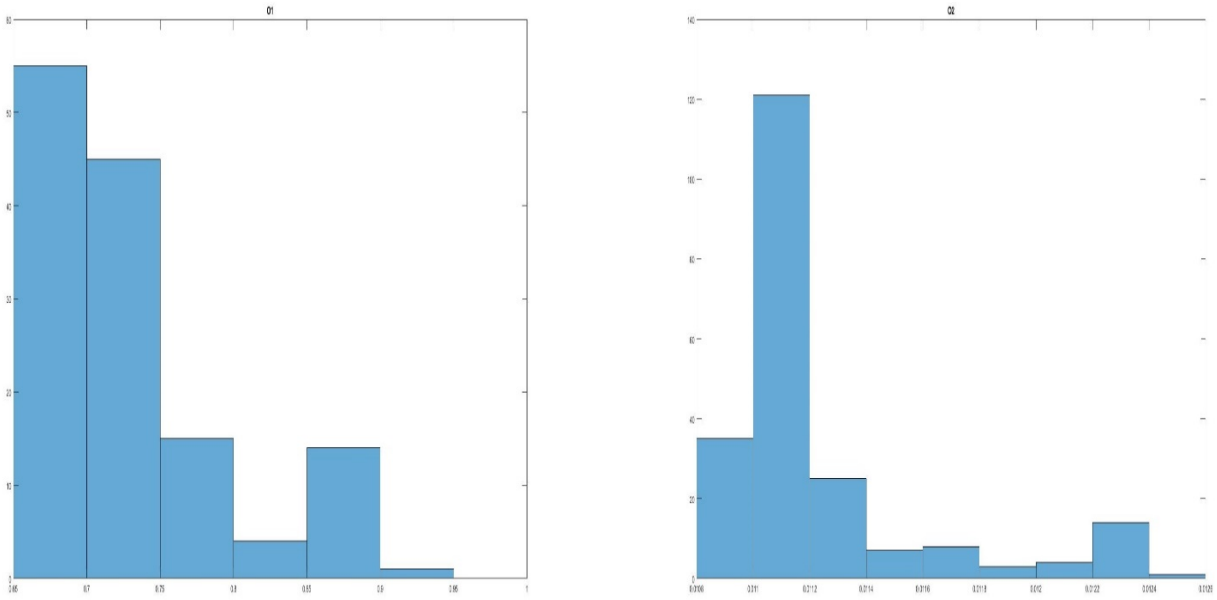
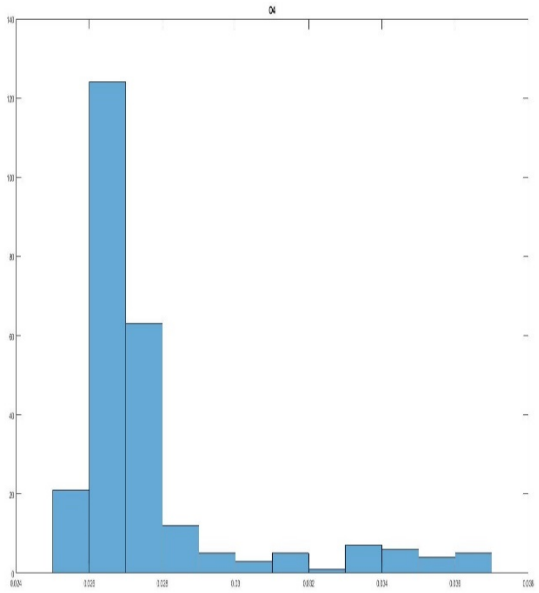


Figure 18. Classic asymmetry factor for the current rate of income ratio for individual analysed green bonds issued in Poland. Source: Own calculations.

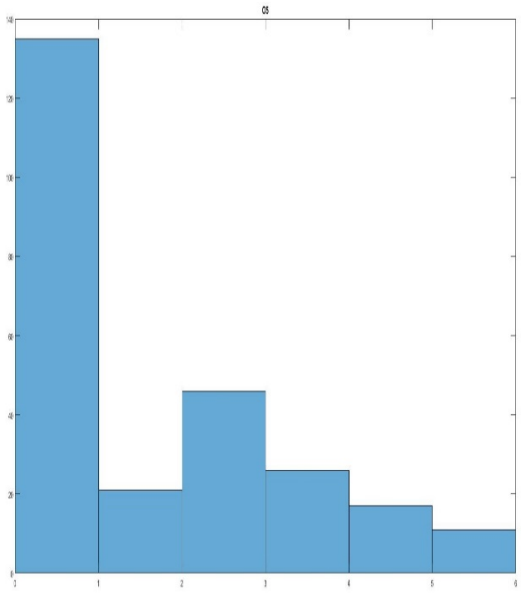


(**a**) (**b**)

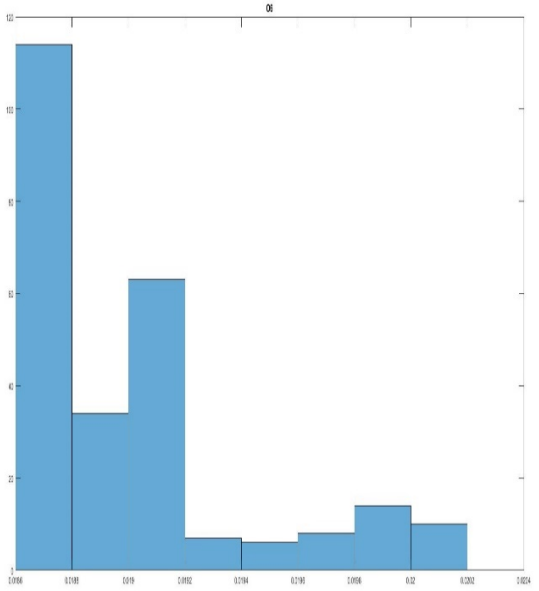
Figure 19. *Cont.*



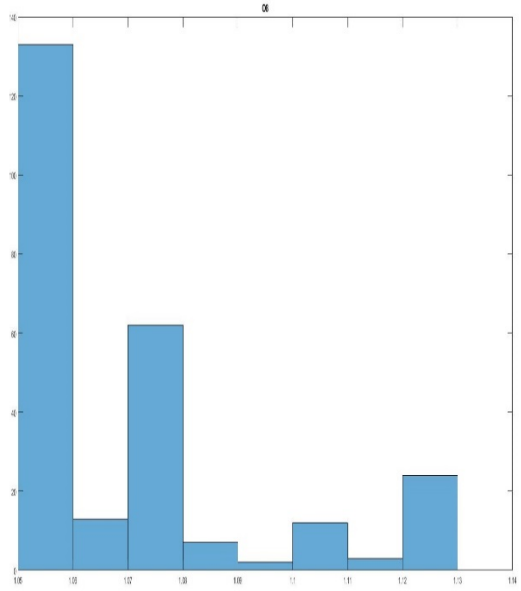
(**c**)



(**d**)



(**e**)



(f)

Figure 19. Histograms presenting the current rate of income (in %) for individual analysed green bonds issued in Poland. Source: Own calculations. (**a**): Histograms presenting the current rate of income (in %) for O1 green bonds issued in Poland; (**b**): Histograms presenting the current rate of income (in %) for O2 green bonds issued in Poland; (**c**): Histograms presenting the current rate of income (in %) for O4 green bonds issued in Poland; (**d**): Histograms presenting the current rate of income (in %) for O5 green bonds issued in Poland; (**e**): Histograms presenting the current rate of income (in %) for O6 green bonds issued in Poland; (**f**): Histograms presenting the current rate of income (in %) for O8 green bonds issued in Poland.

The volatility of the current rate of income ratio for all analysed bonds, except for the O5 bonds, is low, i.e., below 9.1%. The volatility of the current rate of the O5 bond yield is very high (Figure 20).

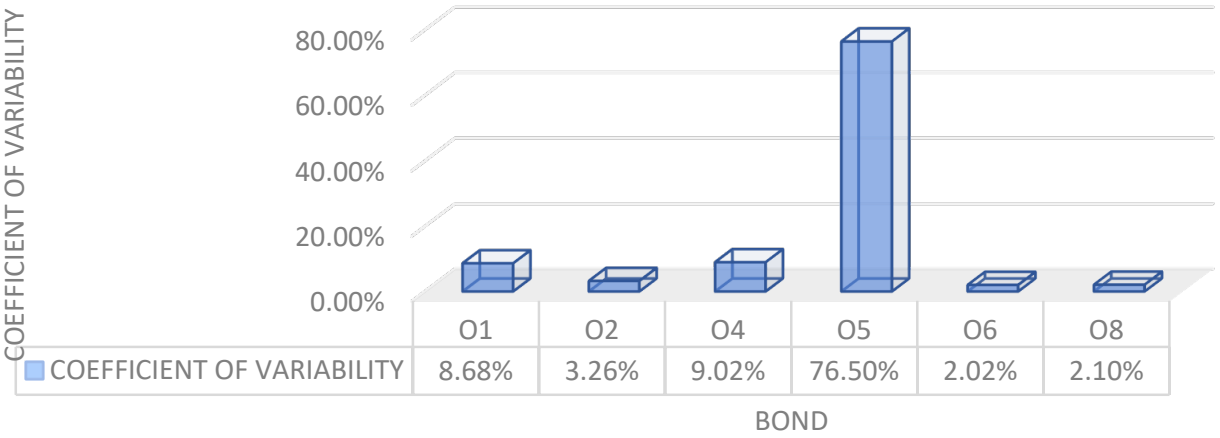


Figure 20. Summary of the volatility of the estimated current bond rate ratio. Green bonds issued in Poland. Source: Own calculations.

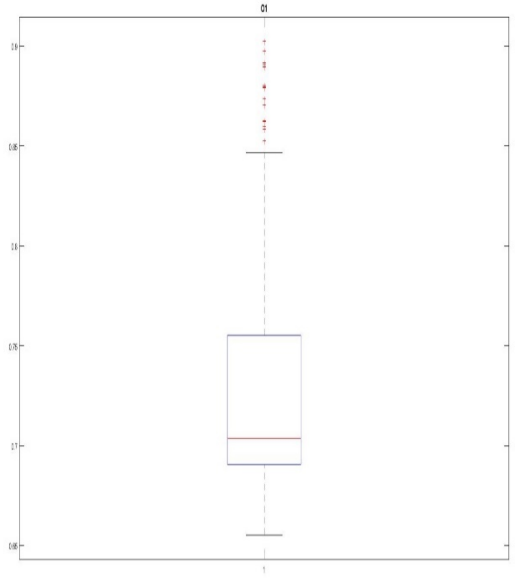
Analysing the yield on bonds through the prism of the current market rate indicator and quantiles, we notice that for 50% of quotations, the value of the current market rate indicator was not lower than 0.69%; for O2 bonds, the value of the current market rate indicator was not lower than 0.011%; for O4 bonds, the value of this ratio was not lower than 0.03%; for O5 bonds it was not less than 0.75%; for O6 bonds—0.02%; and for O8 bonds—1.05% (Figure 21).

The quantile analysis shows that 25% of the value of the current market rate indicator is at the level of. at most:

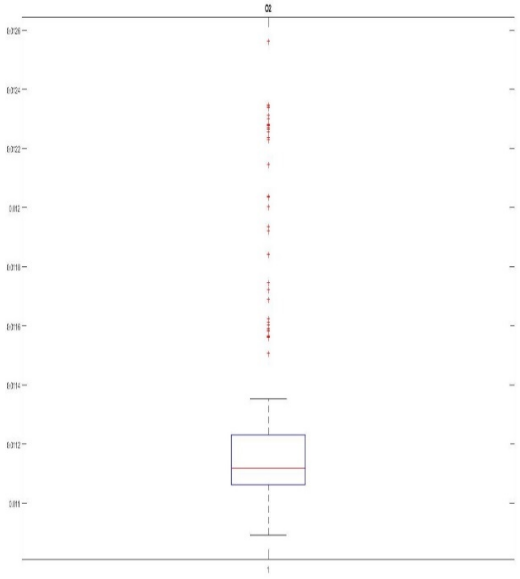
- 0.7% for bond O1;
- 0.02% for bond O2;
- 0.39% for bond O4;
- 0.78% for bond O5;
- 0.02% for bond O6;
- 1.06% for bond O8.

Moreover, the quantile analysis shows that 75% of the value of the current market rate indicator is at the level of, at most:

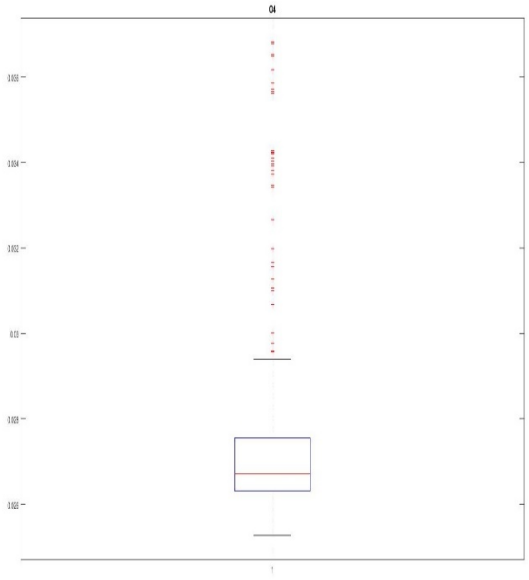
- 0.75% for bond O1;
- 0.75% for bond O2;
- 0.75% for bond O4;
- 2.79% for bond O5;
- 0.02% for bond O6;
- 1.07% for bond O8.



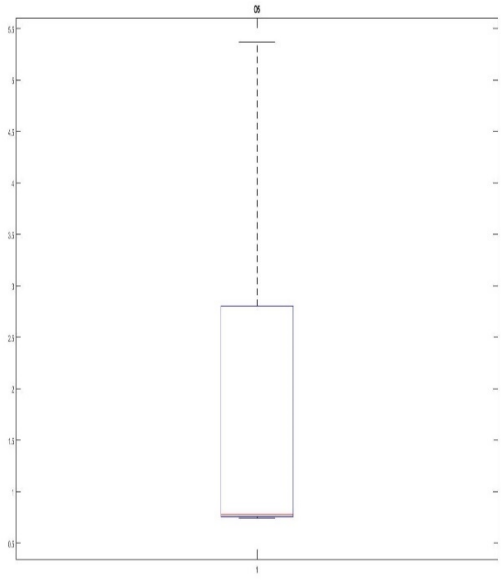
(**a**)



(**b**)

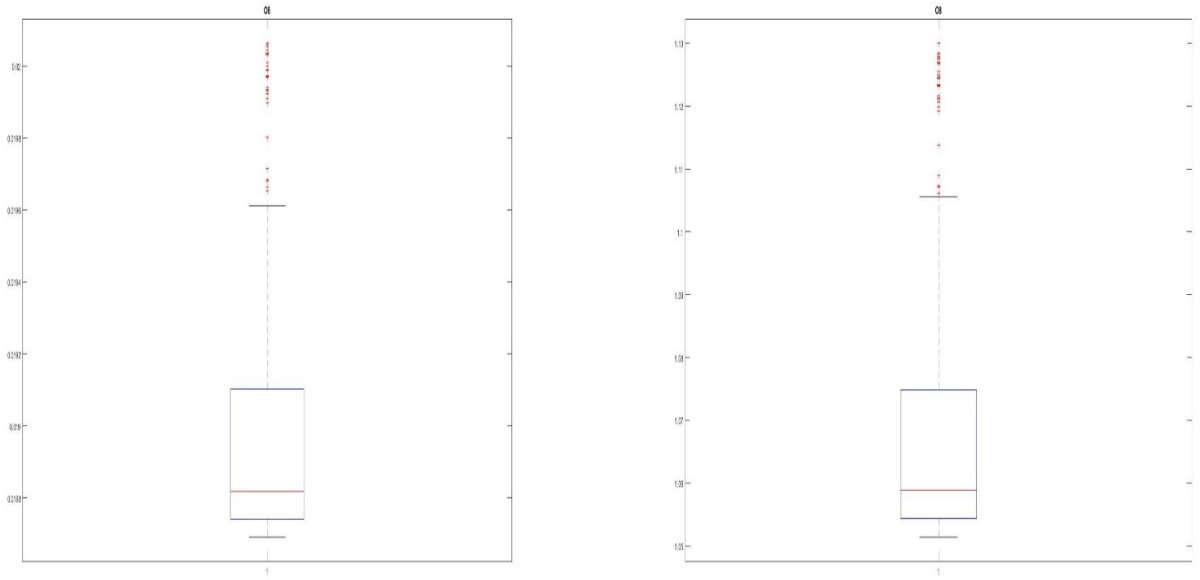


(**c**)



(**d**)

Figure 21. *Cont*.



(**e**) (**f**)

Figure 21. Quantile analysis. The current rate of income (in %) for the analysed green bonds issued in Poland. Source: Own calculations. (**a**): Quantile analysis. The current rate of income (in %) for O1 green bonds issued in Poland; (**b**): Quantile analysis. The current rate of income (in %) for O2 green bonds issued in Poland; (**c**): Quantile analysis. The current rate of income (in %) for O4 green bonds issued in Poland; (**d**): Quantile analysis. The current rate of income (in %) for O5 green bonds issued in Poland; (**e**): Quantile analysis. The current rate of income (in %) for O6 green bonds issued in Poland; (**f**): Quantile analysis. The current rate of income (in %) for O8 green bonds issued in Poland.

As indicated in the algorithm, we determined the dependence of the current rate of income indicator on other indicators included in the analysis. The calculated measure of similarity (dependence) was normalised to the range from 0 to 1. Value 0 means 100% similarity between two series, and value 1 means 0% similarity between two analysed series.

The results of the study (according to the indicated original WDTW algorithm) show the following conclusions for the green bond market in Poland.

CONCLUSION 1

The profitability of all analysed green bonds issued in Poland has not so far been linked to inflation. The determined ratio of WDTW dependence for all green bonds issued in Poland is 1 (on a scale from 0 to 1). This means that the profitability of green bonds is not affected by the volatility of inflation, both in the short and long term (Figure 22).

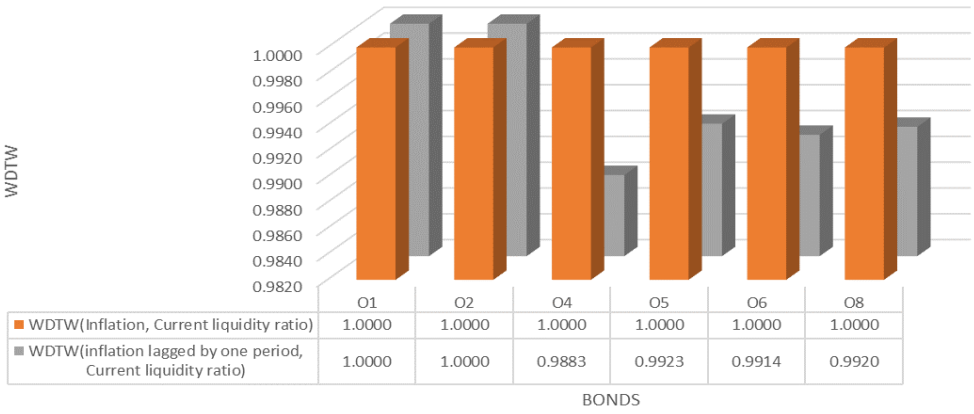


Figure 22. The value of the WDTW ratio in the short term between the profitability of individual green bonds and inflation. (analysis for Poland). Source: Own calculations.

CONCLUSION 2

The yield on green bonds issued in Poland is related to deposits. The research identified the following deposits with original maturity:

- Up to 1 month inclusive (d1);
- Over 1 month up to 3 months inclusive (d2);
- Over 3 months up to 6 months inclusive (d3);
- Over 6 months up to 1 year inclusive (d4);
- Over 1 year (d5).

All bonds are linked to deposits, as shown in the figures below.

CONCLUSION 3

The analysis shows that the yield on green bonds in Poland is related to the formation of deposits with an original maturity of up to 1 month inclusive. The WDTW ratio is low, and it can therefore be concluded that the development of these two indicators is similar. The strongest influence is visible for the bonds O1, O4, and O6. These are bonds issued, respectively, by mBank (O1), PKO (O4), and the Republic of Poland (O6). The O1 bond has a coupon based on 3-month EURIBOR + 1.25%, the O4 bond has a coupon based on 3mWIBOR + 51 bps, and the O6 bond has a coupon based on a 2% interest rate (Figure 23).

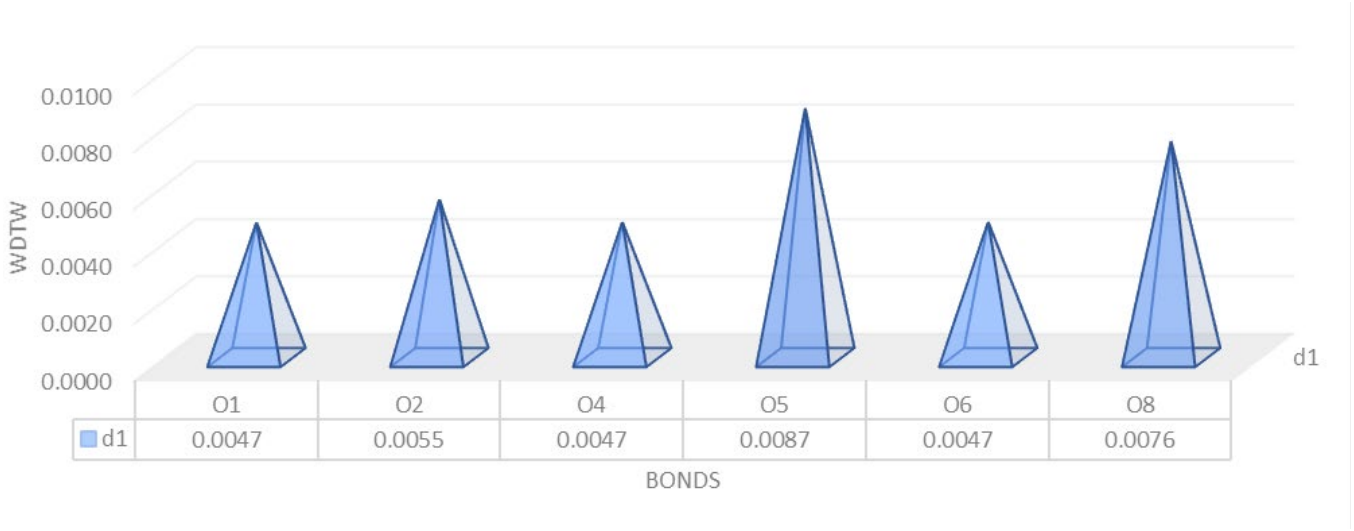


Figure 23. The value of the WDTW ratio in the short term between the profitability ratio of individual green bonds and deposits with an original maturity of up to 1 month inclusive (analysis for Poland). Source: Own calculations.

CONCLUSION 4

The evolution of the profitability of green bonds in Poland is related to the formation of deposits with a maturity exceeding 1 month, up to 3 months inclusive. The WDTW ratio is low, and it can therefore be concluded that the development of these two indicators is similar. The strongest influence is visible for the bonds O1, O4, and O6. These bonds were also most strongly associated with deposits with an original maturity up to and including 1 month (Figure 24).

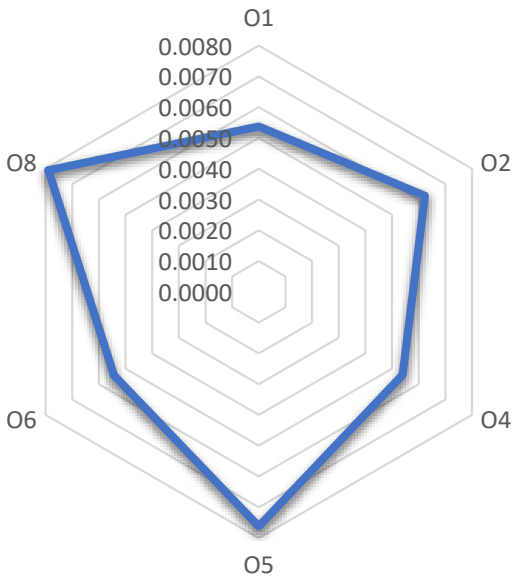


Figure 24. The value of the WDTW ratio in the short term between the profitability ratio of individual green bonds and deposits with an original maturity above 1 month up to 3 months inclusive (analysis for Poland). Source: Own calculations.

CONCLUSION 5

The O5 bond yield is most similar, both in the long and the short term, to deposits with a maturity of over one year.

The WDTW yield of this bond with deposits with a maturity date is, respectively:

- 0.0047—up to 1 month inclusive (d1);
- 0.0054—over 1 month up to 3 months inclusive (d2);
- 0.0064—over 3 months up to 6 months inclusive (d3);
- 0.0071—over 6 months up to 1 year inclusive (d4);
- 0.0027—over 1 year (d5). Analysing the results, it can be concluded that the volatility of the O1 bond yield is related to the volatility of various deposits.

CONCLUSION 6

When analysing the results, it can be concluded that the evolution of the profitability of all analysed bonds is very similar to the evolution of deposits in various time trends, as evidenced by the results obtained (Figure 25).

	O1	O2	O4	O5	O6	O8
d1	0.0047	0.0055	0.0047	0.0087	0.0047	0.0076
d2	0.0054	0.0062	0.0054	0.0076	0.0054	0.0079
d3	0.0064	0.0067	0.0058	0.0073	0.0058	0.0079
d4	0.0071	0.0065	0.0056	0.0073	0.0056	0.0080
d5	0.0027	0.0028	0.0024	0.0145	0.0025	0.0075

Figure 25. The value of the WDTW ratio in the short term between the profitability ratio of individual green bonds and deposits (analysis for Poland). Source: Own calculations.

CONCLUSION 7

The yield on green bonds issued in Poland is related to loans to individual entrepreneurs. The study confirms that the evolution of the profitability of all analysed bonds is similar to that of loans for individual entrepreneurs (Figure 26).

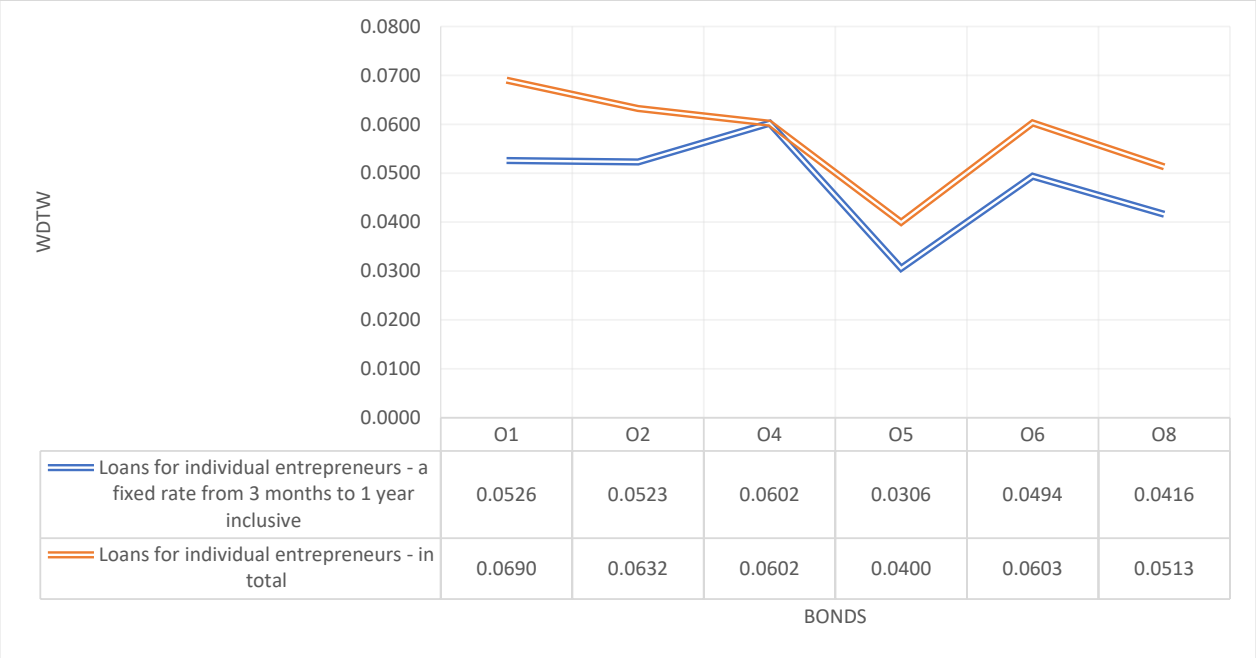


Figure 26. The value of the WDTW ratio in the short term between the profitability ratio of individual green bonds and loans to entrepreneurs (analysis for Poland). Source: Own calculations.

5. Discussion and Conclusions

The research was conducted in the Visegrad countries on only 20 green bond issues (nine in the Czech Republic, two in Hungary, one in Slovakia, and eight in Poland), and it is legitimate to ask whether they can be used as a basis for drawing conclusions about the correlation of the yields of green bonds issued by the World Bank, European Union governments, or other financial and non-financial issuers, with particular economic categories as a basis of reference.

It could be argued that the yield of each bond should depend on the level of inflation in the issuing country, and yet, as this research in the V4 countries shows, this is not the case. The link to inflation is evident in issues in the Czech Republic, while in the other V4 countries, green bond yields are not linked to inflation, and cross-correlation can be seen either with loans or deposits with a maturity of up to three months. Of course, an attempt could be made to analyse whether, to what extent, and at what rate changes in loan and deposit rates are influenced by changes in the level of inflation. The example of Poland shows that while loan interest rates follow changes/increases in official central bank interest rates in a situation of rising inflation, deposit yields have long been very low and their increase has been recorded only after a long delay, accompanied by a high, negative real interest rate.

In the V4 countries, the main issuers of green bonds are the state sector (Poland 66% of total issuance, Hungary 86%) and companies under state control (Poland—the largest bank and the largest oil company). In the Czech Republic and Slovakia, the issuers are companies. The activity of the state sector is indispensable in the development of the green bond market, as it is governments and the companies that depend on them, in particular, that should be aiming for sustainability and making investments in this area. This is a necessary but not sufficient condition. More attention should be paid to private companies (financial and non-financial institutions), which, when making climate protection investments, should be interested in raising capital by issuing green bonds. For this to happen, it is necessary for

the European Parliament to adopt appropriate legal regulations, especially with regard to the qualification of investments as well as the conditions of issuance.

Investor interest is another factor in the development of the market. While this article does not attempt to analyse the structure and behaviour of investors in green bonds, it is clear that investors in this market are institutional investors, primarily financial institutions. The pool of investors should be broadened to include individual, green-focused investors who are looking for new investments with low risk, high issuer reputation and an important social and economic purpose. For this to happen, appropriate decisions by financial market regulators introducing a range of tools are indispensable, on the one hand encouraging issuers to issue green bonds to the public, and on the other increasing investors' financial literacy and stimulating the demand for such bonds. It is the activity of individual investors that shapes the market and its level of development in the long term.

Green bond issues in the V4 countries have so far been few, although the orientation of economies towards sustainable development and the need to meet environmental targets will certainly change this. However, it is important that this is fostered by appropriate legal solutions at the EU level and in individual national jurisdictions, as well as by appropriate action taken by financial market makers to introduce efficient transaction mechanisms. Finally, the keyword is "profitability", as this is one of the factors of interest to investors. The profitability of green bonds must be correlated with the profitability of alternative capital market instruments, and the question of whether it is linked to inflation, deposit rates, or bank lending would seem to be a secondary issue.

Author Contributions: Conceptualisation, methodology: M.H.-D.; B.P., M.C. and J.C.; formal analysis: M.H.-D.; B.P., M.C. and J.C.; investigation: M.H.-D.; B.P., M.C. and J.C.; resources: M.H.-D.; B.P., M.C. and J.C.; data curation: M.H.-D.; B.P., M.C. and J.C.; writing—original draft preparation: M.H.-D.; B.P., M.C. and J.C.; writing—review and editing: M.H.-D.; B.P., M.C. and J.C.; visualisation: M.H.-D.; B.P., M.C. and J.C.; supervision: M.H.-D.; B.P., M.C. and J.C.; project administration: M.H.-D.; B.P., M.C. and J.C.; funding acquisition: M.H.-D.; B.P., M.C. and J.C All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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