EUROPEAN GOVERNMENT GREEN BONDS: ANALYSIS OF YIELD BEHAVIOUR DETERMINANTS

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European government green bonds: analysis of yield behaviour determinants

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Abstract: The subject of this paper are euro denominated green bonds issued by European governments. The aim is to determine the impact that: (1) volatility index of S&P 500 index – VIX, (2) six-month EURIBOR, (3) remaining maturity of the bond, (4) issuer's credit rating and (5) absence of an independent external opinion on compliance of the green bond framework with the *Green Bond Principles* have on green bond yields, as well as whether yields of these bonds provide premium called greenium. Panel regression results show that higher values of volatility index VIX, 6M EURIBOR, a longer remaining maturity of the bond and the absence of an independent external opinion on compliance of the green bond framework with the *Green Bond Principles* lead to an increase in green bond yields, while a higher credit rating allows for a lower required yield. Additionally, a comparison of green and conventional bonds does not show the existence of a greenium.

Key words: green bonds, greenium, sustainability
JEL Code: G10, C10, C21, C22, C23.

Non-technical summary

In recent years, environmental protection and the desire to contain or stop polluting activities harmful to biodiversity and human health have become increasingly important. Agreements such as the UN Agenda 2030, the Paris Agreement and the European Green Deal were made with the aim of putting global warming and climate change on our planet under control and enabling a healthier, better quality life. In order to fulfil these goals, significant amounts of resources and money are needed for projects and investments that would contribute to slowing down environmental threats. This is why the financial sector has largely joined the fight to preserve the planet, because if no action is taken, investments required to remedy the negative environmental consequences would need to be even larger in the future.

Financial markets have recognised the problem and are trying to solve it in different ways, partly through the development of green debt financing instruments such as green bonds. This market is still in its infancy, although the value of these instruments' issuances has seen exponential growth since the publication of the Green Bond Principles in 2014. However, it still represents only a small part of the total bond market. The focus of this paper is on euro-denominated government green bonds issued by the European countries, a market segment that has not been extensively studied so far.

In the paper we test the impact of the volatility index of S&P500 index – VIX, six-month EURIBOR, absence of an external party's opinion on compliance of the green bond framework with the Green Bond Principles, credit rating and the remaining maturity of the bond on green bond yields. The results suggest that higher values of the VIX, six-month EURIBOR, longer remaining maturity of the bond and absence of an independent external opinion lead to an increase in green bond yields, while a higher credit rating allows for a lower required yield.

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1 Introduction

Humanity faces numerous environmental challenges as well as extreme weather events – floods, melting glaciers, rising sea levels on the one hand, and heat waves, droughts, falling river levels, strong storms on the other, all as a consequence of climate change. The Earth was about 1.1±0.1°C warmer in 2021 compared to the end of the 19th century. The previous decade was the warmest on record and it is likely that the temperature difference compared to the pre-industrial levels will reach 1.5°C in the next two decades (World Meteorological Organization, 2022). This can lead to more extreme weather conditions, which would result in lower crop yields, increased hunger and poverty in the world, disappearance or change of habitats for numerous plant and animal species, etc. The consequences of global warming, in addition to the destruction of the world we live in, contribute to large natural and economic losses and costs. The pursuit of environmental protection and healthier living has led to the need for a change in people's habits and behaviour. It has also led to an effort to save the planet, which is in line with the warning of former United Nations Secretary-General Ban Ki-moon in 2016: "We do not have a plan B, because there is no planet B" (Ki-moon, B., 2016).

The first frameworks and protocols aimed at reducing greenhouse gases emissions were adopted during the 1990s: the United Nations Framework Convention on Climate Change and the Kyoto Protocol. At the United Nations Conference on Climate Change in Paris in 2015, the Paris Agreement was adopted with the goal to limit global warming to well below 2°C, preferably to 1.5°C compared to pre-industrial levels. This agreement was signed by almost all the countries in the world with the obligation to report on efforts made to achieve the goal beginning from 2024 on. In the same year the 2030 Agenda of the United Nations was adopted, the goals of which relate to environmental protection, eradication of extreme poverty and reduction of inequality by 2030. In 2019, the European Commission presented the European Green Deal with the aim of making Europe the first continent without greenhouse gas emissions by 2050.

Given that tackling these changes requires extremely large investments, the green bond market is developing as well. Green bonds are debt securities whose proceeds are used to (re)finance environmentally sustainable activities and projects. The first green bond was issued by the European Investment Bank in 2007 (European Investment Bank, 2021). However, this market continues to represent only a small segment of the bond market, which is still not regulated by a single framework. A substantial increase in the volume of issued green bonds began when the International Capital Market Association (ICMA) adopted the *ICMA Principles of Green Bonds* in 2014, which represent a set of guidelines and recommendations for the purpose of achieving maximum efficiency and further development of the green bond market. These principles should relieve investors' concerns that the funds will not in fact finance appropriate green projects, that is, they try to reduce the possibility and risk of the so-called *greenwashing*.

According to Cevik and Jalles (2020), global warming has a significant impact on government bond yields and spreads. This is especially true for developing countries where "a 1% increase in vulnerability to climate change leads to a 3.11% increase in long-term

government bond spreads compared to the US benchmark, while a 1% improvement in climate resilience lowers spreads by 0.75%" (Cevik & Jalles, 2020).

The subject of this paper are green bonds issued by European countries, denominated in euros. The aim is to examine whether there is a price difference between green and conventional bonds and also to examine the impact that the volatility index VIX, remaining maturity of the bond, six-month EURIBOR, credit rating and absence of an external opinion on compliance of the green bond framework with the *Green Bond Principles* have on green bond yields. Daily data from Bloomberg Professional Software Service were used to examine the existence of a greenium, as well as the impact that the before mentioned variables have on green bond yields.

Investors might be willing to pay more for a green bond than for a conventional one, and thus accept a lower yield, in order to finance projects that would have a positive impact on the environment. The negative difference between the yield on green and comparable conventional bonds that occurs in this case is called green premium (greenium) (UNDP, 2022). There is no clear consensus about the existence of a greenium as some authors have managed to identify it, while others have not. In order to test the (non)existence of a greenium, we will use two methods: first, we will compare green bond yields on the first day of trading with reference yield curves, and second, we will compare the average yields of green bonds and conventional benchmarks (in the case of Serbia, since there are two relevant benchmarks that mature in the year before and in the year after the maturity of the green bond, we estimated the yields of a hypothetical bond using linear interpolation). The sample will refer to government green bonds denominated in euros issued until the end of June 2022.

We will use panel regression to test the impact that VIX, 6M EURIBOR, remaining maturity, absence of an external opinion and credit rating have on green bond yields. Thirteen outstanding European government bonds will be sampled over a six-month period (31 March 2021 – 30 September 2021). In search of the best fitting model, the results of two models will be presented: a model with fixed effects and a model estimated by the generalized least squares method.

This paper consists of four chapters. The first chapter describes the basic characteristics of the green bond market and its growth. The second chapter will be devoted to the analysis of the difference between the yields on green and conventional bonds. The results and conclusions of research from the relevant literature will be described, and the differences between government green and conventional bonds of European countries denominated in euros will be analysed. In the third chapter of the paper, hypotheses about the effects that VIX, six-month EURIBOR, remaining maturity, credit rating and absence of an independent external opinion have on green bond yields will be tested using panel regression. The last chapter consists of concluding remarks.

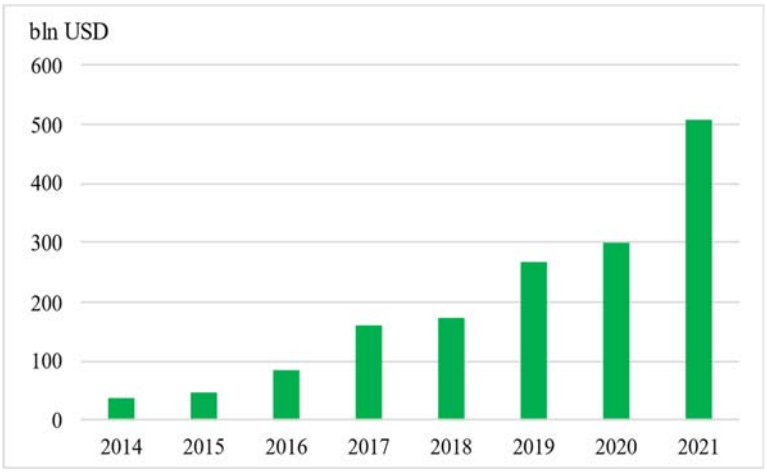
2 Growth and development of the green bond market

Supranational institutions have played a key role in the development of the green bonds market. The first green bond was issued by the European Investment Bank in 2007 in the

amount of USD 807 million (Climate Bonds Initiative, n.d.a). In the next few years, the value of these bond issues was small, and the issuers were usually supranational institutions. This market's growth gained momentum when the International Finance Corporation (IFC) issued a USD 1 billion green bond in 2013, the largest issue at that time. These institutions have contributed significantly to drawing the attention of financial market participants to financing sustainable projects. The importance of supranational institutions lies in the fact that they enter the markets through bonds of different maturities denominated in different currencies. They also use their knowledge and expertise in establishing best practices, training and advising market participants and contributing to the development of taxonomy, principles and standards.

The next important step in green bond market development was the publication of the *Green Bond Principles* in 2014, which represent the first non-binding document at the global level with the aim of reducing risks for all market participants and creating a regulated single market. The publication of the *Principles* contributed to the exponential growth of this market which reached a cumulative value of USD 1.6 trillion in green bonds issued in 2021. The value of green bond issues in 2021 exceeded USD 500 billion for the first time, which meant an increase of 75% compared to 2020 (Climate Bonds Initiative, 2022a).

Chart 1 **Annual value of green bond issues between 2014 and 2021**

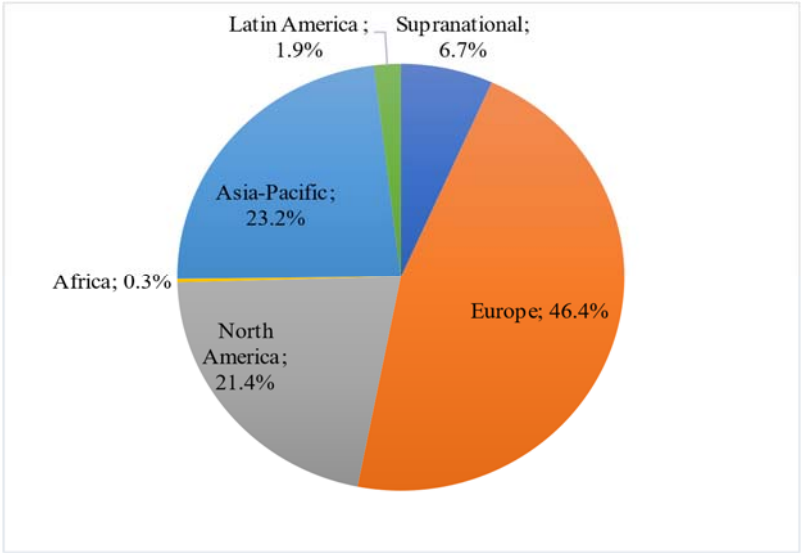


Source: Climate Bonds Initiative, 2022b.

The expertise of supranational institutions and the publication of the *Green Bond Principles* were crucial for the entrance of other types of issuers into this market: governments, municipalities, companies and financial institutions. In recent years financial institutions and non-financial companies are among the issuers with the highest share of issuance. Municipalities and companies entered the market in 2012 and financial institutions – one year later. The first country to issue a green bond was Poland in 2016. In the following year, France entered the market with the largest issue at that time. According to Climate Bonds Initiative data (2022a), financial institutions and non-financial corporations had the dominant share in the cumulative green bond volume, while governments had a share of only 10% at the end of 2021.

Observed by region, Europe had the largest share of cumulative issued green bonds at the end of 2021 (over 46%), followed by Asia-Pacific (23%) and North America (21%). Almost two-thirds of the value of issued green bonds in 2021 comes from developed countries.

Chart 2 **Share of regions in the total green bond issuance (ending with 2021)**



Source: Climate Bonds Initiative, 2022b.

Taking into account all issuer types, the United States has the highest cumulative value of issued green bonds (over USD 300 billion), followed by China (around USD 200 billion), France (over USD 160 billion) and Germany (over USD 150 billion). It was found that countries with better macroeconomic (gross domestic product, trade openness, stock market capitalisation) and institutional factors (capital controls, regulatory quality, rule of law) have a positive impact on green bond issuance volume (Tolliver et al., 2020).

Observed by currency, the euro (43%) and the US dollar (26%) had the highest share in the total issued green bonds in 2021 (Climate Bonds Initiative, 2022a). In recent years, there has been an evident increase in the share of larger market size deals. Those deals are mostly made over a ten-year period, but longer tenors have become more frequent in recent years (European Investment Bank, 2021).

Most of the proceeds are used for energy, buildings and transport (Climate Bonds Initiative, 2022a). Tolliver et al. (2019) explained these allocation patterns by the fact that greenhouse gas emissions reductions "are long-established, priority objectives among environmental policies", which channel money toward categories that would bring about a more substantial decrease in greenhouse gas emissions.

The pursuit of a healthier and better life induced growing interest in sustainable finance, which is not only reflected through green bonds or green loans. There are also instruments such as social bonds, sustainable bonds, sustainability-related bonds and transition bonds. A yearly increase in issuance is characteristic of these bonds too. Recently, the "blue" bonds have attracted attention. They represent a type of green bonds which are intended for funding projects and activities that can improve oceans and water sustainability (International Capital

Market Association, 2021). Oceans cover about 70% of the Earth and are of high importance in mitigating climate change.

3 Examination of the yield difference between green and conventional bonds

3.1 Literature results overview

The existing literature describes some of the incentives for issuing and holding green bonds. Higher ownership concentration was found in green bonds compared to conventional bonds (Baker et al., 2018). Another motive can be the signalling effect, indicating that these investors care about the environment and are ready to hold green bonds even if they bring lower returns compared to the conventional ones (Gilchrist et al., 2021). Hedging strategies, as described in Kanamura (2021) on the example of high yield ETFs (exchange-traded funds), may also attract investors.

Similar motives can be found for issuers as well. Gilchrist et al. (2021) found managerial opportunism as one of the reasons for sustainable business, emphasizing that the presentation of the company as socially and environmentally responsible and, thus, approaching a larger number of customers, brings benefits not only to the company, but also to managers. Thus, the reputation of a company can influence the terms of its funding in the long run. The reaction of the stock market to green bond issues is positive, which means that investors expect no greenwashing. If companies did not take actions toward sustainable projects, announcements of green bond issues would not cause a positive market reaction (Flammer, 2021).

One of the frequently asked questions is whether green bond issues can provide for cheaper financing, that is, whether investors are willing to accept a lower return, compared to conventional bonds, in order to finance sustainable projects. The results that can be found in the literature differ. Baker et al. (2018) found green premium on issued green municipal bonds compared to conventional ones. Zerbib (2019) examined the existence of a green premium on bonds of various issuers: financial institutions, corporations, supranationals, municipals, and found small, but significant negative premium of two basis points on green bonds. On the other hand, Bachelet et al. (2019) found that green bonds have higher yields, while Flammer (2021) found no pricing difference between green and conventional corporate bonds. Hachenberg and Schiereck (2018) came to the same conclusion in relation to bonds of different issuers. As the results found in the literature differ and none of these studies explicitly analysed government green bonds only, this encouraged us to analyse yield differences on European government green bonds.

3.2 European government green bond yield analysis

The preceding two years (2020 and 2021) were very important for the development of the government green bond market. The first sovereign issuance was in 2016 and the market has been increasing since then. Many countries entered this market for the first time during 2020 and 2021, e.g. the United Kingdom, Germany, Italy, Serbia, Spain. According to Climate

Bonds Initiative (2022b), total issuance of government green bonds was USD 72.8 billion in 2021, which is almost equal to the value of issuances in the 2018–2020 period. Europe is the continent with the highest share of the government green bonds volume. Alongside international commitments, the COVID-19 crisis has further drawn attention to environmental problems and the need for addressing them.

The question is whether green bonds enable cheaper borrowing for governments. Since the characteristics of these bonds do not differ much from ordinary ones, the first hypothesis was tested: There is no greenium on government green bonds compared to conventional ones. European government green bonds issued in euros until the end of June 2022 were analysed. There are twenty bonds issued by twelve countries. The analysis is done by comparing the yield on a green bond on the first trading day with the reference yield curve and comparing the average yield on a green bond with the conventional benchmark. The latter method has certain constraints, since there are usually no perfect benchmarks. In the case of sovereign bonds, much depends on the government's activities in the market in which the green bonds are issued. For example, some countries do not have a developed yield curve for bond issues in the international market and green bonds are issued in that market. The analysis compares green bonds with conventional bonds issued in euros in the same market, maturing as close as possible to the green bonds. Also, bonds with a date of issue and coupon rates approximate to that of the green bonds were selected. All data were collected from the Bloomberg Professional Software Service. The largest difference between maturity dates of green and conventional bonds is four years (in the case of Italy). The average yield was calculated from the first trading date of a green bond until the end of June 2022. Bonds issued by Serbia and Germany were reviewed in particular.

The first government to issue the green bond was Poland in 2016. This bond matured in December 2021. After 2016, three more issuances followed: one in 2018 (bond matures in 2026) and two in 2019 (bonds were issued on the same day and mature in 2029 and 2049).

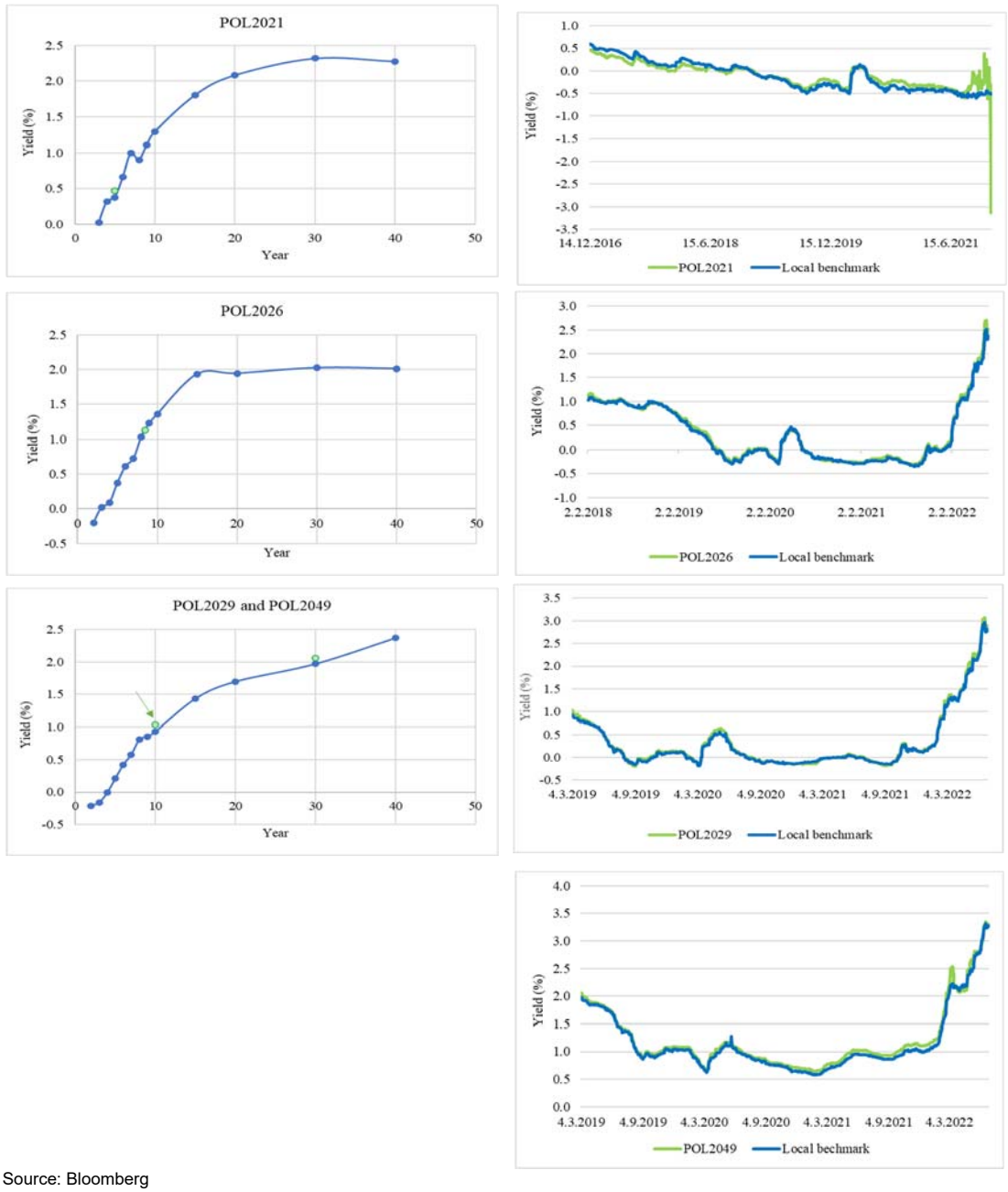
In order to examine the existence of a green premium, the yield on the first trading day was compared with the reference yield curve (left-hand side of Chart 3; the green bond yield is marked with a green circle). The right-hand side of the chart shows the movement of green bond yields from the first trading day until 30 June 2022, as well as the yields on their selected local benchmarks. The results of both methods reveal that the differences in yields are small, but still suggest the absence of a greenium. The average yield on a five-year green bond that matured in December 2021 (shown as POL2021 in the Chart) is almost equal to the yield on its selected benchmark (it is higher by 1 bp) which matured two months later. The average yields on the remaining three green bonds are 2–6 bp higher than the yields on their benchmarks.[1]

France entered the green bonds market in 2017 and has issued three bonds so far: with a maturity of 22 and a half years in 2017 (OAT2039) and with a maturity of 23 years in 2021

[1] The selected benchmark of POL2026 also matures in 2026, while the benchmarks of POL2029 and POL2049 mature five months earlier and two years and five months earlier, respectively. An overview of the differences between the average yields on green and conventional bonds will be presented at the end of the chapter.

(OAT2044), while in 2022 it issued a green bond linked to the harmonized index of consumer prices (HICP) for the first time. This bond has a maturity of 16 years (OAT€i2038).[2]

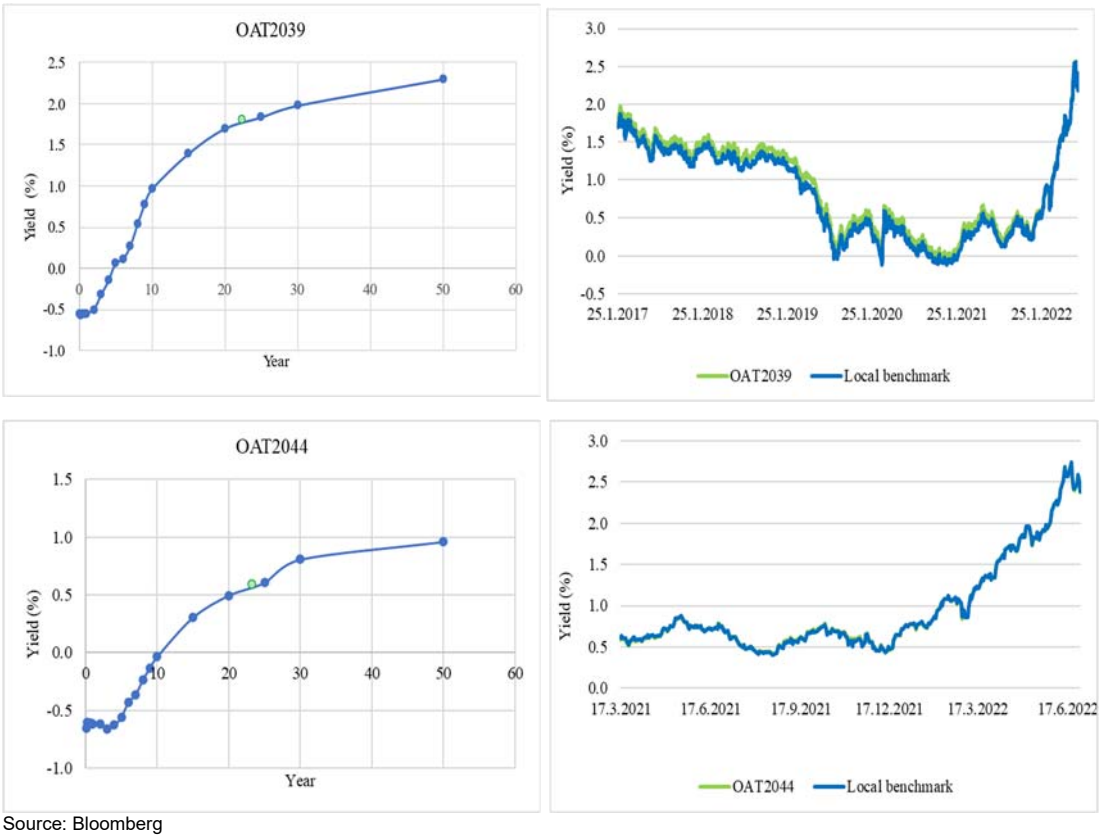
Chart 3 **A comparison of Poland's green bond yields with yield curves and benchmarks**



Source: Bloomberg

[2] The benchmark of the first bond matures three years before the green bond, the benchmark of the second bond matures one year after the green bond and in the case of the third bond the benchmark matures two years before the green bond.

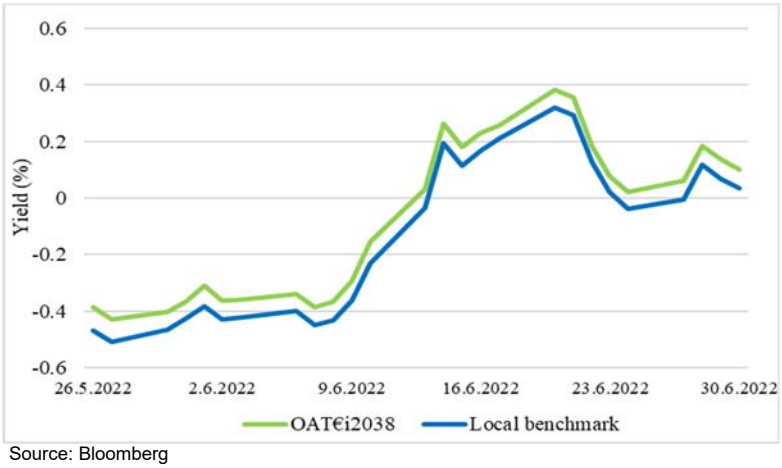
Chart 4 **A comparison of France's green bond yields with yield curves and benchmarks**



Source: Bloomberg

Chart 4 shows the yields on bonds that mature in 2039 and 2044 and, using both methods, we can conclude that the greenium does not exist. The average yields on OAT2044 and its benchmark are almost completely equalized, while the yield on OAT2039 is higher than on its benchmark. The yield on the first trading day of the last issued bond has not been compared with the yield curve, as it is linked to inflation. The second method suggests that, for the time being, the yield on this bond is higher than the yield on its benchmark.

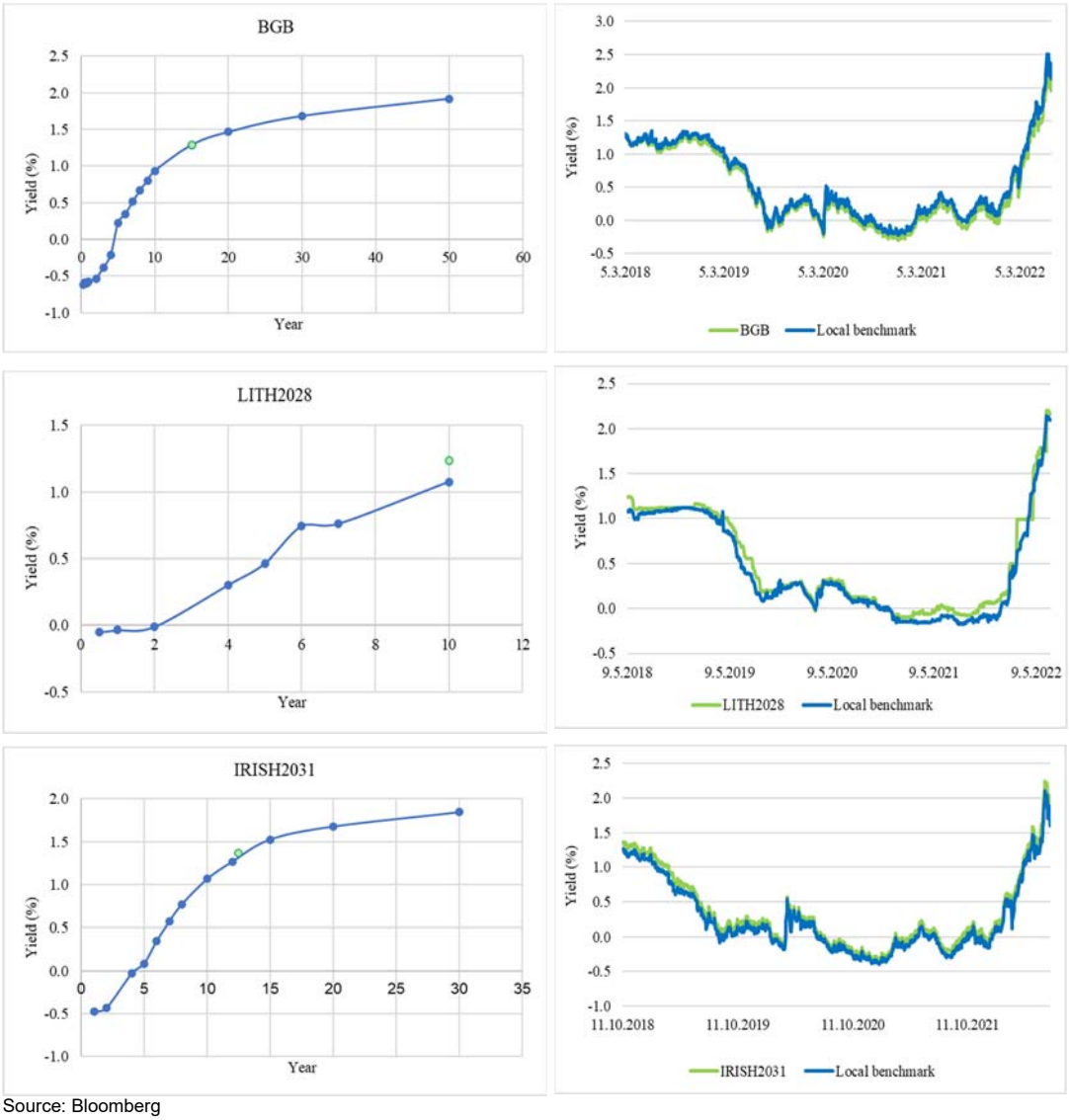
Chart 5 **A comparison of France's green bond yield OAT€i2038 with its benchmark**



Source: Bloomberg

In 2018, three countries entered this market: Belgium, Lithuania and Ireland. Belgium issued a bond with a maturity of 15 years (BGB), Lithuania with a maturity of 10 years (LITH2028) and Ireland with a maturity of 12 years and 5 months (IRISH2031).[3] Using both methods to test for the existence of a greenium, no premium was found in the case of Lithuania and Ireland. However, in the case of Belgium, the average green bond yield in the observed period is lower than the benchmark by 8 basis points. When compared to the yield curve, the greenium is extremely low – 0.3 basis points.

Chart 6 **A comparison of Belgium's, Lithuania's and Ireland's green bond yields with yield curves and benchmarks**

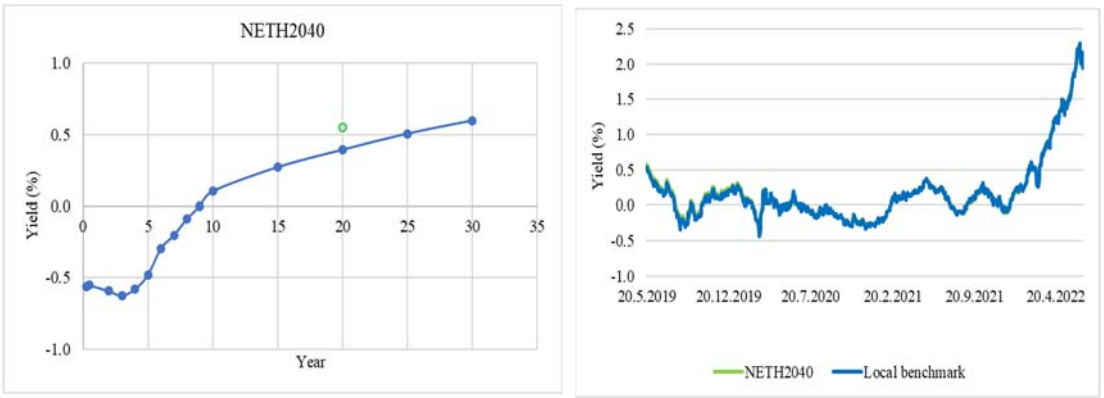


Source: Bloomberg

[3] Belgium's benchmark matures one year after the green bond, while Lithuania and Ireland's benchmarks mature one year before the green bonds.

The Netherlands issued its green bond in May 2019. It matures in January 2040 (NETH2040), while its selected benchmark matures two years later. Chart 7 shows that the yield on the first trading day of this bond is above the yield curve on that day, while the difference in the average yields on this bond and its benchmark is only one basis point – the benchmark has a lower yield, which suggests the absence of a greenium.

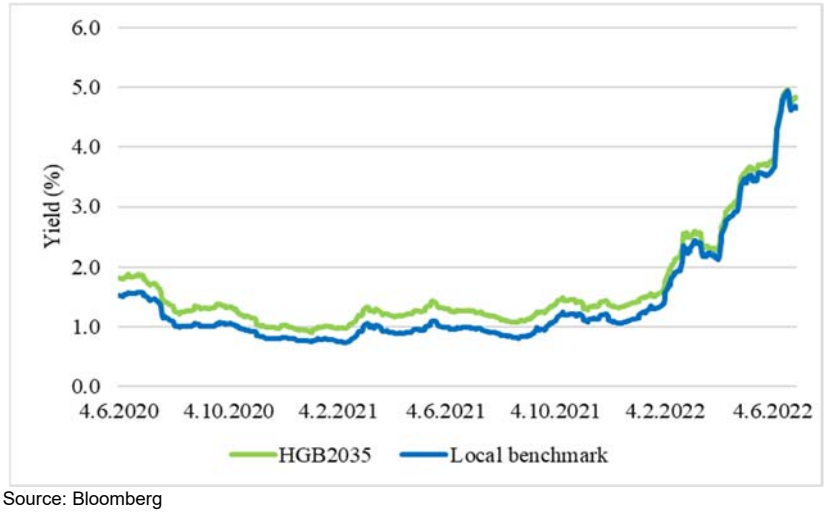
Chart 7 **A comparison of the Netherland's green bond yield with yield curve and benchmark**



Source: Bloomberg

Hungary is the country that has issued green bonds in several different currencies so far: in the yen, yuan, forint and euro. It entered this market in 2020, when it issued two bonds in the Japanese yen and one in euros in the international market. The euro-denominated bond matures in 2035 (HGB2035) and its benchmark in 2032. Given that there is no developed yield curve for bonds issued in the international market in euros, this comparison was not possible. Chart 8 shows that the yield on the green bond is higher than the yield on the benchmark in the observed period, which means that greenium was not found using the second method.

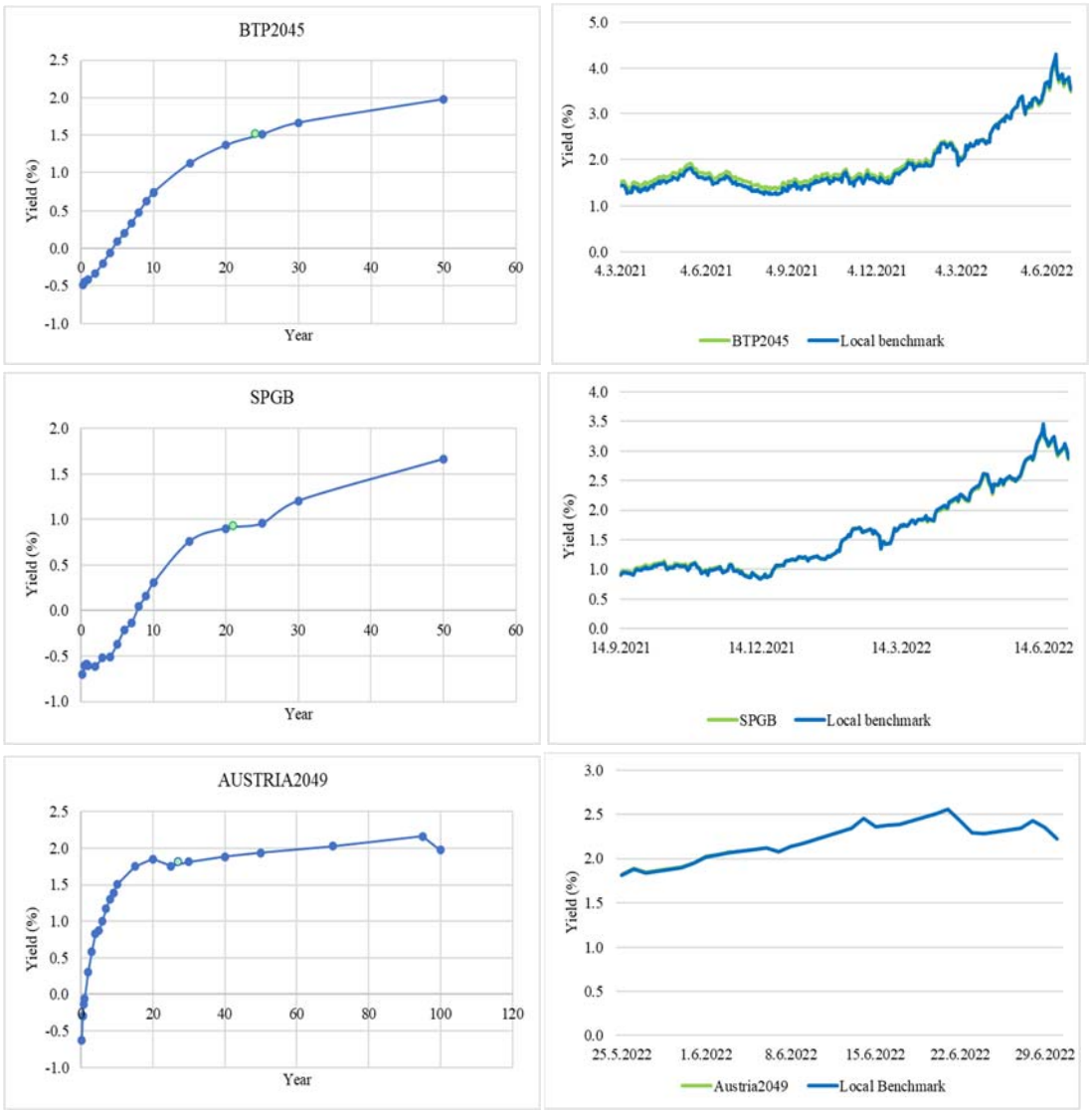
Chart 8 **A comparison of Hungary's green bond yield with benchmark**



Source: Bloomberg

Italy and Spain issued their bonds in 2021. The Italian bond has a maturity of 14 years (BTP2045), and the greenium was not found in this case either.[4] The Spanish bond was issued for a longer term and matures in 2042 (SPGB). No greenium was found when comparison was made with the yield curve and the average yield on it is only 0.1 basis points lower than in the case of its benchmark, suggesting the existence of a premium.[5]

Chart 9 **A comparison of Italy's, Spain's and Austria's green bond yields with yield curves and benchmarks**



Source: Bloomberg

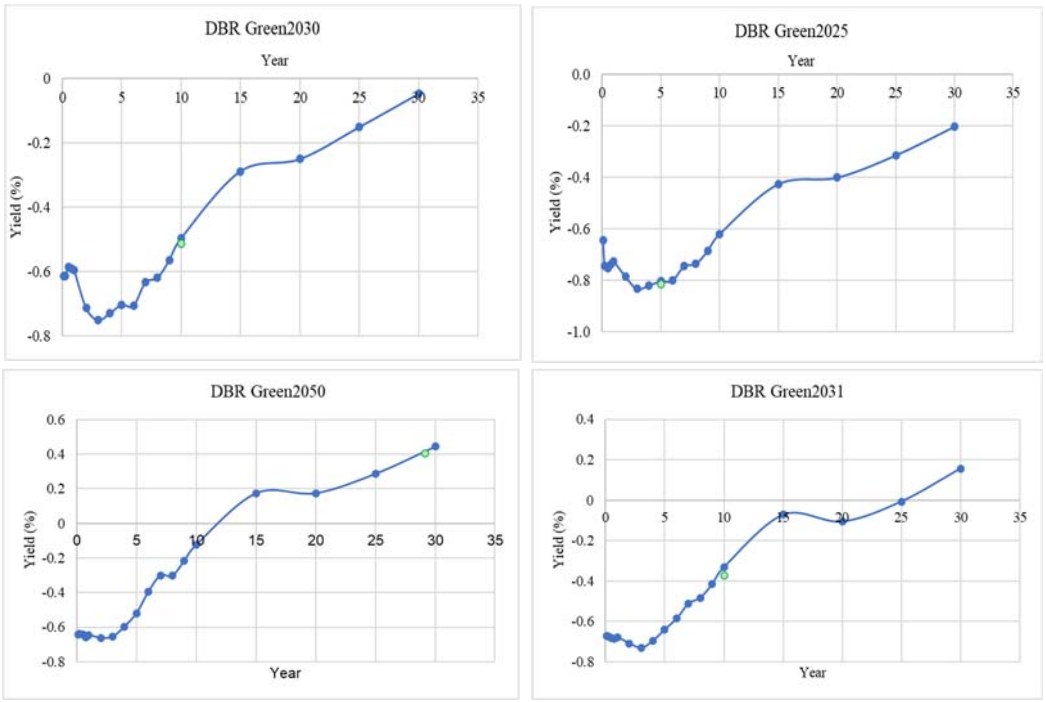
[4] Benchmark matures four years before the green bond.

[5] Benchmark matures two years before the green bond.

In 2022, Austria issued a 27-year green bond. However, the greenium was not found when comparison was made with the yield curve, or when the average yields were compared with the benchmark – the yields are almost equal.[6]

As evident from the example of the previously described countries' bonds, there is no perfect reference conventional bond. The difference between the maturity dates of these bonds is usually in the range of 1–3 years. However, Germany entered the green bond market in a different way in 2020. The Twin Bond Strategy is defined in Germany's Green Bond Framework, meaning that green bonds will be issued together with conventional bonds that have the same key characteristics: coupon rate, interest payment dates and maturities. The difference between these bonds is in the volume of issuance (conventional bonds will be issued in larger amounts), date of issuance (conventional bonds will be issued first) and the ISIN. The goal is to establish a green yield curve with the same maturities as the conventional curve (Federal Republic of Germany, Federal Ministry of Finance, 2020a). It was also pointed out that that the German Finance Agency will "strongly support" secondary market liquidity. The Agency can carry out outright sales and purchases, repurchase agreements and securities lending, using the Federal Government's own stock of Green Bonds and switch transactions. If demand for the conventional twin is higher than that for the green bond, the German Finance Agency can use the switch option and meet demand. In the opposite situation, market regulation is expected. In such a case, the Agency may or may not meet such demand (Federal Republic of Germany, Federal Ministry of Finance, 2020b).

Chart 10 **A comparison of Germany's green bond yields with yield curves**



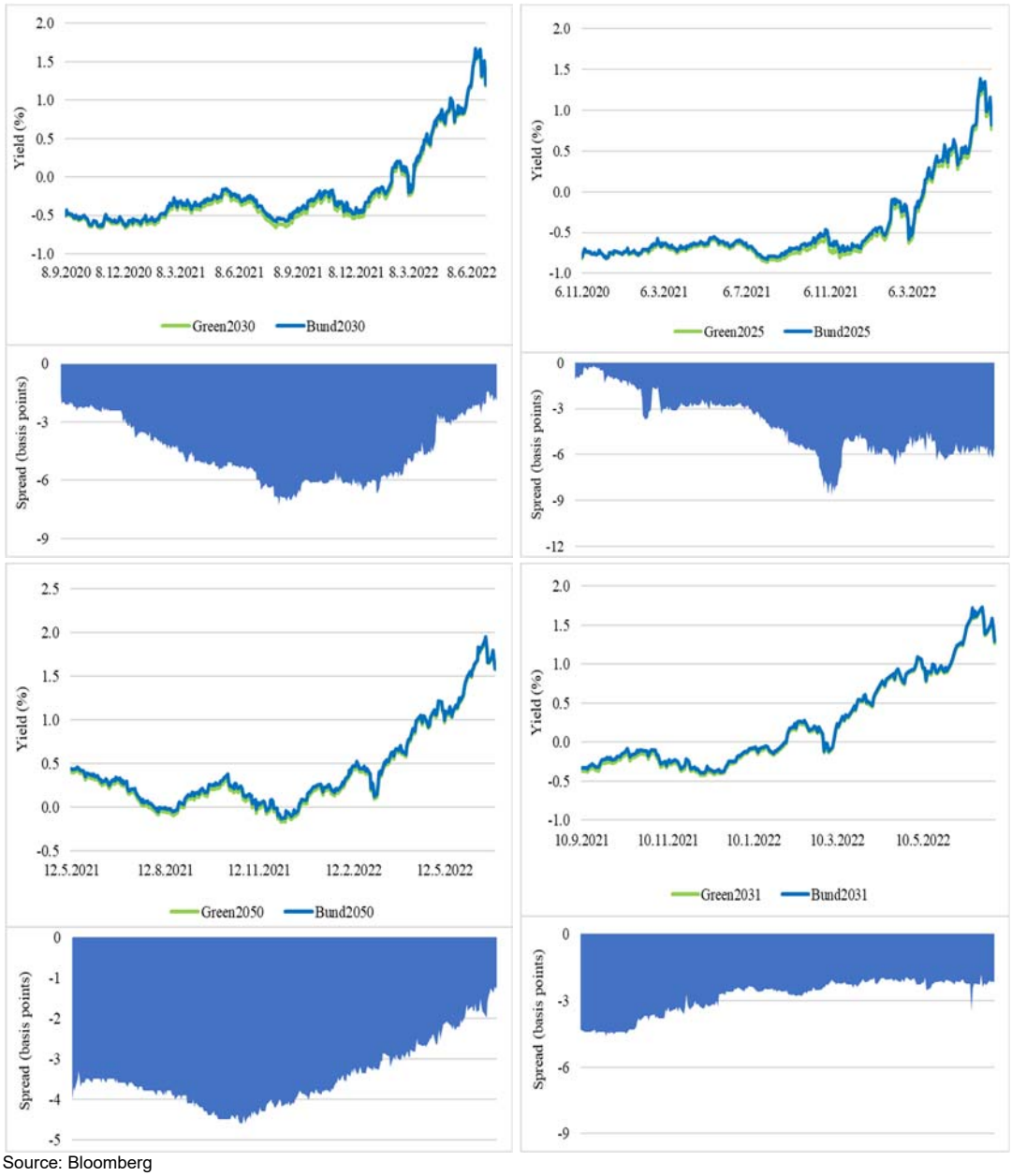
Source: Bloomberg

[6] Benchmark matures two years after the green bond.

Germany has issued four green bonds so far: two in 2020 (with maturities of ten and five years) and two in 2021 (with maturities of ten and twenty-nine years). When yields on the first trading day are compared with the yield curve, the existence of a greenium is observable.

Chart 11 shows the movement of green and conventional bonds. It is noticeable that during the observed period (from the first day of trading of green bonds until the end of June 2022) the green bond yields are lower than the yields on conventional bonds. Using the second method based on average yields, this also means the existence of premium. The average greenium for bonds that mature in 2031 and 2050 is 3 basis points, and for bonds that mature in 2025 and 2030 it is 4 basis points.

Chart 11 **A comparison of Germany's green bond yields with benchmarks**



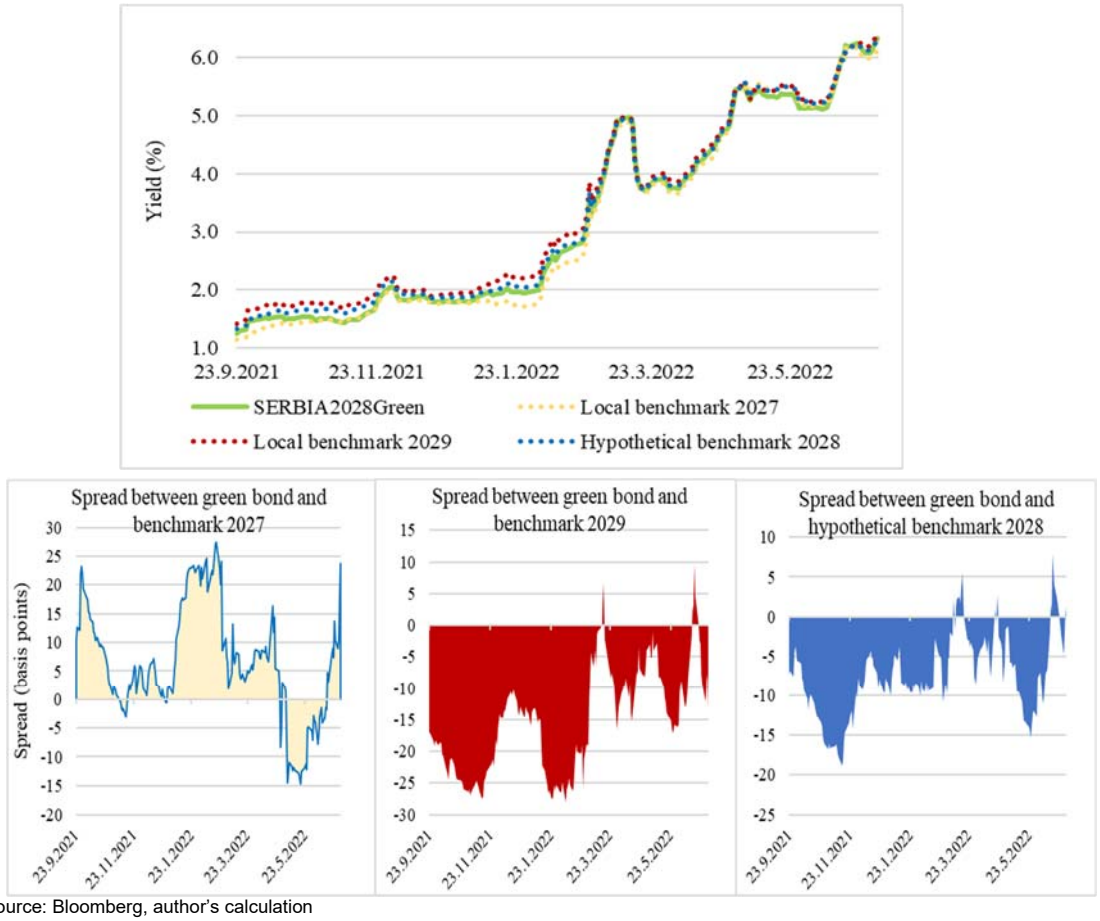
Source: Bloomberg

In 2021, Serbia issued its first green bond in the international market, making it the first (and so far the only) non-EU country in Europe to do so. In its case, as well as in the case of Hungary, there is no developed yield curve for euro-denominated securities issued in the international market. For this reason, it is impossible to implement the first method for determining the existence of the green premium. This bond has a maturity of 7 years and matures on 23 September 2028, that is, in the year between the maturities of other two conventional bonds issued in the international market, but a little closer to the bond that matures in 2029. As there are two relevant benchmarks (one matures in 2027 and the other in 2029) and the results relating to the existence of greenium depend on the decision as to which of the two bonds we take as the benchmark in our analysis, linear interpolation has been done, using the following formula:

$$Y_n = \frac{Y_1 \times (t_2 - t_n) + Y_2 \times (t_n - t_1)}{t_2 - t_1} \quad (1)$$

where Y_n is estimated yield, Y_1 yield on bond with shorter maturity, Y_2 yield on bond with longer maturity, t_n days to maturity of estimated hypothetical bond, t_1 days to maturity of bond with shorter maturity, t_2 days to maturity of bond with longer maturity (Martellini et al., 2003). It shows us the estimated yields that the conventional bond maturing in the same year as the green one (2028) would have.

Chart 12 **Comparison of Serbia's green bond with benchmarks**

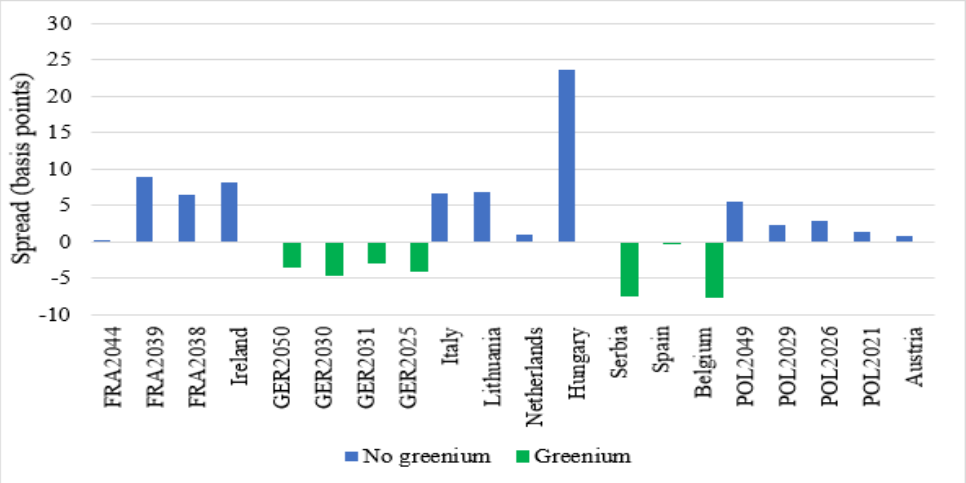


Source: Bloomberg, author's calculation

If the average yields on the green bond were compared to the average yields on the bond maturing in 2027, no premium would be found, although it is noticeable from the lower left part of Chart 12 that there was a premium during certain periods (several days in November and December 2021, few days in April 2022 and in the period from 4 May to 15 June 2022). On the other hand, a comparison of the average yield on the green and the conventional bond maturing in 2029 would show the existence of greenium. Therefore, the comparison of average yields was done over the estimated yields of the hypothetical bond. Given that the maturity of the green bond is closer to the maturity of the bond maturing in 2029, the yields of this benchmark had a higher weight than the yield of the benchmark maturing in 2027 (0.65 vs. 0.35). As a result, the comparison of the average green bond yield and the average hypothetical bond yield shows a greenium of 7 basis points.

Looking at the results of 20 green securities (issued by twelve countries), only seven of them have a greenium. These are the bonds issued by Germany, Spain, Serbia and Belgium. These findings are represented in Chart 13. According to these results, we can accept the first hypothesis that there is no greenium when European government green bonds are compared with conventional ones denominated in euros.

Chart 13 **Differences in average green and conventional (benchmark) bond yields**



*in the case of Serbia, the green bond was compared to an estimated hypothetical benchmark

Certainly, we should not forget that there are no perfect benchmarks for green bonds (except in the case of Germany). This is a market in its infancy and the following years may allow us to make better comparisons and examine the existence of a greenium. However, given the serious environmental warnings and the signed agreements, it may happen that almost every bond or loan in the future will finance sustainable projects and that the label “green” would no longer have the meaning it has today.

4 Analysis of green bond yield determinants[7]

4.1 Descriptive statistics

In this part of the paper we are examining the impact that:

- remaining maturity of the bond,
- six-month EURIBOR,
- volatility index of Standard & Poor's 500 index – VIX,
- credit rating and
- absence of an independent external opinion on compliance of the Green Bond Framework with the *Green Bond Principles*

have on green bond yield behaviour. We use daily data (working days) on outstanding European government green bond yields from 31 March 2021 until 30 September 2021 (data were collected from Bloomberg)[8]. The sample contains of 13 bonds: two bonds issued by France, two by Germany, one by Ireland, one by Italy, one by Lithuania, one by the Netherlands, one by Hungary, one by Belgium and three bonds issued by Poland.

The volatility index VIX represents the volatility of the S&P500 index based on market expectations of stock price movements over the next 30 days. Credit rating and no second party opinion are two dummy variables. All countries that have a credit rating of A3 or higher given by Moody's take value one, and zero otherwise. Absence of an independent external opinion is a dummy that takes value one if the country does not have an external opinion on compliance of its Framework with the *Green Bond Principles*, and zero otherwise. An overview of the variables is shown in Table 1 below.

Table 1 **Dependent and independent variables**

Variable name	Variable label	Source
Yield	Yield on European government green bonds	Bloomberg Professional Software Service
Remaining Maturity	Remaining maturity of bond	Created by author
VIX	Volatility Index of S&P500 index price movements	Bloomberg Professional Software Service
6M EURIBOR	Six-month EURIBOR	Bloomberg Professional Software Service
Dummy Credit Rating	Takes 1 if Moody's credit rating is A3 or higher, zero otherwise	Created by author
Dummy Absence of external opinion	Takes 1 if there is no external opinion on the compliance of the Green Bond Framework with the Green Bond Principles, zero otherwise	Created by author

[7] The results of this analysis were presented at the scientific meeting SYM-OP-IS 2022.

[8] Poland's 2016 bond was not included in the analysis, because it matured in December 2021.

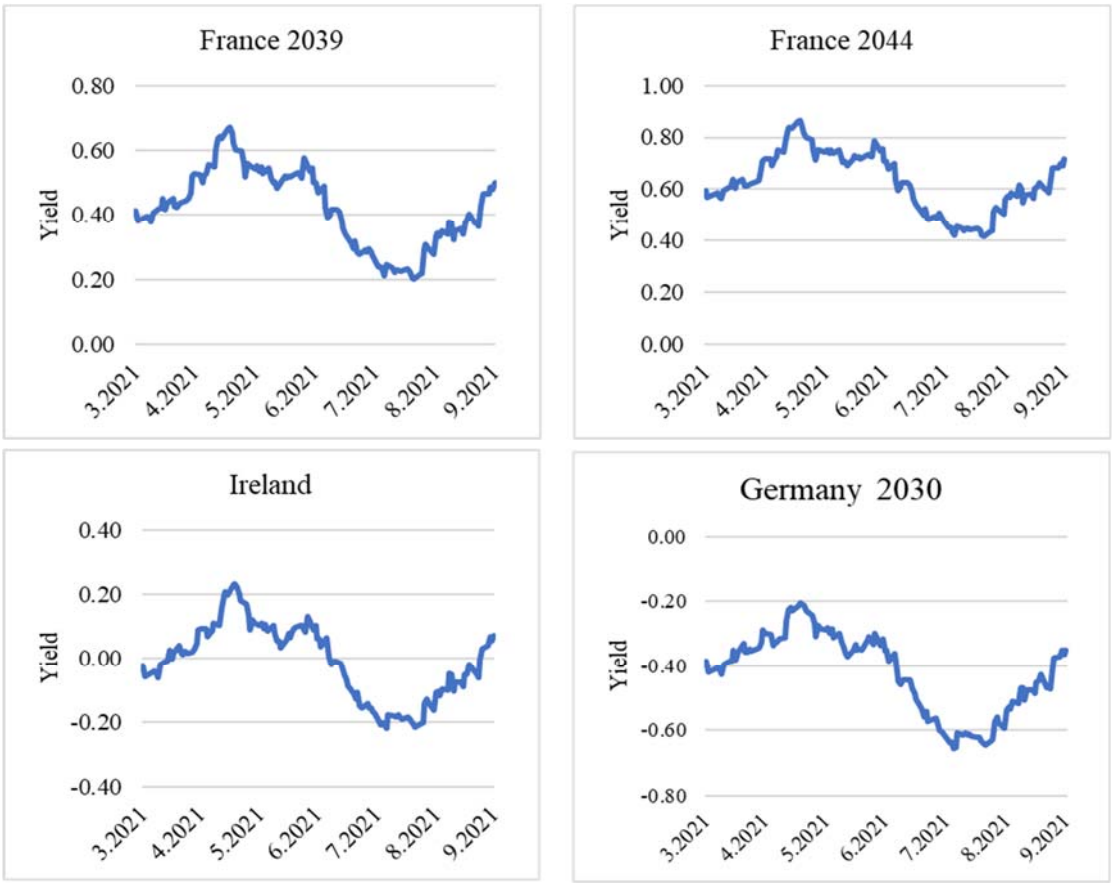
Table 2 shows mean, standard deviation, minimum and maximum of dependent and independent variables. Minimum yield refers to the German 5-year green bond that has a rating of Aaa, while the maximum refers to the Italian bond that has a rating of Baa3. The average yield is 0.27 and the standard deviation 0.64, meaning that there was no high return on these bonds, but also no high risk. All green bond yields during the observed period are represented in Chart 14.

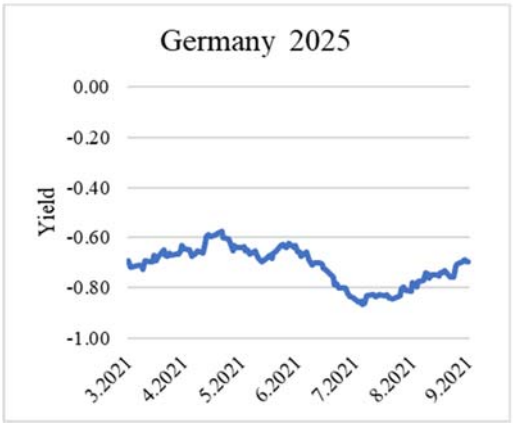
Table 2 **Descriptive statistics**

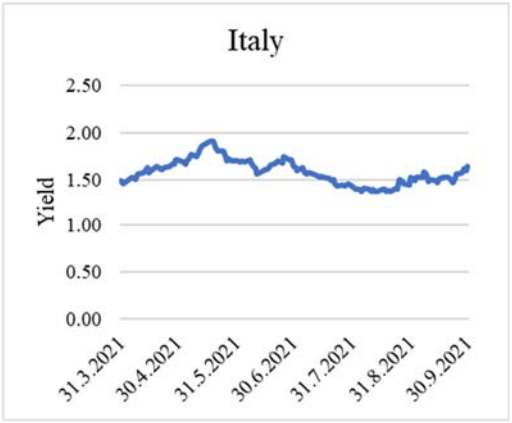
Variables	Observations	Mean	Standard deviation	Minimum	Maximum
Yield	1,690	0.2747373	0.6443952	-0.868	1.912
Maturity	1,690	13.24438	7.366417	4	27
VIX	1,690	18.10946	2.173647	15.07	27.59
6M EURIBOR	1,690	-0.5182385	0.0061522	-0.531	-0.505

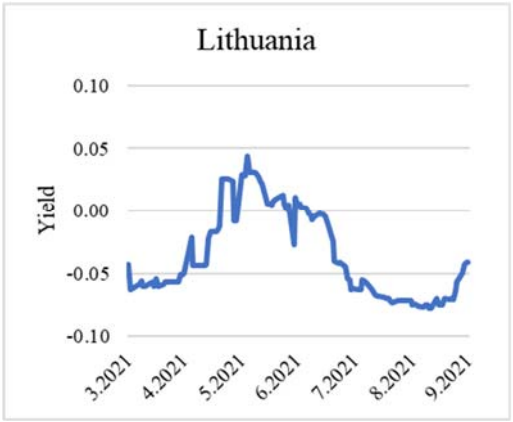
The average remaining maturity of bonds is 13 years. The average value of the volatility index during the observed period is 18, which means that high volatility was not expected. 6M EURIBOR is -0.52 on average and it shows no significant movements during the observed six-month period (from -0.53 to -0.51).

Chart 14 **Green bond yields from 31 March 2021 to 30 September 2021**

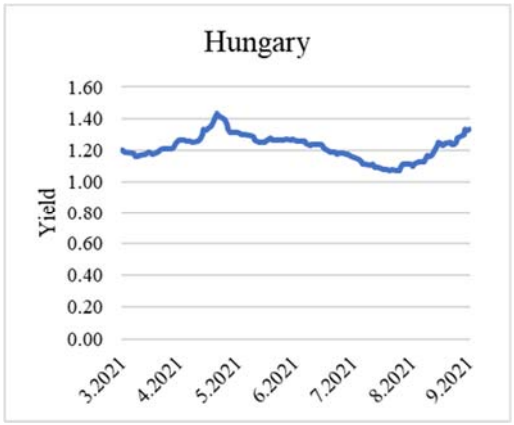


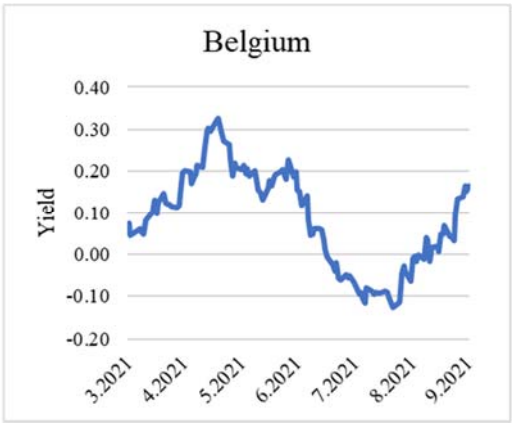

Germany 2025
Yield
0.00
-0.20
-0.40
-0.60
-0.80
-1.00
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021

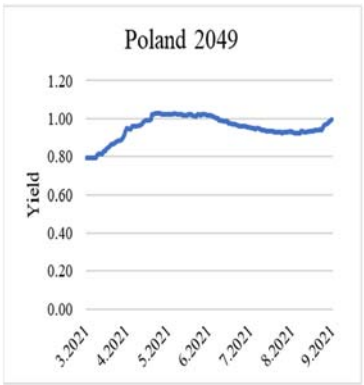

Italy
Yield
2.50
2.00
1.50
1.00
0.50
0.00
31.3.2021
30.4.2021
31.5.2021
30.6.2021
31.7.2021
31.8.2021
30.9.2021

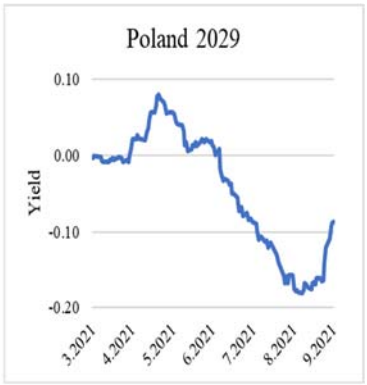

Lithuania
Yield
0.10
0.05
0.00
-0.05
-0.10
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021

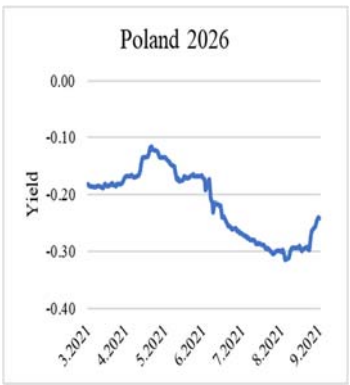

The Netherlands
Yield
0.60
0.40
0.20
0.00
-0.20
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021


Hungary
Yield
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021


Belgium
Yield
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021


Poland 2049
Yield
1.20
1.00
0.80
0.60
0.40
0.20
0.00
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021


Poland 2029
Yield
0.10
0.00
-0.10
-0.20
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021


Poland 2026
Yield
0.00
-0.10
-0.20
-0.30
-0.40
3.2021
4.2021
5.2021
6.2021
7.2021
8.2021
9.2021

From Table 3 we can conclude that there is no multicollinearity between explanatory variables. Correlations between independent variables are smaller than ±0.5. These results have been confirmed by the Variance Inflation Factor (VIF), where the VIF for all independent variables is between 1.02 (in the case of VIX) and 1.17 (in the case of Remaining maturity).

Table 3 **Correlation between variables**

	Yield	Maturity	VIX	6M EURIBOR	Credit rating	No external opinion
Yield	1,0000					
Maturity	0,7787	1,0000				
VIX	0,0202	-0,0028	1,0000			
6M EURIBOR	0,0985	0,0164	-0,1465	1,0000		
Credit rating	-0,7462	-0,2903	0,0000	0,0000	1,0000	
No external opinion	-0,1389	-0,2773	0,0000	0,0000	0,1231	1,0000

4.2 Panel regression analysis

We are testing two hypotheses:

- Higher values of volatility index VIX, 6M EURIBOR, a longer remaining maturity of the bond and the absence of an independent external opinion on compliance of the green bond framework with the Green Bond Principles lead to an increase in green bond yields.
- Green bonds with a higher credit rating allow for lower required yields.

To assess the effect of these variables on yields, it is necessary to determine which model we should use: a fixed or a random effects model. Applying the Hausman test at a 5% level of significance, we reject the null hypothesis that suggests the use of a random effects model and start with a fixed effects model (FE) for balanced panel data, which can be described by the following equation:

$$Y_{it} = \alpha + \beta X_{it} + \mu_i + \vartheta_{it} \quad (2)$$

for t = 1, ..., T and i = 1, ..., N, where Y_{it} is the dependent variable, α the intercept, β the coefficients, X_{it} the independent variables, μ_i, the individual specific effects, and ϑ_{it} remainder disturbance (Brooks, 2019). The advantage of this model is that it takes into account individual specifics.

Problems that we have are cross-section dependency, autocorrelation and heteroskedasticity in residuals. We have managed to overcome the last problem by using the fixed effects model, however, but not the others. Given that time dimension in our panel is larger than the number of cross-sections, we used a model estimated thorough the generalized least squares method (GLS) to address the before mentioned issues. The results of the evaluated models are shown in Table 4:

Table 4 **Testing impact of independent variables on Yield using a fixed effects model and a model estimated by the generalized least squares method**

	(1) FE	(2) GLS
Maturity	0,0319	0,0428***
	(0,0201)	(0,000944)
VIX	0,0105***	-0,000342
	(0,00189)	(0,000276)
6M EURIBOR	10,24***	0,0216
	(1,334)	(0,147)
Credit rating		-0,931***
		(0,0137)
No external opinion		0,0171
		(0,0192)
Constant	4,965***	0,631***
	(0,804)	(0,0817)
N	1690	1690
r2	0,449	
r2_o	0,602	
r2_b	0,620	
r2_w	0,449	
sigma_u	0,493	
sigma_e	0,0758	
Rho	0,977	

Standard errors are shown in parentheses.
* p<0,05 ** p<0,01 *** p<0,001

We conclude that not all explanatory variables are statistically significant in both models by comparing the results obtained by the evaluation of the panel model. We can derive the following conclusions: The longer the remaining maturity, the higher the yield. The higher the expected volatility, the higher the yield. 6M EURIBOR, as one of the main reference rates for euro, also suggests that the yields move in the same direction as it does. Bonds that do not have an external opinion on compliance of the green bond framework with the *Green Bond Principles* bear higher yield, since they may carry a higher risk that the proceeds may not be used to finance environmentally sustainable projects. According to these results, we can accept the hypothesis that higher values of volatility index VIX, 6M EURIBOR, a longer remaining maturity of the bond and the absence of an independent external opinion on compliance of the green bond framework with the *Green Bond Principles* lead to an increase in green bond yields. Countries that have a lower credit rating (Italy and Hungary in this case) have higher yields than those with higher credit ratings. Hence, we can accept next hypothesis – green bonds with a higher credit rating allow for lower required yields.

5 Conclusion

Recently, more and more attention has been paid to ecology, environmental protection and healthier living. This is a consequence of different "warnings" from nature, which also encouraged the adoption of international frameworks, agreements and strategies in order to slow down global warming. High investments in environmentally sustainable projects enabled the creation and development of the green bond market. This market is still emerging and the amounts and number of issued green bonds is rising every year. The base of investors and issuers of these bonds is increasing, as is the number of currencies in which green bonds are issued. Still, there are some challenges that need to be overcome in order to increase confidence that these bonds will finance green projects. One of the major questions is what projects can be considered as environment-friendly and how to avoid investing in "green" bonds that do not actually finance sustainable projects. The number of standards and taxonomies is increasing in order to prevent greenwashing and regulate this market.

The entry of governments into the green bond market can have a positive impact on the entry of other participants and increase investor confidence that green projects will be financed (Tolliver et al., 2020). The government green bond market is currently dominated by European countries, especially since the beginning of the COVID-19 pandemic. That is the reason why we focused on European government green bonds in our analysis. The goal was to examine whether green premium exists and how 6M EURIBOR, VIX, remaining maturity of the bond, absence of an external opinion on the green bond framework and credit rating affect green bond yields.

We compared green bond yields on the first trading day with their reference yield curves and found no greenium in most of the cases. The same conclusion was reached when the average yield on these bonds was compared with conventional benchmarks. That can be due the fact that there are no perfect benchmarks for green bonds. Germany is the only country in the sample that issued both conventional and green bonds with the same key characteristics and in that case greenium was found. In the case of Serbia, where the results of the analysis depend on which of the two conventional bonds we choose as the benchmark, we estimated the yield of the hypothetical conventional bond using linear interpolation, and the results of this comparison show the existence of greenium. Also, some countries lack various maturities when forming the yield curve, which can also affect the results. Since this market is rising, it is expected that more countries will enter this market and that issuance of these bonds will continue to grow rapidly. Furthermore, with a larger sample the existence of greenium could be assessed more accurately.

We used panel regression to test the impact of 6M EURIBOR, remaining maturity, VIX, credit rating and absence of external opinion on green bond yields. The following can be concluded:

- higher values of volatility index VIX, 6M EURIBOR, a longer remaining maturity of the bond and the absence of an independent external opinion on compliance of the green bond framework with the *Green Bond Principles* lead to an increase in green bond yields;
- green bonds with a higher credit rating allow for lower required yields.

Appendix

Table 1 **Decomposed variances of variables**

Variable		Mean	Std. Dev.	Min	Max	Observations	
Yield	overall	.2747373	.6443952	-.868	1.912	N =	1690
	between		.6621129	-.7150846	1.582177	n =	13
	within		.1016594	.0220527	.6045604	T =	130
Maturity	overall	13.24438	7.366417	4	27	N =	1690
	between		7.65674	4	27	n =	13
	within		.3406872	12.50592	14.12899	T =	130
VIX	overall	18.10946	2.173647	15.07	27.59	N =	1690
	between		0	18.10946	18.10946	n =	13
	within		2.173647	15.07	27.59	T =	130
MEURIBOR	overall	-.5182385	.0061522	-.531	-.505	N =	1690
	between		0	-.5182385	-.5182385	n =	13
	within		.0061522	-.531	-.505	T =	130
Credit~g	overall	.8461538	.360908	0	1	N =	1690
	between		.3755338	0	1	n =	13
	within		0	.8461538	.8461538	T =	130
NonSec~n	overall	.0769231	.2665482	0	1	N =	1690
	between		.2773501	0	1	n =	13
	within		0	.0769231	.0769231	T =	130

*Abbreviation NonSec refers to the absence of an independent external opinion.

Table 2 **Partial correlations between independent variables and Yield**

Variable	Partial Corr.	Semipartial Corr.	Partial Corr.^2	Semipartial Corr.^2	Significance Value
Maturity	0.9047	0.5933	0.8184	0.3520	0.0000
VIX	0.1251	0.0352	0.0156	0.0012	0.0000
MEURIBOR	0.3133	0.0922	0.0982	0.0085	0.0000
CreditRat~g	-0.8910	-0.5483	0.7938	0.3006	0.0000
NonSecond~n	0.3520	0.1051	0.1239	0.0110	0.0000

Table 3 **Hausman test**

	Coefficients (b) fe	(B) RE	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
Maturity	**.0319438**	**.0402662**	**-.0083224**	**.0034003**
VIX	**.0105255**	**.0105356**	**-.0000101**	**4.13e-06**
MEURIBOR	**10.23539**	**10.0726**	**.1627884**	**.0665108**

b = consistent under Ho and Ha; obtained from xtreg
B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi2(**1**) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= **5.99**
Prob>chi2 = **0.0144**
(V_b-V_B is not positive definite)

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