Saint Petersburg State University
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Analysis of Green Bond premium

Master's Thesis by the 2nd year student
Concentration – Master in Corporate Finance
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ЗАЯВЛЕНИЕ О САМОСТОЯТЕЛЬНОМ ХАРАКТЕРЕ ВЫПОЛНЕНИЯ ВЫПУСКНОЙ КВАЛИФИКАЦИОННОЙ РАБОТЫ

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_____01.06.2021_____ (Дата)

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АННОТАЦИЯ

Автор	Лиженина Ксения Николаевна
Название ВКР	Анализ премии «зеленых» облигаций
Образовательная программа	Корпоративные финансы
Направление подготовки	Менеджмент
Год	2021
Научный руководитель	Окулов Виталий Леонидович
Описание цели, задач и основных результатов	Данная работа ставит целью исследовать премию зеленых облигаций. Для достижения поставленной цели было проведено сопоставление зеленых облигаций с аналогичными не зелёными облигациями и выявлены разницы в доходностях между зелеными и не зелеными облигациями, которые далее были приняты за величину зеленой премии. В исследуемую выборку вошли 59 пар облигаций на временном интервале с 2015 по 2021 годы. Методология исследования включала: анализ временного ряда через Гауссово сглаживание, полиномиальная аппроксимация временного ряда, поиск связи между переменными через причинность Грэнджера. Результаты анализа доказали существование зеленой премии и ее периодичность. Анализ разницы в ликвидности между зелеными облигациями и не зелеными аналогами и анализ взаимосвязи показателя и зеленой премии показал, что между зеленой премией и ликвидностью существует причинная взаимосвязь. При этом, ликвидность не является предиктором зеленой премии, из чего следует вывод, что динамика зеленой премии может объясняться бихевиористическими мотивами инвесторов и их отношением к зеленым облигациям на разных интервалах жизненного цикла последних.
Ключевые слова	Зеленые облигации, премия зеленых облигаций, ликвидность зеленых облигаций, взаимосвязь премии и ликвидности зеленых облигаций, доходность зеленых облигаций

ABSTRACT

Master Student's Name	Ksenia Lizhenina
Master Thesis Title	Analysis of Green Bond premium
Educational Program	Master in Corporate Finance
Main field of study	Management
Year	2021
Academic Advisor’s Name	V. L. Okulov
Description of the goal, tasks and main results	This research aims to investigate the premium of green bonds. To achieve this goal, a comparison of green bonds with similar non-green bonds was provided and the differences in yields between green and non-green bonds were revealed, which were then taken as the value of the green premium. The studied sample included 59 bond pairs in the time interval from 2015 to 2021. The research methodology included: time series analysis through Gaussian smoothing, polynomial approximation of the time series, search for relationships between variables through Granger causality test. The results of the analysis proved the existence of the green premium and its periodicity. Analysis of the difference in liquidity between green bonds and non-green peers and analysis of the relationship between the indicator and the green premium showed that there is a causal relationship between the green premium and liquidity. At the same time, liquidity is not a predictor of the green premium, from which it follows that the dynamics of the green premium can be explained by the behavioristic motives of investors and their attitude to green bonds at different intervals of the latter's life cycle.
Keywords	Green bonds, green bonds premium, liquidity of green bonds, relationship of premium and liquidity of green bonds, yield of green bonds

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INTRODUCTION

Formal definition for green bongs, which is provided by ICMA is:

"Green Bonds are any type of bond instrument where the proceeds will be exclusively applied to finance or re-finance, in part or in full, new and/or existing eligible Green Projects"

Green Projects in this case can be identified as projects, which contribute to environment objectives, such as: climate change mitigation, climate change adaptation, natural resource conservation, biodiversity conservation, and pollution prevention and control (The Green Bond Principles: Voluntary Process Guidelines for Issuing Green Bonds, 2018).

As far a question of environment changes has begun really worrying not only for society and "green" organizations, but also for government and companies, the problem of choice of the ways for financing of "green" projects is important for discus nowadays too.

In the most of cases "green" projects require a lot of investments, while resources of the government and companies are limited. The solution of this problem is constructing debt from the socially responsible investors (who are interested not only in profit, but also in the environment aspect of their investments) by green bonds (here and after GBs) issuing.

The significant boost to development of green bond market was made by the Copenhagen Accord in 2009 (Bachelet, Becchetti, & Manfredonia, 2019), which has established, that financial markets have to play the central role in climate changes outcomes mitigation. As far resources of the government and corporations are limited, the best solution is to promote financial products, which appeal investors. Green bonds is the most suitable example of financial product, which is able to satisfy demand in resources for environmental projects development and to satisfy demand of investors in stable and low-risky fixed-income investment product.

Green bond investment is a solution not only for environmental, social and governance focused investors, but also for conventional fixed-income investors who eagerly seek efficient ways to 'green' their portfolios (Nanayakkara & Colombage, 2019).

While green bond is one of the ways of investments' attraction for the issuer, for investor this is the question of portfolio diversification and environment concerned investments.

Nowadays, education of the modern investor is focused not only on profitable ways of income, but also on sustainable development of investments. This fact can be proved by oversubscription in the most of cases when GBs were issued: for Unibail Rodamco issue value were EUR 500m, while volume subscribes was EUR 3000m; for Xingjiang Goldwind issue value were USD 300m, while volume subscribes was USD 31400m. That is why experts argue, that green bonds market has huge imbalance in supply and demand of GBs (Laskowska, 2018).

Also, we should remember about reputation features, which have GBs. Current trend on sustainable development and corporate responsibility provides an opportunity for issuers to improve their reputation. Sometimes, the fact of responsible activities of the company can have an impact on the assessment of the assets and investment risk management.

Risk characteristics, associated with the issuer, are the same for comparable green bonds (GBs) and conventional bonds (CBs). However, GBs are serviced not only by cash flows which are associated with any green project, but also by investors' attitude to characteristics of the project (in our case "greenness" of the project). As a result, a tighter yield spreads (YS) reflects investors' willingness to pay a premium for GB issuance in contrast to CBs. Despite, GBs are usually associated with lower cash flows; investors value the "label" of GBs due to lower risks and positive ethical side of investment. From the issuer's point of view, lower spread may be a signal to lower cost of capital and higher investment opportunity, what provide a motivation to issue more GBs by lowering the overall cost of capital (Nanayakkara & Colombage, 2019).

On the one hand, GBs are less risky, have lower volatility and higher liquidity due to market imbalance and high demand on these financial products and should demonstrate lower premium. On the other hand, GBs are associated with lower cash flows and risk of "greenwashing" (risk of that the issuer reports reflect greater eco-friendly activities, then they are in reality) and thus in terms of higher level of uncertainty should demonstrate higher returns. That is why, it is crucial to study GBs during their "life cycle" to identify which characteristics are more highly valued by investors and detect the investors perception of GBs. This question is the core question of the topic. Thus, we can formulate the research goal as follows: *"to estimate green bonds premium during life cycle of this bond: at the different stages after issuance".* The answer on the research question could provide as an opportunity to formulate particular recommendations for investors in terms of understanding GBs premium behaviour during the life cycle and creation of possible investment strategy. Thus, to provide significant impact into theoretical and practical GBs understanding we can formulate the following research questions:

1. *How the green bond premium changes over its life cycle?*
2. *If the GBs premium changes over life cycle from positive to negative or opposite, when turning point happens?*

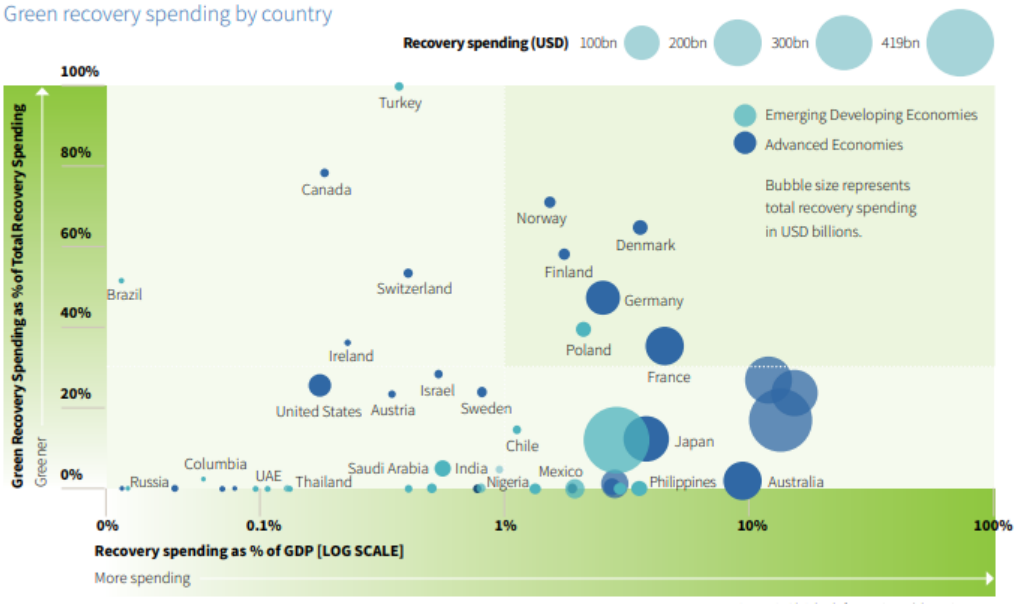
CHAPTER 1. THEORETICAL BACKGROUND OF GREEN BOND PREMIUM

1.1. Green Bonds market overview

Strengthened perception and concern about ecological threats have permeated into the financial sector and fostered different financial instruments which are able to provide ecological and social benefits with financial benefits at the same time. GBs showed their effectiveness in terms of solution of climate and social problems.

GBs market was created in 2007 when the European Investment Bank issued a "climate awareness bond". Later, World Bank issued GBs as an answer on the request of Scandinavian pension funds which were looking for stable and safe investment opportunities with connection to climate changes. After that, GBs market grew slowly until 2013 when USA Massachusetts state issued the first significant GBs volume of USD 100 million (Breen & Campbell, 2017). Nowadays GBs are assumed to be an instrument, which is able to provide significant financial resources for green projects and increase awareness among issuers, investors and society in general about climate changes risks.

Already many countries put a question about climate changes mitigation and sustainability at the core and multiple countries already have committed to become carbon neutral by 2050 year or even early (Harrison & Muething, 2021). That is why many countries (especially Developed economies) already spend significant funds into sustainability projects. Details on financing green recovery is represented in picture 1:



Pic. 1. *Green Recovery spending by country. Source: Climate Bond Initiative, 2021*

In 2020 cumulative volume of GBs market achieved USD 1.1 trillion. Separately, in 2020 at the end of December volume of Green market reached USD 290.1bn. 2020 year was started by strong offer of new GBs until March when attention of issuers was switched on social and sustainable bonds to mitigate negative impact of COVID-19 on countries economy. However, the third quarter showed the highest issuance volumes of GBs what laid to significant increase of GBs market for 2020 year in general. Detailed information about GBs market cumulative results is represented in table 1:

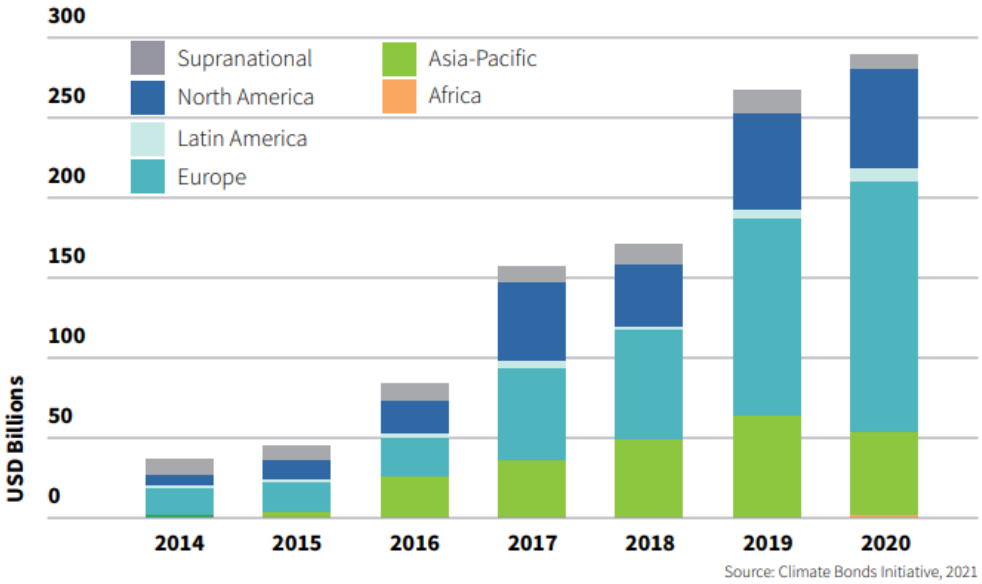
Table 1. Cumulative size of GBs market

Cumulative size: Green Bonds December 2020		
	Value 2020	**Value vs previous year**
Total size of the market	USD 1.1tn	+9%
Number of issuers	1428	+14%
Number of instruments	7716	-9%
Number of countries	71	+6%
Number of currencies	42	unchanged

From the region perspective, it should be noted that in 2020 80% of GBs issuance happened in Developed markets (for comparison in 2019 – 73%) while Emerging markets decreased their volume in GBs issuance till 16% (in 2019 – 22%). The main reason is the switching of Chinese government and municipals into Social bonds issuance to mitigate COVID-19 negative impact on economy.

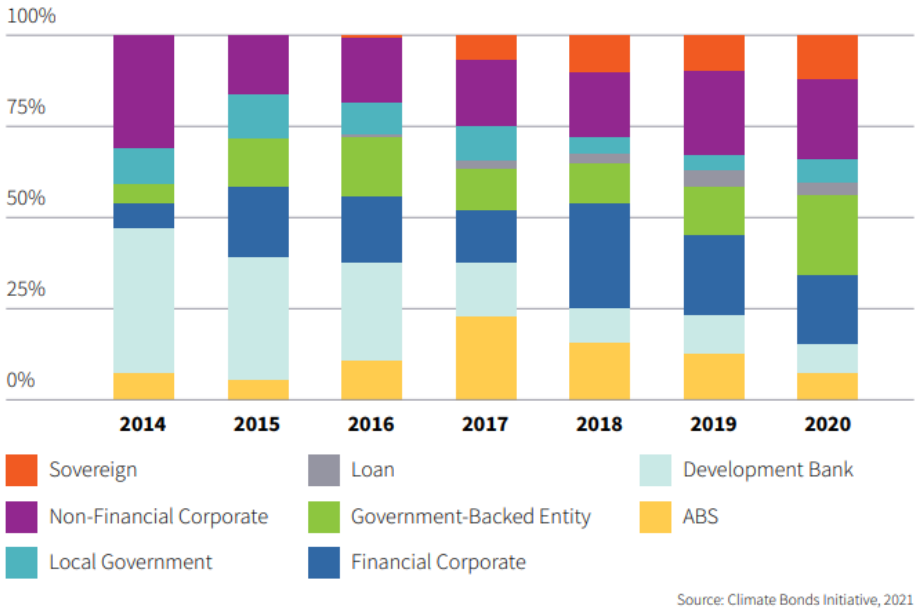
Europe became the largest source of Green Bonds in 2020 and issued 48% of total GBs volume. And while North America showed stability in GBs market (USD 61.5bn in comparison with USD 60bn in 2019), Latin America demonstrated growth of 65% compared to the prior year. Detailed regional split of GBs issuance in 2020 is represented in the Picture 2.

Talking about issuer type, 2020 year showed significant growth of sovereign GBs issuance (78% of growth in comparison with 2019 year). This type of issuers is the most important for GBs market in general due to the extremely high volume of their issuance and high ratings of these issuers. They are playing as “market creators” in this case and afford smaller issuers to play on this market successfully. As far sovereign issuers dominates GBs market and usually provide long-term issuance with longer maturity, in 2020 62% of issuance have maturity up to 10 years and 40% have a 5-10 years maturity.



Pic. 2. *Regional split of GBs issuance. Source: Climate Bond Initiative, 2021*

Despite an opinion, that commercial sector especially financial corporate is not sensitive to macroeconomic changes in terms of choice investing instruments issuance due to long-term pre-aligned investment plans, this year showed significant switching of Financial Corporate sector into social bonds for COVID-19 effects mitigation (this year volume of their GBs issuance decreased from USD 58.7bn to USD 55.7bn). Detailed information about issuers split in dynamic is represented in Picture 3:



Pic. 3. *Issuer-type split of GBs market*[1]*. Source: Climate Bond Initiative, 2021*

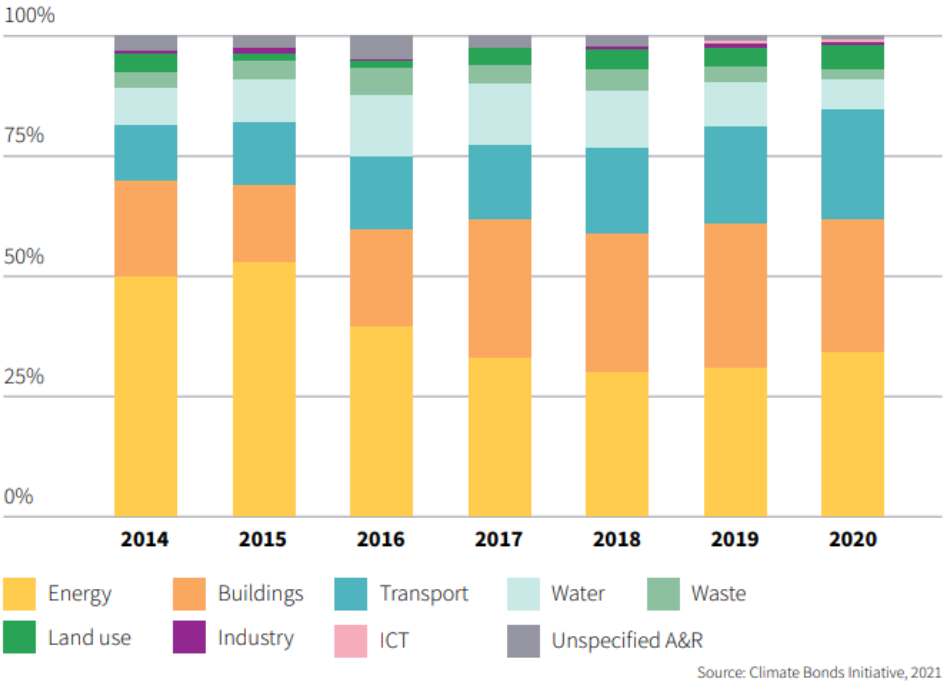
[1] ABS – Asset-Backed Securities

As for use of proceed (or underlaying projects) here unchanged leaders are Energy, Building and Transport sectors. These sectors contributed 85% of total volume in GBs market in 2020. However, the only increased sectors were Energy, Transport and Land Use.

Sovereigns and government-backed entities provided 26% of Transport sector. Large and long-term projects are not so liable to negative pandemic effects and it is assumed that was the reason why the sector did not suffer. The highest contribution in the sector GBs issuance came from France (USD 14.8 bn) and China (USD 3.8bn) on their 11 separate metro projects.

GBs investments of Renewable Energy increased by 19% comparing with 2019. About 46% of these investments came from as financial so non-financial corporates including energy corporates and telecom providers.

Land use GBs investment direction showed the most significant growth of 59% comparing with 2019 year, however it still stays one of the smallest sectors in GBs market with only 5% contribution in total market volume. In this sector sovereign issuers dominates with projects which relate to land use expenditures in their frameworks. More detailed information about GBs market use of proceed in dynamic is represented in Picture 4.



Pic. 4. *UoP split of GBs market*[2]*. Source: Climate Bond Initiative, 2021*

[2] ICT – Information and Communication Technologies

It is expected that GBs market will show further growth from the following reasons (Breen & Campbell, 2017):

- Those companies/ sovereignty/ municipalities who is already concerned about climate changes will have access to GBs market and look for investments there.
- Green building projects and sectors which are reasoned in climate changes will have to provide climate changes mitigation projects due to developing legislation in this area and thus will look for investments on GBs market.
- GBs indices showed significant demand on GBs market which is increasing. That indicates that investors look for ways how to "green" their portfolios and there are more interested in GBs investors.
- The International Energy Association argues that USD 1 trillion of additional investments will be needed to mitigate negative effects of climate change for the next 3 decades. These resources can be acquired via GBs market.

In general, public funds[3] are able to cover only 10 to 15% of all needed funds to climate related projects according to research results of Green Finance Committee. Respectively, the most reasonable way to cover these financial needs is GBs market.

1.2. Features of Green Bonds

In general, GBs are really similar to the common bonds. The main difference is the direction of investments. While general bonds accumulate finance for different purposes, GBs allow to obtain financial resources only for financing of eco-friendly activities. That is why, we can say, that GBs is a kind of "theme" bonds, which were often used in the past (for example "war bond" for financing military needs, railroad, or highway bonds for investment of huge infrastructure projects).

Nowadays several GBs classifications and identifications with their own criteria and features exist. According to one of this classifications GBs can be *labeled* as green bonds if the issuer wants to inform investors about that their investments will be used for financing eco-friendly ventures. In opposite there exist another type of bonds - *unlabelled* "climate-aligned bond". The funds that arise from this type of bonds are not specially marked for environmental projects, while the assets, which are used in the projects are climate-affected (like emission reduction or climate change adaptation).

Also, we can classify Green Bonds into 3 groups:

- corporate Green Bonds (issued by companies)
- sovereign Green Bonds (issued by national governments)

[3] Public funds is money that comes from the government, often through taxes

- sub-national Green Bonds (issued be local government)

In general, GBs are not totally different from other bonds except their direct investment purposes (environment projects). Green Bond is a fixed income financial instrument of the debt capital market. “The issuer of GBs raises a fixed amount of capital from investors over a set period of time repaying the capital when the bond matures and paying an agreed amount of interest along the way.” (WIŚNIEWSKI, 2019)

The main advantage of GBs is the improvement of the image of issue (responsible and sustainable development) and investor (socially responsible investment). Also, one of the main advantages of the GBs is the high credit rating. This fact can be explained by the issuer reliability (most of issuers are local or national governments and big companies) and by government support (like in China, where GBs issuance is in the second place in the world). All other advantages and disadvantages of GBs in comparison with conventional bonds are represented in Table 2:

Table 2. Advantages and disadvantages of GBs

For issuer	
Advantages	**Disadvantages**
• to Environment, Social and Governance (ESG) issues • improving diversification of bond issuer investor base, potentially reducing exposure to bond demand fluctuations • reputational benefits • strong investor demand can lead to oversubscriptions and potentially increase issuance size • evidence of more ‘buy and hold’ investors (lower bond volatility in secondary market) • articulation and enhanced credibility of the sustainability strategy • access to ‘economies of scale’ as majority of issuance costs are in setting up the processes	• reputational risk if a bond’s green credentials are challenged • up front and ongoing transaction costs from labeling and associated administrative, certification, reporting, verification and monitoring requirements (cost estimates vary) • investors may seek penalties for a ‘green default’ whereby a bond is paid in full but its issuer breaks the agreed green clauses
For investor	
Advantages	**Disadvantages**
• investors can balance risk-adjusted financial returns with environmental benefits • improved risk assessment in an otherwise	• lack of unified standards may stir up confusion and result in reputational risk if green integrity of bond is questioned

opaque fixed income market through the use of proceeds reporting • recognized by the United Nations Framework Convention on Climate Change (UNFCCC) as non-state actor 'climate action' • potential use pure-play, project to actively hedge against climate policy risks in a portfolio that includes emissions-intensive assets	• small and nascent market • small bond sizes • lack of standardisation can lead to complexities in research and need for extra due diligence that may not always be fulfilled • limited scope for legal enforcement of green integrity

The main features of GBs are low risks (and not high yields as a result) and long maturity (for the most of GBs 10 years), which explained by the long-term of environment projects. These facts can be seen as favorable for attraction of strategic investors like pension funds.

Investments in GBs can be interesting for all types of investors who is looking for fixed-income instruments as green so conventional. First, investments in GBs helps to conventional investors to mitigate risks of their portfolio which are connected with climate legislation risks or other types of environment connected risks. In turn, GBs which assumes high transparency of issuers due to certification can be useful to decrease risks of any portfolio (Weber & Saravade, 2019).

Moreover, GBs payments are not restricted only by return from green project, but could be provided also from the income from any other company's, government income (the only exception is when all issuer's assets are connected with green project). That is why credit risk of GBs is totally the same as for conventional bonds of the same issuer all other factors identical. The main difference in this case is the direction of GBs investments into green projects (Bongaerts & Schoenmaker, 2021).

During the last few years ecological and environmental questions became so worrying, that the growth of "Green market" in 2020 achieved outstanding volume, which indicates high extent of interest as for issuers, so for investors of GBs market. This interest is so significant, that was emerged the term "Green premium" or "Greennium" which can be calculated as the difference between the yields on a conventional bond (CB) and a GB with similar characteristics (Agliardi & Agliardi, 2019). Negative Green premium existence means, that an investor is willing to accept the asset with lower yield then a comparable conventional bond has. For example, at the primary market GBs can be offered at a higher price than comparable CBs. In opposite, at the secondary market, where market laws can affect and correct the asset price, GBs can be traded at a lower price. That is why, in this case we can say, that an investor is willing to

accept lower yield in exchange for opportunity to invest in pro-environment alternative (non-financial benefit), while an issuer is rewarded by lower cost of capital.

On the other hand, issuance and investing in GBs can be connected with additional problems for both sides. As for investor, it could be difficult to identify real green bond which finances will be definitely directed into green projects. This could be the case, when GB was not certified by authorities but labeled by issuer as green. In opposite, for issuer GBs issuance is connected with additional costs such as certification costs and costs are connected with additional transparency and reporting requirements specific to GBs certification process. However, all of these additional costs could be covered by the market premium to the price of the green bond (Fatica, Panzica, & Rancan, 2021). That is why the question of GBs pricing is so uncertain and should be further investigated. Is the green premium a result of additional issuer costs connected with certification process? Or green premium is a result of investors willingness to pay more for certified GBs due to lower level of uncertainty and higher level of transparency?

As GB market developed, literature and researches on the topic number has grown. All of these research are unique due to diverse methodological approaches, control variables, data studied, which became cause of diverse results and absence of consensus about existence of GBs premium. This research aims to find consensus between previous research and fill the research gap via providing new research methods and results and studying the GBs premium over its life cycle.

1.3. Evidence of Green Bonds premium

Since first GB was issued, a lot of researchers investigated its premium. However, results of these research were contradictory. For example, using comparison method between GBs and CBs and regression analysis (Bachelet, Becchetti, & Manfredonia, 2019) found that in general at the secondary market GBs have higher yields in comparison with conventional bonds and positive GB premium was detected at the level from 2.06 to 5.9 bps in the overall sample. Also, evidence of positive GB premium at the secondary market was detected by (Partridge & Medda, 2020) in amount of 4 bps. The author has used the same comparison methodology and had approximately the same results. However, during the same analysis of the primary market, no significant GB premium was detected. Finally, evidence of GB premium existence was found by (Nanayakkara, 2019) during the secondary market analysis and the value of the premium was detected at the level of 6.7 bps. Another research (Fatica, Panzica, & Rancan, 2021) which studied GBs premium on the secondary market via linear regression analysis did not detect any statistically significant GBs premium over all sample but detected positive one during regression analysis over different subsets: positive GBs premium of 80 bps was detected for supranational

institutions issuers while for non-financial institutions there was not detected any statistically significant premium. This research is interesting as far it considers linear regression where dependent variable is yield for GBs and CBs and as independent variable was included binary variable Green (1 for GBs and 0 for CBs). That's also interesting because the research does not match GBs and CBs in terms of green premium (or "greennium") studying but regresses a "mix" of observations to exclude biasedness which can be provided by time-series data in limited observations samples. Here research consider cross-sectional data which provide an opportunity to study more separate bonds observations and take into consideration more effects of the data. Moreover, research detected that repeated GBs issuance provide positive green premium at 44 bps for all sample (in comparison with one-time GBs issuers). This mean that additional issuance of GBs provide additional information transparency on the market and more investors are ready to accept the discount of GBs in exchange for green label. Overall, negative GBs premium indicates that issuers benefit from lower cost of debt in comparison with debt obtained from CBs.

In opposite, several researchers detected negative GB premium. For instance, (Karpf & Mandel, 2018) used method of analysis of yield curves at the secondary market and found that the GBs curve is below then for conventional bonds. Green bonds on average pay lower interest rate and that is why providing better financial conditions than conventional bonds. The same results were observed by (Larcker, 2019) via regression analysis method at the secondary market. The author detected that investors are not willing to pay premium to support eco-friendly projects. The difference in yields of GBs and non-green bonds was 0.45 bps (a slight GBs discount). Finally, (Zerbib, 2019) has found that, in average, the green bond premium is -2.3 bps. All of above-mentioned authors studied only secondary market and used different analysis methods: regression analysis and analysis of yield curves.

A number of studies stand out in accordance with their results. These studies did not find any statistically significant GB premium in comparison with CBs. For example, (Hyuna, 2020) studied bid-ask spreads difference between GBs and CBs at the secondary market via regression analysis. As a result, the author argues that there is no statistically significant difference in bid ask spread between groups (GBs and CBs), however, green bonds have lower coupon rate and issuing amount. Similar result was observed by (Ehlers & Packer, 2017). They did not note any price premiums in their secondary market analysis, but they do find a price premium for GBs in the primary market.

As a result, we can argue that despite there are a lot of research, which aimed to study GBs premium, still there is no any consensus about the value and the direction of this premium: is it positive or negative. That is why, it seems crucial to study GBs premium taking into account

factors, which hypothetically could become the reasons of differences in previous research results. As possible reasons, we can detect:

- Methods used by researchers.
- Type of GBs studied: municipal GBs or GBs of private companies.
- Life cycle period of GBs at which the analysis was taken primary or secondary market analysis

As far to detect the only true method of analysis is impossible, we should pay attention to other possible factors. Moreover, this research assumes that the main driver of GBs premium is the "greennium" (the direct connection with eco-friendly project which is the base of GBs), we should not make any difference in analysis approach for municipal GBs or GBs of private companies. The studied sample should include both types of GBs.

Finally, the main concern about GBs analysis is the timeline of analysis. Results, observed by previous research were different for primary and secondary market even during of analysis of the same sample. As a result, we assume that the main reason of difference in research results which should be analyzed is the timeline of GBs premium behavior. The goal of this research may be formulated as *"to estimate green bonds premium during life cycle of this bond: at the different stages after issuance".* During the analysis we expect to find out if the GBs premium changes over its lifecycle and when turning point happens. That is why we can detect the following research questions:

3. *How the green bond premium changes over its life cycle?*
4. *If the GBs premium changes over life cycle from positive to negative or opposite, when turning point happens?*

The potential results of research will be applicable for both directions: theoretical and practical.

For theoretical part – the research will fill the gap, which is questioning for different results of previous research, explain why previous research authors observed different volume of GBs premiums and will give a tool which will be applicable for correct future studying of GBs premiums at different stages of life cycle.

For practical part – the research will be applicable for issuers in terms of forecasting of future GBs premium behaviour, potential costs and volume of investments. As far the question of issuance of GBs by companies is more controversial today and the main motivation for companies is rather an image story than a financial one, we want to find confirmation and evidence that issuing green bonds can be useful or not useful for companies from a financial point of view. In addition, this study develops a practical toolkit for financial managers to assess and justify the need to issue green bonds, or vice versa, evidence base for prohibiting the issue. In addition to providing a rationale for financial managers to issue green bonds, this study

examines important factors needed to predict the behavior of green bonds and estimate future cash flows from their issuance.

1.4. Factors of Green Bonds premium

As for characteristics, which may influence GBs premiums, previous researches detect several the most important of them: existence of the third-party certification (Hyuna, Parkb, & Tianb, 2020), liquidity (Partridge & Medda, 2020), (Karpf & Mandel, 2018) amount of issuance (Wang, Zhou, Luo, & Ji, 2019), maturity (Wang, Zhou, Luo, & Ji, 2019), (Zerbib, 2019), (Karpf & Mandel, 2018). Most of factors, observed by previous research are applicable theoretically, but in practice may be useful mostly for issuers when they make a decision about future bonds issuance details. For instance, (Karpf & Mandel, 2018) paper showed, that the spread between GBs and CBs widens with the maturity. This information may push the company make the maturity shorter not to admit the spread between GBs and CBs increase significantly. Another example (Nanayakkara, 2019) showed, that the bonds denominated in local currency tighten the credit spread by 5.6 BPS, compared with a bond denominated in foreign currency. This result will motivate issuers to denominate GBs in foreign currency and leave local market without attention with the loss of potential income.

That is why, in addition to the mentioned determinants, it seems necessary to study factors (potential determinants), which cannot be defined in advance by the issuer, but will be useful for potential investor during the decision making process of detection in which bond to invest. For the purposes of current research, we will study liquidity of green bonds as a factor of green premium. Despite a lot of previous researchers study such factors as currency of denomination, rating of the issuer or maturity, we will not include these factors into the analysis as far we are planning to analyse green premiums via comparing GBs and paired CBs observations and set strict restrictions on the methodology of pairs construction. That is why such factors as currency of denomination, rating of the issuer or maturity will be identical for our paired GBs and CBs. The only differencing components can be green premium and liquidity. Detection of this factor have any influence on GBs premium and at which extent; we will offer the potential investor an opportunity to analyse and forecast future income from GBs using only external information factors to observe which do not require additional systematic analysis.

As a result, we can formulate the following research question: *If there exist any other components of green premium? What they are? How do they influence on green premium value?*

1.5. Hypothesis development

Presence of GBs premium

On the one hand, risk characteristics, associated with the issuer, are the same for comparable GBs and CBs. Respectively, in terms of risk and return high-ESG and low-ESG (where ESG is Environmental, Social, and Governance) bonds should be valued identically by investors (Larcker, D., 2019). However, GBs are serviced not only be cash flows which are associated with any green project, but also by investors' attitude to characteristics of the project (in our case "greenness" of the project). As a result, a tighter yield spreads (YS) reflects investors' willingness to pay a premium for GB issuance in contrast to CBs. Despite, GBs are usually associated with lower cash flows; investors value the "label" of GBs due to lower risks and positive ethical side of investment (Nanayakkara, M., 2019). Some other authors (Hyuna, S, 2020) also argue that greenness information affects to green bond premium. Moreover, the high demand on GBs market (oversubscription) makes it possible for issuers to lower the coupon rates which leads to lower cost of capital. In this case investors should be willing to accept such kind of conditions: to pay higher price for lower yields. Resulting, this fact should lead to lower yields for GBs in comparison with CBs.

Finally, from the one point of view, environmentally concerned investors may be willing to receive lower yields for GBs due to direction of their purpose. In this case, the difference in yields between GBs and corresponding (paired) CBs should be negative. Moreover, the lower volatility and higher level of trust from investors should increase demand on GBs and, respectively, decrease risk premiums. On the other hand, when we are talking about GBs there always exists the possibility of greenwashing. In this case investors may require higher returns for such kind of GBs.

The most of studies detect green premium via comparison GBs and paired CBs. Moreover, risk characteristics, associated with the issuer, are the same for comparable GBs and CBs. The only possible difference in this case will be included in the GBs premium (premium for "greenness"). As far there are controversial results among most of authors which are connected with GBs premium value a direction and, in general, its overall existence, we should start our analysis with identification of green premium and prove that it exists. That is why, we can formulate the following hypothesis:

H1: GBs are traded with a green premium in comparison with paired CBs, ceteris paribus.

The literature review showed us that there is no consensus among researchers (who has identified green premium) what is the value of green premium: is it positive or negative. For example, (Nanavakkara. M., 2019) identified that GBs are traded with the premium in

comparison with CBs with a tighter spread of 62.7 BPS, while (Larcker, D., 2019) showed the difference in yields of GBs and non-green bonds was 0.45 BPS with a slight GBs discount. Earlier we assumed that the reason of such a different result is in different stages of studied bonds life cycle. Most of researchers frame the data via yearly borders without attention to issuance and maturity dates of the bonds. In contrast, our research is aimed to check if there are any patterns in GBs premiums among different stages of their life cycle. If we believe that previous research provided true results and the main reason of difference is the difference in time frames, we can provide the following hypothesis:

H2: Green premium of GBs is non constant over its life cycle.

Generally speaking, when we are talking about green bonds analysis it seems reasonable to analyse it via comparison with CBs. In the situation, when we have for 2 paired bonds all characteristics are identical (issuer, currency, structure, maturity), the only observed difference in this case could be green premium and liquidity. Previous research also makes an accent on liquidity component of the GBs premium structure, but there is no evidence, that there exists any causality relations between green premium and liquidity, because most of researches or consider liquidity as a predictor value of green premium or did not find any statistically significant relationship between liquidity and green premium. As far we are going to understand the nature of GBs premium but not just to prove its existence, we should make a closer look on the liquidity measure of GBs and understand – if it is a component of GBs premium (in this case we will talk about liquidity risk premium in comparison with some benchmark) or it is a predictor of green premium (in this case we will talk about higher interest of investors to GBs and resulting increase in liquidity and decrease green premium) or even we can assume that the green premium as caused to liquidity measure. For the final scenario we can argue that investors provide true interest not only green side of this financial tool, but also see their under-pricing and higher yields and, resulting, via speculative activities increase liquidity measure of GBs. Resulting, we can formulate the last hypothesis:

H2: There exists linear relation between green premium and liquidity for GBs.

1.6. Review of previous research methods

There are numerous of methods used by previous researchers. However, we can detect some of them which were duplicated by other studies and proved their validity, we will consider below to detect the most appropriate one for our purposes.

In this section, we will look at a few of the most common methodologies encountered in the existing literature on the topic of green bond premium pricing. Consideration of the methodologies will allow us to determine the most appropriate for the research purposes, or

perhaps create a combined model for further analysis. Thus, analysis of previous research methods will allow us to avoid possible biasedness which possibly presented in previous research and create own one.

Option – adjusted spread analysis (Nanayakkara & Colombage, 2019)

The sample included GBs and CBs with the same issuer companies during the same period. The main research method is panel data regression analysis. The following model was used in the analysis:

$$ln\,OAS_{i,t} = \alpha + \beta_1 BOND_i + \beta_2 CUR_i + \beta_3 MR_{i,t} + \beta_4 TR_{i,t} + \sum_{i=1}^{J} \beta_5 MC_{i,t} + \sum_{n=1}^{N} \beta_6 F_i + \sum_{z=1}^{Z} \beta_7 B_{i,t} + \in_{i,t} \quad (1)$$

Where

$ln\,OAS_{i,t}$ is the natural logarithm of OAS, for bond i at time t (a measure of price differential)

$BOND_i$ is the type of bond (GB or CB)

CUR_i is the currency in which the bond is denominated (local or foreign currency)

$MR_{i,t}$ is the market risk for bond i at time t

$TR_{i,t}$ is the US 10-year treasury rate for bond i at time t,

$MC_{i,t}$ is the vector of macroeconomic variables for bond i at time t,

F and B are vectors of firm-specific and bond specific effects for bond i at time t,

$\in_{i,t}$ is an error

Application in the research:

This method study the GBs premium as OAS and investigates different factors, which can influence on GBs premium (determinants), however, in this case to calculate the OAS we have to study not just comparable conventional bonds, but exactly treasury bonds (risk-free). This factor set for us several limitations: we will detect only the premium in comparison with treasury bonds and the most suitable GBs in this case are governmental or (with strong approximation) municipal bonds. In this case the study will be limited by toolkit and recommendation for governmental issuers and will not allow us to extrapolate results. Moreover, the study will be limited by smaller sample and the model will not take into account country-based characteristics of the government which has issued GBs. That is why, the results can be biased by chosen pool of countries.

Creation of synthetic conventional bond yield (Zerbib, 2019)

The author compares each green bond with an otherwise identical counterfactual conventional bond. Green bond premium is defined as the yield differential between a green bond and an otherwise identical conventional bond (identical characteristics except liquidity). It is assumed that the difference in premiums is formed by liquidity and greenness of GBs. The author used ask spreads for analysis. The yield of conventional bond was identified via the regression:

$$y^{CB} = \alpha + \beta Maturity_{GB} \quad (2)$$

Where he interpolates the two conventional bonds' yields linearly at the green bond maturity date to obtain a synthetic conventional bond yield, which thus shows the same properties as the green bond except for the difference in liquidity.

Finally, the premium (which still includes the liquidity factor) was identified as the yield spread between the green bond and the equivalent synthetic conventional bond. To control liquidity and identify green bond premium the author creates the following regression:

$$\Delta y_{i,t} = \alpha + \beta \Delta Liquidity_{i,t} + \in_{i,t} \quad (3)$$

Where the risk premium is the intercept in the fixed-effect panel model.

To analyse the influence of different factors on premiums value the author construct the regression with control variables: rating, sector, currency, maturity and issue amount.

Application in the research:

The method of creation of synthetic conventional bond yield is good in sense of step-by-step execution of only GBs characteristics from the potential bond. The author progressively allocates a green premium by eliminating external factors such as liquidity. However, the calculation of synthetic returns raises questions about the reliability of the result. The author highlights the factor of the premium for maturity. While there may be other factors that influence premiums but will still be included in the synthetic yield. In addition, since this study focuses on the life cycle of bonds, we cannot exclude the maturity as an extra factor from the analysis; but on the contrary, they should take it into account at the stage of selecting bonds for research. Therefore, we consider this method to be suitable for static study of green bond premium rather than dynamic.

Creation of indexes for detection of GBs premiums (Partridge & Medda, 2020)

At the first step the authors analysed the yields of GBs after issuance on the primary market and on the secondary market to detect the differenced in yields. On the second step the authors have created the index of bonds to compare the performance of GBs in comparison with benchmark. The second step allowed to identify trends and the premiums for greenness what was impossible on the first step of the analysis. The benchmark bond index included municipal bonds, financial resources from which are directed other than eco-friendly projects or which do not have any certification about their "green" direction.

To identify the difference between GBs and benchmark index there was calculated liquidity premium to extract it from the green premium. It was identified as The Index of Martin (volume-based liquidity index for a basket of assets):

$$IoM(i,t) = \sum_{i=1}^{N} \frac{(P_{it} - P_{it-1})^2}{V_{it}} \quad (4)$$

Where P_{it} is the closing price for asset i on day t,

V_{it} is the trading volume for each asset i on that day t.

After that, to detect the "activity" of the bonds was calculated Amihud's illiquidity measure (AI):

$$AI = \sum_{i=1}^{N} \frac{1}{TD_i} * IoM_i \quad (5)$$

Where TD_i is the number of days where each asset was traded. This measure showed the activity of bonds trading.

For the first step, the authors have created yield curves for the primary and secondary market for GBs and vanilla bonds. After that, they provided comparison between curves to detect differences in performance.

At the second stage of analysis there was used S&P Investment Grade Municipal Bond index (includes any municipal bonds) as a benchmark. Also, the authors have created their own index, which consisted of only green municipal bonds. Finally, they have created the regression:

$$R_i = \alpha i + \beta IR_i(t) + e_i(t) \quad (6)$$

Where R_i is the excess index returns

IR_i is the benchmark excess returns

β is the systematic risk

After that they have compared the performance of the climate indices with their S&P counterpart.

Application in the research:

Calculating and creating an index as a benchmark is a good approximation for assessing the premium of green bonds, since the index already includes all the basic properties of bonds and allows you to find a benchmark for almost any bond, which significantly expands the field of research and allows you to extrapolate the results quite widely. However, this methodology is again good for static research but not dynamic research. The creation of an index for each period of the bond's life cycle is very time-consuming and laborious, and the use of a single index for different stages of the life cycle is incorrect due to the too high level of approximation. We already know that GBs market grow fast, and we would have to recreate index for different years to consider all of current market trends. Moreover, we want to consider trends without connection to particular year, but with connection to bonds life cycle and there is no confidence that we would be able to consider all of current market tendencies for each GBs observation. Accordingly, a similar method can be used only for either static research or dynamic research, but on a small sample of data.

CAPM model usage (Wang, Zhou, Luo, & Ji, 2019)

As far CAPM model return of security can be divided into risk-free rate and risk premium. In case of GBs the authors assume, that GBs premium can be calculated as yield to maturity minus the risk-free rate of the green bond primary issuance market. As risk-free rate they assume national credit-based government bonds (with zero credit risk and high liquidity). Yield to maturity is calculated as:

$$P = \sum_{i=1}^{n} \frac{C_i}{(1+r)^i} + \frac{M}{(1+r)^n} \quad (7)$$

Where

P is the issue price,

C are coupon cash flows and M is principal.

After that the authors create regression model to study the effect of different characteristics on the green bond premium:

$$y = \alpha + \sum \beta_j Controls_j + \varepsilon_i \quad (8)$$

Where y is the green bond issuance risk premium.

Application in the research:

The approach is highly simplified and can be used during the static research. However, it does not consider such important characteristics as premium for liquidity, premium for greenness certification and other important attributes, which are specified only for GBs and cannot be detected only by excluding risk-free rate.

Evaluation of GBs premium via NPV approach (Bachelet, Becchetti, & Manfredonia, 2019)

The authors used comparison method for green premiums identification. They matched each green bond with the closest non-green neighbour (issued by the same organization, have the same currency, rating, bond structure and coupon type). For maturity date matching they have used two years lag. For the issuance amount there was assumed amount in for times higher or lower than in case of green bond. For the coupon rate they used an assumption in 0.25% difference. In case when there was not found any paired CBs for the green bond they have used synthetic bond creation method (linear combination of features from two the closest CBs).

Yields of the bonds were calculated with the NPV formula, taking into account the price paid for acquiring the bond and future cash flows from its holding. Liquidity was computed as bid-ask spread. Zero trading days were identified as dummy variable (1 if there were transacions with the bond).

After that, the authors have created the regression to study effects with may influence on premiums:

$$\Delta y_{it} = \alpha_0 + \alpha_1 \Delta Liq_{it} + \alpha_2 \Delta ZTD_{it} + \alpha_3 \Delta \sigma_{it} + \sum_j \beta_j \Delta B_{ij} + \varepsilon_{it} \quad (9)$$

Where

Δy_{it} is the daily yield spread for the ith bond couple on day t,

α_0 is the time invariant green effect

ΔLiq_{it} is is the daily difference in liquidity between a green bond and its brown bond twin

ΔZTD_{it} is the difference in no trading days between the green and brown bond (another measure of liquidity)

$\Delta \sigma_{it}$ is the difference in bond yield variance,

B variables are characteristics of bonds such as coupon, issued amount, maturity.

Application in the research:

This approach can be easily used to dynamically investigate the premium of green bonds. First, the methodology is simple and the evidence base for NPV is beyond doubt. Secondly, the

NPV can be calculated at any point in time in the past, which will allow assessing the premium at different stages of the bond's life cycle. However, the authors do not take into account factors that may be different in green and ordinary bonds. For example, the authors do not exclude a bond liquidity premium which, for example, may be higher for a comparable bond, but will also be taken into account when calculating the NPV. In this case the results can become biased due to the fact that liquidity premium for CBs were higher and as a result green premium became negative.

Liquidity-adjusted ask yield spread analysis (Hyuna, Parkb, & Tianb, 2020)

The authors create the sample of 60 certificated green bonds with the paired conventional bonds of the same issuer, currency, maturity, credit rating and bond structure. After, they examine the liquidity-adjusted ask yield spread of green binds in comparison to the paired conventional bond.

Yield spreads were calculated as difference in ask yields between GBs and CBs. Yield spread driving by greenness was identified by excluding the liquidity-driven yield spread. This liquidity-driven yield spread was calculated with the regression:

$$Diff\_askyld_{i,t} = \alpha + \beta Diff\_bidask_{it} + u_{i,t} \quad (10)$$

Where

$Diff_askyld_{i,t}$is the difference between ask yield on green bond i and that on its paired conventional bond at time t

$Diff\_bidask_{it}$ is the difference between the bid–ask spread for green bond i in the green bond market and that for i's paired conventional bond in the conventional bond market at time t.

After that, the authors identify green premiums by estimation of intercept. Also, the authors use another approach to identify green premiums by addition to intercept residuals of the regression. Residuals in this case mean the liquidity-adjusted yield spread that cannot be explained by liquidity differences between green bonds and conventional bonds.

Finally, the authors add dummy variables to the model to evaluate greenness information influence on the GBs premiums and control variables.

Application in the research:

This approach can be applied in the study, since it firstly takes into account all the important factors when calculating the green premium, including maturity and liquidity. In addition, the approach can be applied on a dynamic study and does not impose restrictions on the sample for the study. We can use the method during the analysis of green premium and liquidity relation but with possible corrections.

1.7. Summary

Literature review gave us an opportunity to understand main features of green bonds market, features of GBs as a financial instrument, how existing research study green premium and which results they obtained. Thus, here we would like to underline several aspects.

Green bonds market is a dynamic developing market which shows significant growth even in conditions of difficult economic situation of 2020 year. Moreover, taking into account new ecological concerns of governments and policies of negative effects on nature mitigation, experts forecast that this growth will continue. Thus, we can say, that GBs is an instrument which should be studied well to provide for investors and issuers better understanding of its trading mechanisms and premium behavior.

Also, during literature review we have detected that there is no consensus among previous research concerning value and direction of green premium. These studies based on different research methods, but most of them provided static data research of particular period of time. That is why it seems important to investigate green premium over its life cycle to fill this research gap and provide practical recommendations for investors.

Finally, there exists several research which argue that GBs is only a type of “theme” bonds and there is no difference between mechanisms of green premium fluctuations and premium of ordinary bonds. Another part of research argue that green premium is a unique phenomenon which includes investors attitude to underlying green projects. That is why it seems necessary to deepen our research in terms of identification of green premium factors. Thus we can accept liquidity of GBs as a factor which also should be investigated and its influence or dependence on green premium should be analyzed.

CHAPTER 2. EMPIRICAL RESEARCH OF THE GREEN BOND PREMIUM

4.1. Research design

Step 1. Sample creation

The main goal of our research is to analyze the green premium of green bonds. It seems reasonable for us to use the method of comparative analysis of green bonds and their paired observations among conventional bonds. At the same time, we must select such pairs of GB and CBs so that the following characteristics are identical:

1. Issuer
2. Currency of denomination
3. Bond structure
4. Maturity
5. Issuance date

The risk of any bond can be decomposed into the following components - the risk of default of the issuer, interest rate risk, currency risk. Since the issuer, currency, and structure are identical for paired bonds, we eliminate the possibility of an omitted variable appearing. In the end, we received pairs of bonds, in which only the yields explained by the green premium and liquidity will be different.

Step 2. Identification of the green premium and its preliminary analysis.

To identify and study a green premium, we will use an analysis of the yields of green bonds and paired conventional bonds. Here and after we will assume, that yields analysis is a good way to study GBs premium as far we do not need to work with scale of prices (which can be even incomparable in case of different par value of bonds). YTM for each observation will be obtained based on mid-price value to avoid biasedness of results. For example, if we analyze based on ask returns, we risk pulling our results away from market trends and into investor behavior. Conversely, by analyzing the yields based on the bid price, we risk losing our valuation of the green premium market.

A preliminary analysis of the green premium will be based on a trend analysis of the averages over the entire life cycle. Since our hypothesis 2 assumes that the green premium is periodic, we must first analyze the averaged trends in order to detect the statistical relationships. If the preliminary analysis shows the existence of a green premium and its periodicity, we can use statistical approximations to highlight trends inherent in all observations of panel data.

First, we will be able to use Gaussian smoothing to determine smoothed trends. Also, Gaussian smoothing will allow us to determine whether the trends we have identified are in fact

statistically significant trends or are white noise and there is no statistically significant periodicity in our data. The Gaussian smoothing method is widely used for smoothing the independent variable signals.

When f(x, y) is a continuous function, a Gaussian smoothing of f(x, y) is defined as the convolution with a Gaussian function:

$$F(x) = f(x) * g(\sigma; x) = \int_{-\infty}^{\infty} f(x')g(\sigma; x' - x)dx' \quad (11)$$

Where

$$g(\sigma; x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}} \quad (12)$$

In practical applications, the Gaussian kernel is decomposed into a number of Gaussian kernels with smaller values of σ's where σi's are usually taken to be the same and the number of convolutions n is chosen so that an adequate degree of smoothing is attained. In simple words, the Gaussian method allows you to calculate the relative position of each observation based on the standard deviation values and get rid of noise in the data. Research (Moon, 2001) declares that the Gaussian method is applicable for eliminating noise and determining trends in the explanatory variables.

If Gaussian smoothing shows that our trend in the mean values of the observation in each period is shown and does not represent white noise, then we can apply a polynomial approximation to all panel data. Initially, we performed the analysis based on mean values. However, the analysis of the dynamics of averages has less stability of the result, since some outliers can pull over the trend of the mean values. Accordingly, for a more reasonable result, we must take into account the effects that occur in each observation of our panel data, but not just their averaged signals.

And in the case of polynomial approximation on panel data, this problem is solved. If the constructed polynomial approximation confirms the dynamics of green premiums, which we obtained on the average values after Gaussian smoothing, then we can declare that our results are robust and stable, since the polynomial approximation accepts and accumulates not just the average trend, but the individual trends of each observation on panel data.

In short, polynomial analysis is a more resistant and statistically significant method for analysis of nonlinear trends than analyzing the dynamics of mean values.

Based on robust results, we will be able to put forward more informed practical recommendations for investors and issuers of green bonds.

Step 3. Analysis of liquidity for Green bonds.

As we said earlier, the analysis of pairs of green and non-green similar bonds leaves us with the opportunity to analyze two main factors - the green premium and liquidity, since only these factors are not excluded due to methodology of construction of bond pairs.

In addition, we need to understand whether the liquidity premium is a component of the green premium and, in general, whether these factors are interrelated in the case of green bonds.

However, before analyzing this relationship, it is necessary to understand the direction of liquidity for green bonds (liquidity is higher or lower in comparison with CBs), its trends and frequency.

For the above purposes, we will conduct a similar analysis of the liquidity of green bonds. As a measure of liquidity, we will use the bid-ask spread of the bond and, accordingly, look for the difference between the spread for green bonds and the spread for conventional bonds. As a result, in this case, negative values of the spread difference will signal a narrower spread for green bonds and better liquidity relative to their paired counterparts, and vice versa, positive values will signal a wider spread for green bonds and their weaker liquidity.

Next, we will again find the average values for each time period from the observations of our panel data. Next, we will analyze Gaussian smoothed graphs, which construction is based on Gaussian functions (11), (12) to determine if there is a trend or periodicity, or observed fluctuations are white noise. Finally, we will also validate the robustness of our results through a polynomial fit to take into account not just averaged values, but the signals of each observation of our panel data. The above methods will help us to tentatively determine the trends of liquidity, identify how the liquidity of green bonds differs from the liquidity of paired counterparts, and make assumptions about the nature of the relationship between the green premium of a green bond and liquidity of green liquidity.

Step 3. Analysis of the relationship between the green premium and the liquidity of green bonds.

We will begin the analysis of the relationship with the previously described panel regression methodology (Hyuna S., 2020). Thus, we will be able to check whether the relationship exists as a whole and whether it is linear.

$$Diff\_midyld_{i,t} = \alpha + \beta Diff\_bidask_{it} + u_{i,t} \qquad (13)$$

Where $Diff\_midyld_{i,t}$ is the difference between mid-price yield on green bond i and that on its paired conventional bond at time t and $\beta Diff\_bidask_{it}$ is the difference between the bid–

ask spread for green bond i in the green bond market and that for i's paired conventional bond in the conventional bond market at time t.

If the regression model turns out to be significant, we will be able to state that the dynamics of the green premium is more likely due to liquidity, and not to the behavioural motives of investors. And, accordingly, the liquidity premium is a component of the green premium.

In the situation when our regression does not give statistically significant results, then we can test our observations using the Granger (Granger, 1969) test to determine the causal relationship between the variables. In this case, the test will help us to understand what is primary - the dynamics of the green premium, which will affect the movement of liquidity or vice versa.

Granger defines causality in this case as follows: "We say that Y_t is causing X_t if we are better able to predict X_t using all available information than if the information apart from Y_t had been."

The Granger test sequentially tests two null hypotheses: "x is not the cause of Granger y" and "y is not the cause of Granger x". To test these hypotheses, two regressions are constructed: in each regression, the dependent variable is one of the variables tested for causality, and the lags of both variables act as regressors (in fact, this is vector autoregression).

$$y_t = \alpha_0 + \alpha_p y_{t-p} + \cdots + \beta_p x_{t-p} + \cdots + \varepsilon_t \quad (14)$$

$$x_t = \alpha_0 + \alpha_p x_{t-p} + \cdots + \beta_p y_{t-p} + \cdots + \varepsilon_t \quad (15)$$

Where

Y_t and x_t – are stationary time series which are tested on causality

α_0 – is the intercept of the model

ε_t – are errors of the model

α_p and β_p – are lag coefficients.

For each regression, the null hypothesis is that the lag coefficients of the second variable are simultaneously zero.

4.2. Sample selection

For the analysis of GBs premium, we should collect as many green bonds as possible with the simplest structure. We abandoned the inclusion of green floating coupon bonds, exotic structure (e.g., sukuk) bonds in the sample and included only bullet bonds in the sample. A bullet bond is a non-callable bond wherein the total principal amount or its total value is paid in a lump

sum on the bond's maturity date. In this case, we will be able to work with the simplest bond structure, which, moreover, is widespread and has many examples in the market. It is the prevalence factor that plays the most important role for us, since in the future we plan to generate pairs for green bonds from among ordinary bonds. Finally, we use a simple bond structure so that we can analyze the green premium in more detail, eliminating the possibility of influencing the outcome of factors related to the bond structure - for example, dependence on LIBOR (or any alternative money market reference rate) in the case of floating coupon bonds.

To collect the sample data at the first stage we should collect GBs for the further analysis. Data collection process is provided via CBonds add-in. First, we have selected GBs, which are currently traded and have a fixed coupon with par value payment at the maturity date (bullet bonds). At this stage we have selected as corporate so governmental and municipal GBs. Resulting, we have 981 GBs which satisfy the research restrictions. As far for the model we should know issuer, currency, maturity, credit rating, bond structure, we have excluded from the sample bonds, where this information is not available. Also, bonds with indexed coupons and coupons which changes its values after settlement date were also excluded from the sample. Resulting we have 900 GBs for the further analysis. Further we have excluded perpetual GBs, amortization GBs, convertible, mortgage, indexed, non-market GBs and sukuks. Resulting we have 454 bonds.

To obtain more or less homogeneous sample, we have excluded bonds which issuers are based in developing countries and China. Now we will focus on the sample of GBs from Europe countries, USA, Canada and Australia. The exclusion from the sample of bonds from developing countries was carried out on purpose for the following reasons. Firstly, in the case of developing countries (countries of the East, Russia) there are very few examples of green bonds on the market. Accordingly, since local markets are poorly familiar with the new instruments, the assumption that investors distinguish between conventional bonds and green bonds may not be true. As for the Chinese market, here we can see a large number of green bonds that meet our requirements (in our case, the initial sample included almost 200 observations). However, the Chinese financial market is known for a number of its features: firstly, the main issuers in the market are either state and municipal entities or commercial banks. Secondly, the Chinese financial market is highly dependent to government regulation, and in terms of investors, commercial banks dominate the market. Due to these factors, the market is known for its low liquidity and fragmentation. This is reflected in multiple systems of regulation with different regulatory concepts, operation mechanisms, and regulatory styles on different trading levels by different regulators (ACRA, 2019). Considering all the above features, we can say that the inclusion of Chinese bonds in the sample would require the control of additional factors and their

inclusion in the model (since the number of observations of this market would constitute a significant part of the sample and would certainly affect the final result) what we cannot afford. For the further analysis we have left 234 observations.

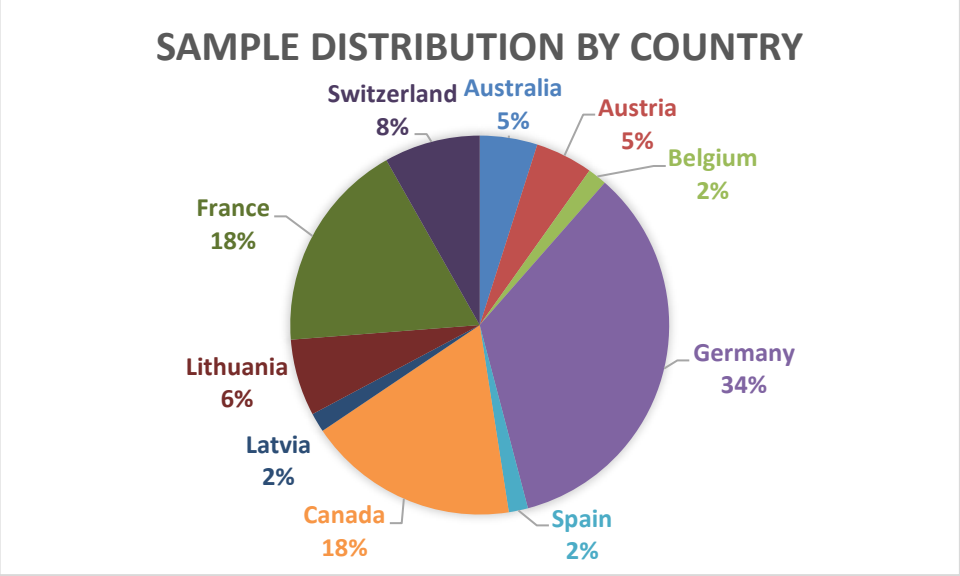
Since the purpose of this study is to identify the green premium, and not just to analyze the premium of a specific financial instrument, we selected paired bonds for green bonds from among the CBs. For the detection of the closest observations, we have set the following restrictions on the CBs:

6. Identical issuer as for GBs
7. Identical currency as for GBs
8. Identical bond structure as for GBs
9. Identical maturity as for GBs
10. Issuance date is limited by 3 years prior and after issuance date of GBs

Finally, to make our research more informative and sustainable, we have excluded from the sample observations, which were seemed as low liquid (where there was no any trading activities within at least during a week for the whole period of life cycle). Resulting we obtained 59 pairs of GBs and CBs which is 33,629 and 33,286 observations respectively.

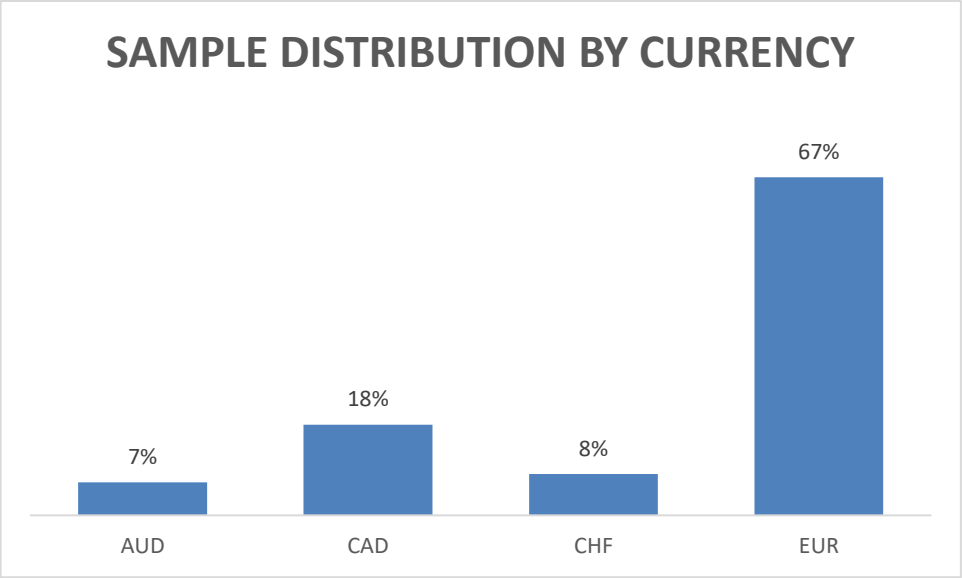
4.3. Preliminary data analysis

As it was mentioned earlier, we have 59 pairs of GBs and compared CBs. Sample distribution is represented in the graph below. As we can see, most of observations are bonds of issuers from Germany, France and Canada. Sample distribution by countries is represented on Picture 5.



Pic. 5. *Sample distribution by country*

In terms of issuer nature, we have 34% of municipal or governmental bonds and 66% of corporate bonds in the sample. We deliberately did not separate these groups of bonds for the following reason: since the purpose of the study is to study the green premium, we assume that regardless of the issuer group, the investor equally evaluates this premium for the green nature of the bond, excluding bias regarding the issuer group. Also, in order to exclude possible effects associated with the denomination currency of the bond, we tried to include different currencies in the sample. Nevertheless, the euro turned out to be the most abundant currency in the sample at 67%. Sample distribution by countries is represented on Picture 6.



Pic. 6. *Sample distribution by currency*

As for the frequency of coupon payments, here 25% of the bonds included in the sample have 2 coupon payments per year and, accordingly, 75% of the sample pay a coupon once a year. Average maturity for our sample is 9 years (as for GBs so for CBs as far this condition was strictly – identical maturity for paired bonds). Resulting – the only significant issuance measure for GBs and CBs is amount issued. Average amount issued will be not provided due to uninformative due to different denominating currencies, but on average, the volume of green bonds is half the size of the issuance of paired bonds.

For the further analysis we have obtained additional trading information for paired bonds during their whole life cycle. Description of the obtained variables is provided in the Table 3.

Table 3. Variables description

Variable	Short description
Bid_price, %	Price of the bond on bid in % of nominal value
Ask_price, %	Price of the bond on ask in % of nominal value
Bid_ask spread, bps	Bid price of the bond – ask price of the bond in basis points
Avg_price, %	Average price of the bond in % of nominal value
Current coupon rate, %	Current coupon rate of the bond in % of nominal value
YTM on bid price, %	Yield to maturity calculated based on bid price in %
YTM on ask price, %	Yield to maturity calculated based on ask price in %
Mduration	Modified duration
G-spread, %	G-spread of the bond calculated based on country benchmark

When all data was available, we have created a descriptive statistics of our data to obtain some additional insights about our data.

Table 4. Descriptive statistic of GBs variables

	n	mean	standard deviation	trimmed mean[4]	min	max	range
Bid_price, %	33629	102.72	5.17	102.34	10.00	135.67	125.67
Ask_price, %	33540	103.31	5.27	102.77	85.00	200.00	115.00
Bid_ask spread, %	33513	59.49	438.41	37.13	0.08	16000.00	15999.92
Avg_price, %	33540	103.02	4.74	102.56	55.50	150.45	94.95
YTM on bid price, %	33610	0.50	0.81	0.41	-0.77	38.16	38.93
YTM on ask price, %	33534	0.40	0.83	0.33	-44.75	4.36	49.11
Mduration	33537	6.74	4.66	6.17	0.17	40.18	40.00
G-spread, %	27236	68.60	60.04	63.87	-2726.75	1529.91	4256.66

As we can see for GBs our data is unbalanced. The biggest lack of data is for G-spread variable, as far this is a calculated indicator. As far our methodology is based on comparison of GBs and CBs we will analyze descriptive statistics in comparison.

[4] A method of averaging that removes a small percentage of the largest and smallest values (5% of sample) before calculating the mean. After removing the specified observations, the trimmed mean is found using an arithmetic averaging formula.

Table 5. Descriptive statistic of CBs variables

	n	mean	standard deviation	trimmed mean	min	max	range
Bid_price, %	33286	102.36	5.75	101.81	10.01	140.76	130.75
Ask_price, %	33039	103.33	6.84	102.39	88.89	200.00	111.11
Bid_ask spread,%	32823	95.75	780.32	43.97	0.01	16000.00	15999.99
Avg_price, %	33039	102.85	4.99	102.12	80.00	141.08	61.08
YTM on bid price, %	33273	0.48	1.22	0.36	-4.54	47.31	51.85
YTM on ask price, %	33028	0.30	0.98	0.25	-31.42	3.30	34.73
Mduration	33140	6.00	2.86	5.81	0.92	20.10	19.19
G-spread, %	26533	64.80	44.59	60.84	-1037.98	334.18	1371.96

As we can see, our data is unbalanced due to absence of some variables for different periods of time. The biggest data lack in for G-spread value. As far this value is calculated on the basis of benchmark via internal Cbonds methodology we cannot fill these gaps and, as result, use this value in the further statistical analysis. That is why, we will analyze it only by descriptive statistics value. Also, via min-max and, resulting, range values we see number of outliers in our data. This fact should be corrected for statistical analysis, but for analysis of descriptive statistics we will calculate additional value – trimmed mean which does not take into account outliers for each variable at 5% level of lowest and highest quantile and analyze mean values via this variable.

The first point of interest is price (in percent of par) of GBs in comparison with CBs price. As we can see as bid and ask prices so, resulting, average price for GBs is higher than for paired CBs. This difference in prices may be a sign of higher average premium for GBs. At the same time, we can see lower standard deviation of prices for GBs than for CBs, what confirms the idea that higher prices for GBs are not resulted by extreme high outliers' values and sample for this variable is shifted into higher prices values.

Another interesting point about descriptive statistic is bid-ask spread values. As we can see, for GBs bid-ask spread is narrower than for CBs. In other things being equal, we can say that bid-ask spread is a measure of liquidity of our bonds. In this case narrower spreads are the sign of higher average liquidity for GBs. One of the main determinants of comparable high liquidity can be higher issuance value of the bond. However, as it was previously noted, issuance amount for GBs is twice lower than issuance amount of CBs. Logically, when we have lower

issuance amount than we should have lower liquidity value as far there are less opportunities for speculative trading and, as a result, this part of trading activity should be partially excluded. However, in our case we can see an opposite situation – when despite lower issuance amount of GBs we can see higher average liquidity (narrower bid-ask spreads). Moreover, our results could be accepted to be more sustainable if we take into account standard deviation of spread measure – it is lower for GBs then for CBs despite the same abnormal range. It would be good practice to confirm our idea about better liquidity of GBs via measuring of trading volume, however, this information is not available in full amount due to high volume traded on over-the-counter markets. However, we should understand the nature of higher liquidity of GBs is comparison with CBs. Many previous research (e.g. Zerbib, O, 2019 or Partridge, C., 2020) assumes that one of the main feature of GBs market is that the greatest interest in green bonds is shown by investment funds and other institutional investors who purchase green securities at the stage of their issuance and hold them until maturity, which negatively affects the trading volume of these securities, their liquidity and prices in the secondary market. However, as we can see, curently on average GBs liquidity is higher than CBs liquidity what comes in conradictory with previous thesis about dominan institutional investors interest. Higher average liquidity may be a signal that more investors are interested in GBs premium and demand overcome the offer for this type of bonds. Here we can assume, that "green" side of these bonds (in terms of underlying green projects) is valuable for investors more than stability and common structure of comparable CBs. This thesis can be proved by oversubscription for GBs which was discussed previously. That is why, for the further analysis of GBs premium we will also take into account their liquidity to understand its nature and possible influence on the value of green premium.

Also, as we can see, calculated YTM for GBs as based on bid so based on ask prices are higher for GBs than for CBs with again, lower value of standard deviation, what makes our results more stable. This is interesting point as far some previous researches detected lower GBs yields due to high ratings of its issuers and skew to the side of municipal/governmental bonds on the general GB market (C. Partridge, 2020) and (Karpf, A., 2018). That is why, to exclude this biasdness from our sample we have included as municipal/govermental bonds so corporate bonds in our sample. In general, corporate bonds (66% of the sample) are assumed to be more risky and as a result higher yield instruments. We assume, that the higher value of YTM for GBs is due to skew in corporate bonds side in our sample. That is a good strategy to analyze more risky financial instruments, as far we can assume that GBs are interesting to investors not only due to low risk of governmental/municipal issuer which are more stable but also due to higher yields and "green" nature of these bonds.

Finally, we can analyze G-spreads for our samples. G-spread is the spread between the bond yield and the interpolated yield of the government curve. As we can see, on average, G-spreads for GBs are higher than for CBs. We can compare G-spreads for GBs and CBs as for one of selection criterion was identical maturity for our bonds. Implementing rule for G-spread analysis is: between two bonds with similar maturities a bond with greater G-spread value is cheap (and basically should be purchased) in comparison with a bond with lesser G-spread value. In our case we can see that G-spreads are higher for GBs and, based on the implementation rule, GBs should be cheaper. However, previously we saw that on average prices for GBs are greater and this comes into contradiction with our results. Possible reason for that fact is wider standard deviation for GBs G-spread which is resulting in skewing of results and cannot be assumed as sustainable.

To summarize, analysis of descriptic statistics showed us the following:

1. GBs average prices are higher with lower deviation
2. GBs average YTM are higher with lower deviation
3. GBs bid-ask spreads are lower with lower deviation

Based on this 3 main outcomes we can make the following assumptions: green premium existsts in our sample and resulted in more high YTM values; GBs are more liquid and the reasons for this liquidity can be explained by higher interest of investors to GBs due to their "greenness" nature but not just by more stable issuer with low risk features (because we have higher YTM which indicates risk premium). That is why, our further analysis we will focuse on 2 main "green" features – liquidity and green premium.

4.4. Green premium analysis

Analysis of existing literature showed that there is no consensus between research about presence and value of green premium. Some of research detected positive green premium while others have detected negative one or even did not detected any difference in terms of premium between GBs and comparable CBs. To overcome this point, we assumed earlier that green premium is not stable and cannot be described or statistically significant detected via linear regression. Moreover, previous research provided their analysis based on a particular time interval (e.g. 2015-2018 years observation) without taking into account at which stage a particular bond was at the moment. In this research we are going to overcome this inaccuracy and analyze GBs and their paired CBs during their whole life cycle. That is why, all of variables which were discussed before and will be analyzed after, we are moving in time to the zero point. At this 0 point the bond was issued independently what year it was. After this, to overcome a problem of mismatching observation between GBs and CBs we have transferred our sample

from the daily observation to weekly observations. This procedure was provided for each bond in the sample. Resulting, we have weekly variables observations for each bond, where starting point is 0 (issuance date) and all the following time-scaled observations are in accordance with ordered number of the week of the bond life cycle.

As discussed earlier, the analysis of the premium of green bonds must be carried out exclusively in tandem with their counterparts among conventional bonds. In the general case, we study bonds' premium by their yield (YTM in our case). For each observation, we have the bid and ask yield as a percentage of par value. To detect the most appropriate YTM measure for the further analysis, we should calculate YTM at mid-price, which is calculated by the following formula:

$$Mid\ price\ YTM_{\ i,t} = (Ask\ price\ YTM_{i,t} + Bid\ price\ YTM_{i,t})/2 \qquad (16)$$

Where:

$Ask\ price\ YTM_{i,t}$ – YTM calculated based on ask price for bond i in time t

$Bid\ price\ YTM_{i,t}$ – YTM calculated based on bid price for bond i in time t

Values of Ask and bid YTM were obtained from the Cbonds resources.

After Mid-price YTM (here and after yields) were calculated for each bond observation (as for GBs so for CBs). Than we have to exclude from our sample outliers and abnormal values of spreads. Abnormal values were detected via the formula:

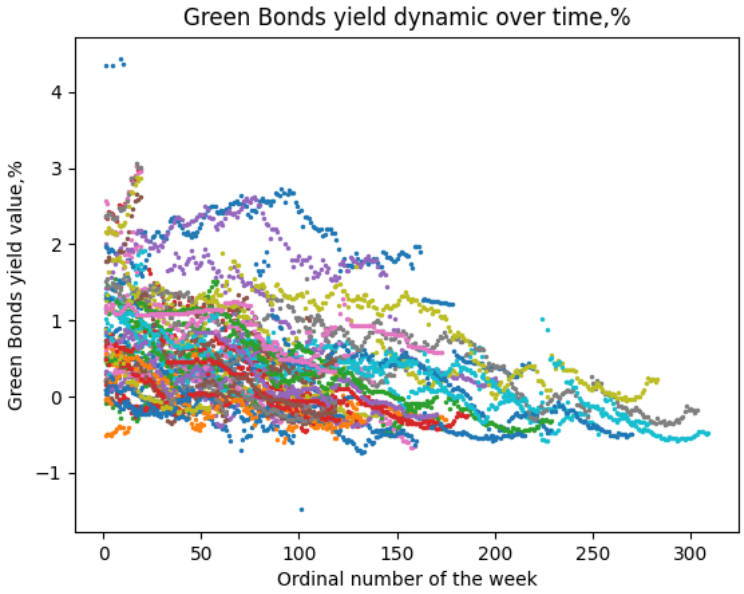
$$Abnormal\ value = mean_i\ (Bid - ask\ spread) + 2 * std_i\ (Bid - ask\ spread)\ |\ mean_i\ (Bid - ask\ spread) - 2 * std_i\ (Bid - ask\ spread) \qquad (17)$$

Where:

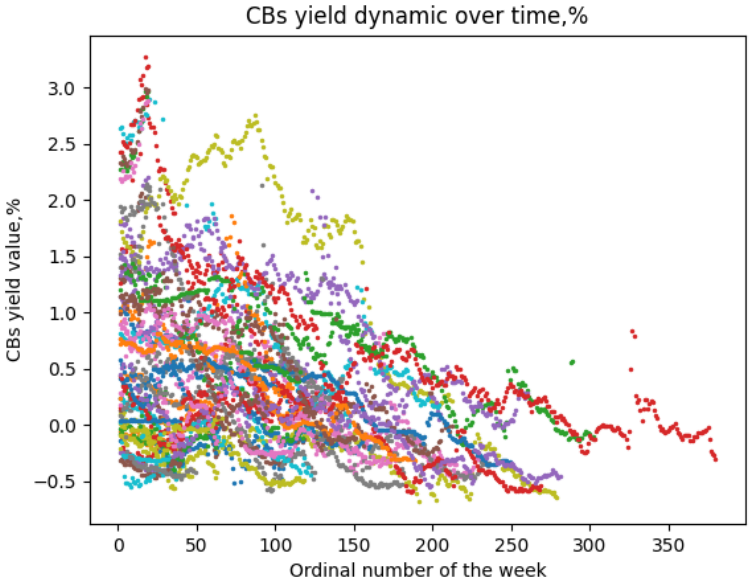
$mean_i\ (Bid - ask\ spread)$ – is the mean value of Bid-ask spread for i bond observation

$std_i\ (Bid - ask\ spread)$ - is the standard deviation value of Bid-ask spread for i bond observation

Finally, after abnormal vales exclusion, we have created scatter plots of each bond yields values dynamic over time, which are represented in Pictures 7 and 8.



Pic. 7. *GBs yields dynamic over time, %*



Pic. 8. *GBs yields dynamic over time, %*

Despite, we excluded from the sample abnormal observations, nevertheless, we still see obvious outliers on the graphs regarding the homogeneity of the entire sample, which we will not accept into consideration in further analysis (in the case of green bonds, observations are above 4% and below -1%).

In addition to the strong and obvious autocorrelation of the series for both conventional bonds and green bonds, it should be noted that there is an obviously smaller spread in the yields for green bonds. Also, we cannot draw unambiguous conclusions regarding the difference in the value of returns - most observations are concentrated in the region from 3% to -0.5% throughout

the entire life cycle. Interestingly, the decline in green bond yields appears to be slower than the decline in conventional bond yields over time. If you visually draw a trend line, its slope for green bond yields will be significantly weaker.

Here we are going to introduce in our analysis new definition and clarify terminology which will be used during the analysis. Earlier we discussed that GBs premium analysis can be based on yields analysis of GBs and their paired CBs. However, classically the term "premium" is more associated with the value of bonds *price* which exceeds or vice versa is lower than par value of the bond. At the same time yields and prices of bonds are related with inverse relationship. Positive yield is a signal that price of the bond is lower than its par value and vice versa. Thus, in the aim to widen clarity of further results discussion, we should clarify that our further analysis considers not just premium of GB as exceed value or discount to its par value, but we are interested only in the part of this premium which relates to eco-friendly motives of investor. Thus, we "divide" premium of GB in two parts: one is the premium for risk, issuer, which should be equal for paired GB and CB and the second part is "green premium" which is directly connected with the nature of GB's underlying project. That is why, in the further analysis we will assume the following definition*: "Green Premium" – is the part of green bond's yield which is directly connected with the green nature of underlying projected and exists due to investors perception of this green nature of bond.* Green premium here and after can be defined as "*Greennium*" to exclude the possible misunderstanding. Resulting, as far we are focused on yield values, we should remember, that in our case positive value of green premium indicates GB's price discount (in terms of bond's par value) in comparison with paired CB and, in opposite, negative value of green premium indicates GB's price excess in comparison with paired CB.

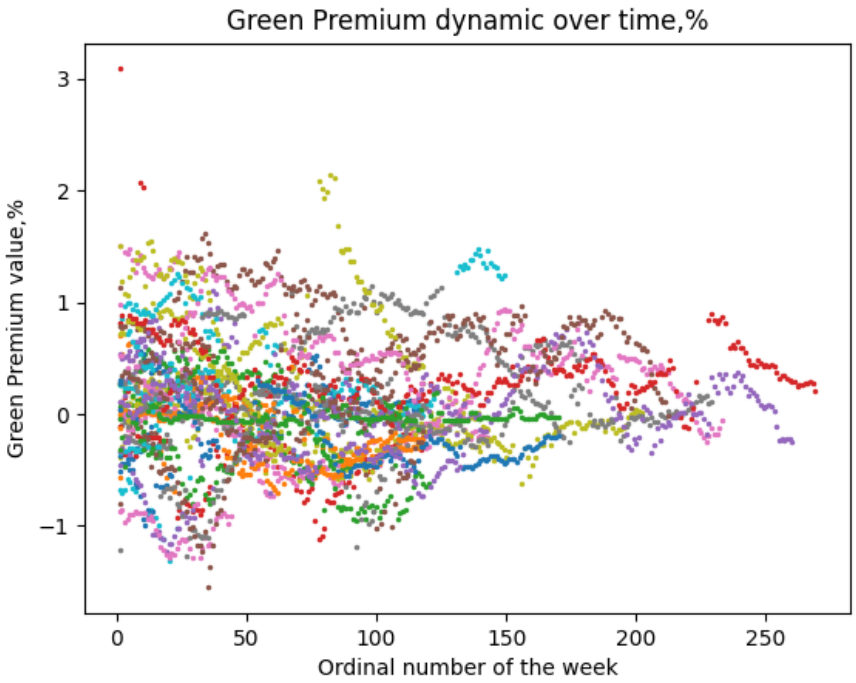
To test our hypothesis that there is a green premium, we calculate the difference between the yields for green bonds and their paired conventional bonds using the following formula:

$$Green\ premium_{i,t} = Mid\ price\ YTM_{GB,i,t} - Mid\ price\ YTM_{CB,i,t} \qquad (18)$$

Where:

$Mid\ price\ YTM_{GB,i,t}$– Mid price YTM for i observation in time t for GBs

$Mid\ price\ YTM_{CB,i,t}$ – Mid price YTM for i observation in time t for CBs

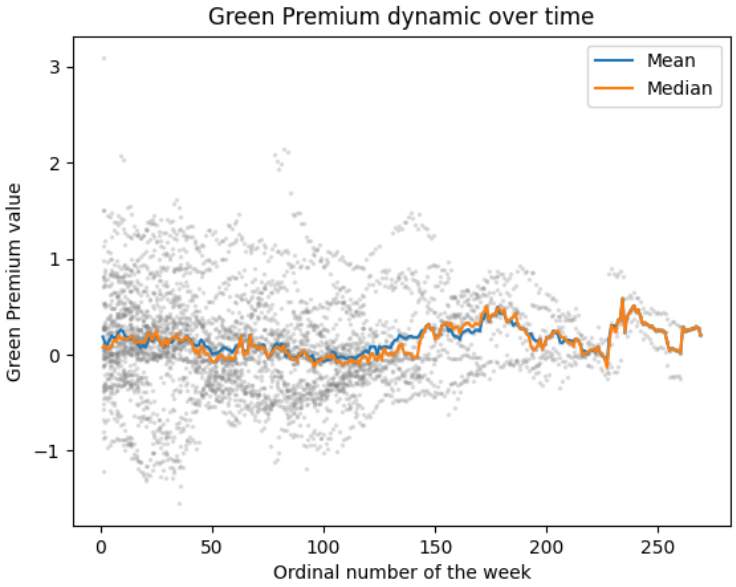


Pic. 9. *Green premium dynamic over time, %*

Resulting we obtain the Green premium as one of the 2 main features which can be different for GBs and CBs. A visualization of the dynamics of the green premium is presented in the chart above. The spread of the green premium is on the region from 3% to -1.5%. At the same time, in its dynamics, several features can be distinguished: if at the beginning of the life cycle, when the green bond is just issued, the green premium has a strong spread around zero, then over time its spread decreases and tends to zero. Also, the skew of the scatter towards the positive area is obvious, i.e. a significant number of observations are in the area of more than 1% yield, while the threshold of -1% breaks through very few observations.

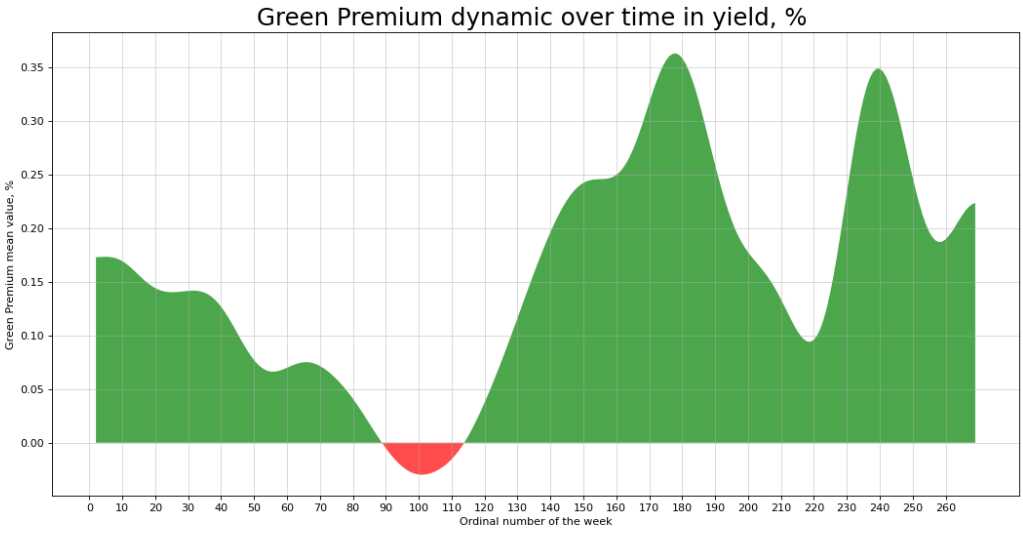
Analysis of the graph allows us to assume that the green premium exists (a skew of the spread towards the positive area), but its periodicity in this period is difficult to assess.

To assess the periodicity in the behavior of the green premium, let us add the average and median values to our graph in Picture 10.



Pic. 10. *Green premium dynamic over time, %*

As we can see from the visualization, indeed the average value of the green premium (green yield) is predominantly in the positive area and only slightly breaks the 0 mark around 100 weeks after the issue. It is also interesting that after about 125 weeks after the issue, the premium shows a significant and rather rapid growth immediately on a significant number of observations. In order to check whether our observations at later stages are not white noise values, we should construct the Gaussian smoothing chart based on method described before (11) and (12). Results are represented in Picture 11.

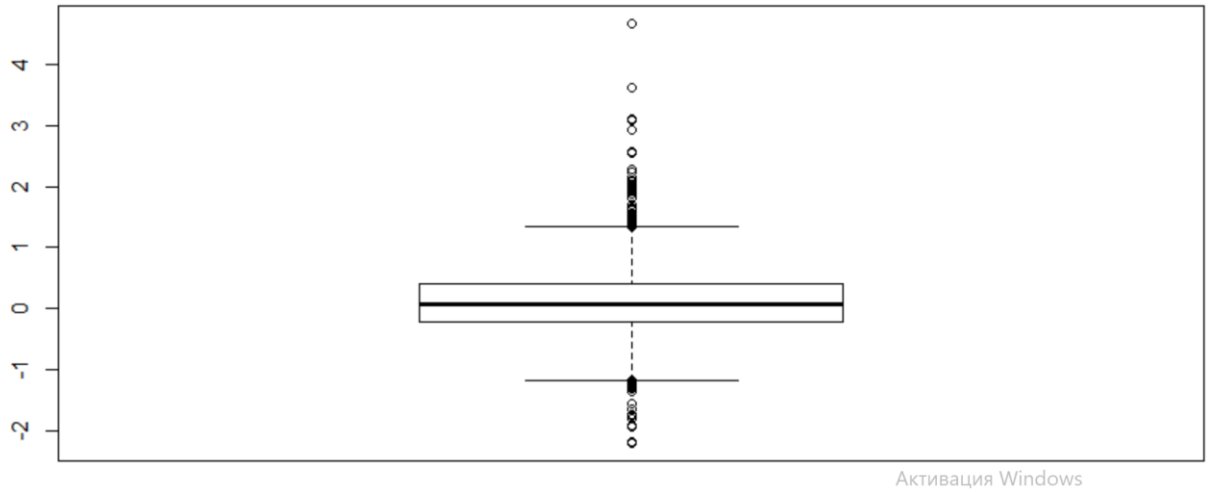


Pic. 11. *Gaussian smoothing of green premium mean value, %*

As we can see, all of values are represented in the chart which means that Gaussian smoothing detects statistically significant trends in our data at later stages of life cycle. This is important remark, as far Gaussian smoothing detects white noise and exclude it from chart representation. As we can see in our case Gaussian smoothing has not excluded any part and detected that statistically significant trend exists till 270 weeks of our observation. A more detailed approximation allows us to conditionally divide the life cycle of a greennium into three stages: a stage of a relatively small positive greennium before week 90, a small stage of negative greennium from weeks 90 to 115, and a stage of a relatively high green greennium after week 115.

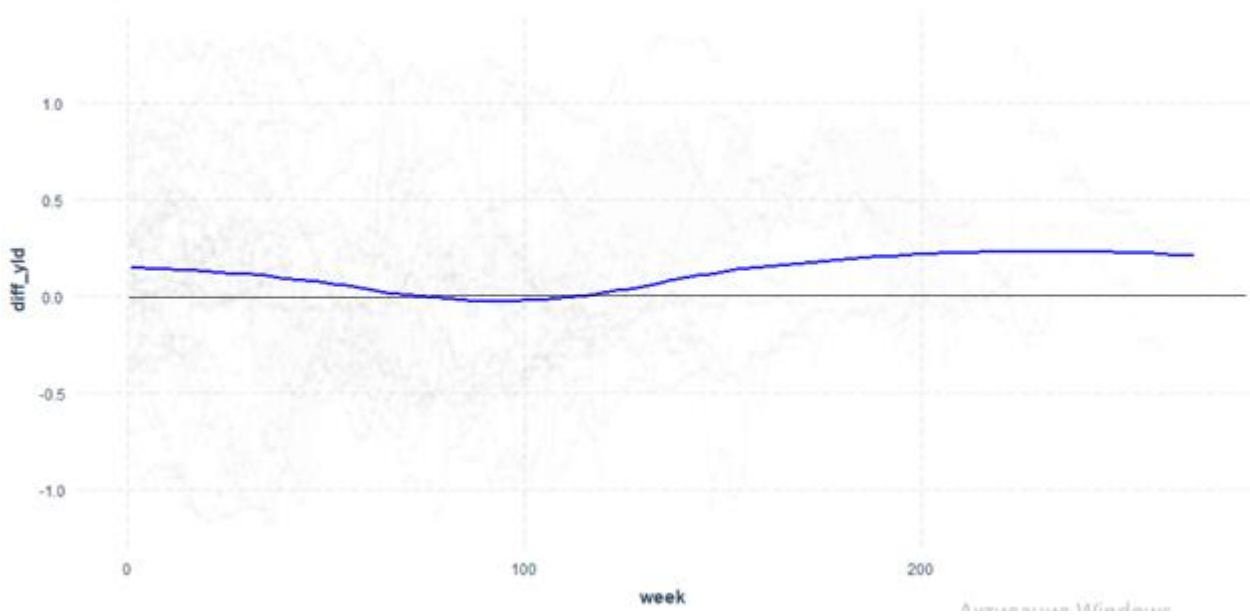
Thus, we have proven the existence of a green premium (greennium) and its recurrent nature throughout the life cycle. Indeed, investors appreciate the socially significant nature of green bonds and are willing to pay for it. At the same time, green bonds offer investors higher returns than their counterparts. Thus, the assumption that since the predominantly issuers of green bonds are government or municipal with a higher rating and a more stable reputation, the inclusion of a significant number of corporate bonds in the sample proves the opposite - green bonds can indeed be a tool that offers more than just stability, but also higher yields in comparison with conventional counterparts. The last stage with relatively high returns (after week 130) is especially interesting for analysis. While the maturity date is getting closer, the greennium is only growing. This behavior of the greennium can be explained by a simple factor - the projects, on which the GBs are based, have a higher degree of uncertainty (especially infrastructure projects or projects to introduce new emission mitigation technologies). Accordingly, the uncertainty and, as a result, the risk do not decrease over time. Therefore, green bonds are able to maintain a higher level of yield relative to their counterparts among conventional bonds, where, classically, with the oncoming of the maturity date, the yield of the bond decreases as the risk of uncertainty decreases. Also, for the analysis, the second short stage is very interesting, when the greenium goes into the negative area (90-115 weeks). Most notably, the turning point, when the premium change its direction from decreasing to increasing is placed at 100^{th} week. Thus we should prove our results via robustness test. As it was discussed in the methodology section, robustness of our results can be proved via polynomial approximation.

First, we should preliminarily clear our sample from outliers, based on the criteria inherent in the entire sample. As we can see in Picture 12, there is a significant number of outliers in our sample that must be removed.



Pic. 12. *Box Plot for Green premium values*

After the outliers have been removed from our sample, we move on to constructing a polynomial fit for our data. First, consideration of the polynomial will allow us to test our hypotheses regarding the dynamics of the behavior of the green premium and its periodicity, and will also allow us to test our results for robustness, since in this case the trend and dynamics of each observation in terms of bonds are taken into account and approximated. The graph below shows the nominal fit of our data:



Pic. 13. *Polynomial fit on panel green premium*

Analysis of the polynomial graph allows us to say with confidence that the previously identified patterns are indeed present in the dynamics of the green premium. In the first, over a

longer period of the life cycle, the premium is positive and its short transition to the negative area just falls on 90-110 weeks.

Resulting, we can say, that observed results are robust and stable and we can accept Hypothesis 1 and Hypothesis 2 and claim that the green premium exists and has a periodicity.

4.5. Green Bonds liquidity analysis

We will start our liquidity analysis from the assumption, that the liquidity in our case will be measured as bid-ask spread for each bond by the following formula:

$$Spreadi = Ask\ price_i - Bid\ price_i \quad (19)$$

Where:

$Spreadi$ – bid-ask spread for i bond observation (liquidity measure in our case)

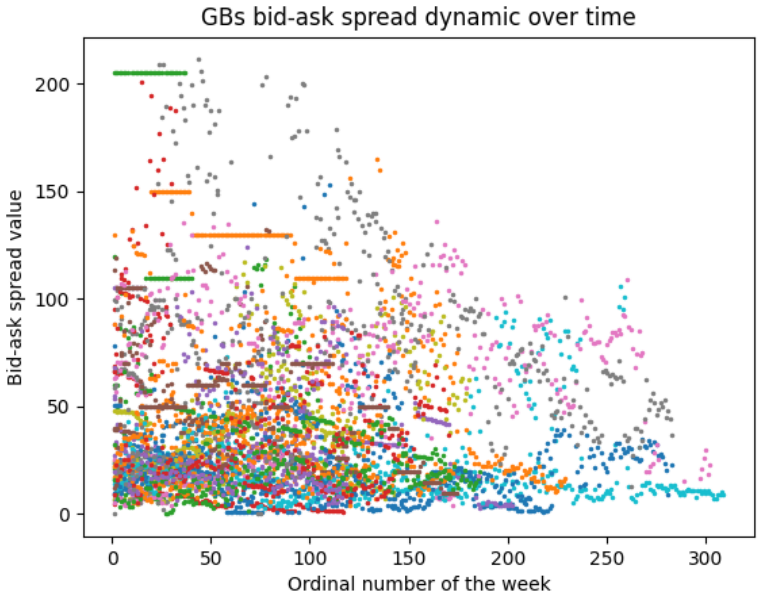
$Bid\ price_i$ – price at which investor is willing to buy an i bond observation

$Ask\ price_i$ – price at investor is willing to offer an i bond observation

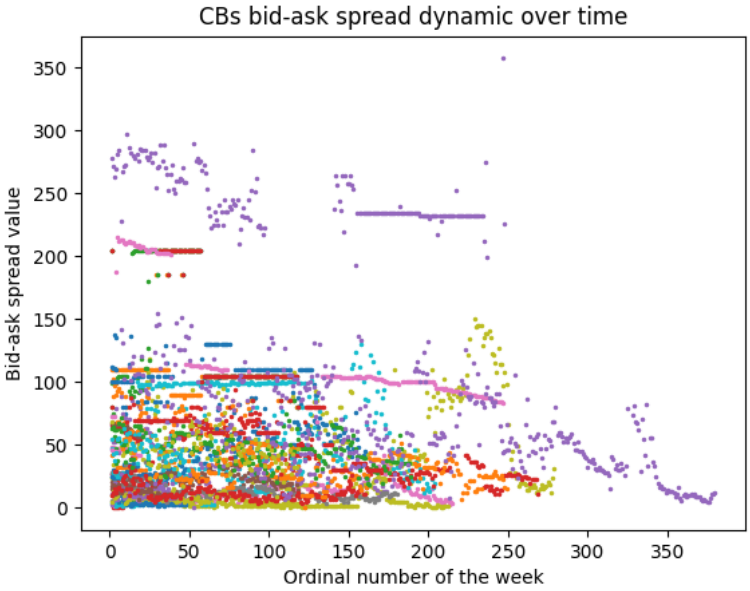
After we again exlude abnormal values from our sample. In other words, as abnormal values we have detected values which are twice standard deviation lower or greater than the mean value for a particular bond. We do not call these abnormal values as outliers, as far they are calculated in terms of a particular bond, but not of the whole sample. We do not exclude outliers in terms of whole sample at this stage as far we are interested in liquidity dynamic for whole scope of bonds and want to avoide biasdness for pairs of GBs and CBs due to centered on the trends of the entire sample.

For the further analysis we have created a plot which shows us liquidity of GBs and CBs for each observation in Pictures 14 and 15. As we can see, bid-ask spreads for GBs are evenly spread in comparison with CBs even after abnormal values exclusion.

In general, bid-ask spreads for conventional bonds are higher (up to 350 bps), while for green bonds this indicator is at just over 200 base points. Considering the fact that extreme values have already been removed from our observations, we can say that, in general, the spread of values for conventional bonds is higher, despite the fact that most observations are concentrated at the mark below 150 base points. In case of green bonds, we see that observations are more dispersed along the graph, but nevertheless, most of them also do not go beyond 150 base points. Accordingly, here we cannot make an unambiguous conclusion regarding the tendency characteristic of all observations in one of the bond groups, except that the scatter of observations of conventional bonds is wider.

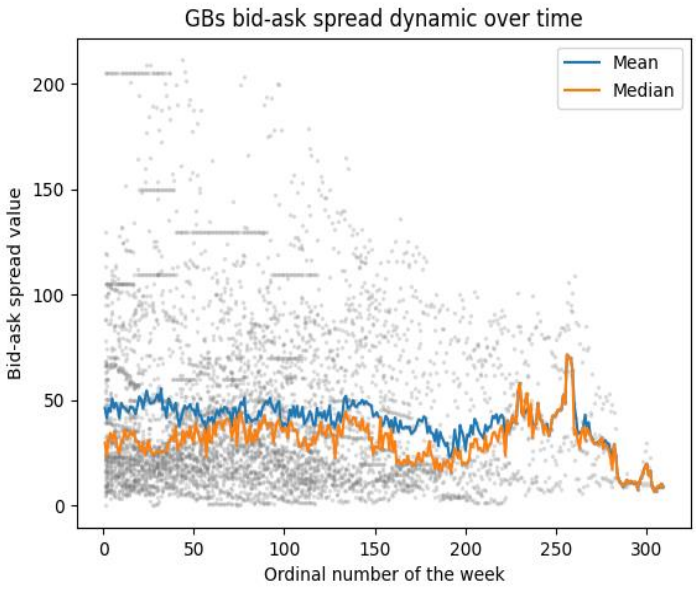


Pic. 14. *GBs bid-ask spread dynamic over time, bps*

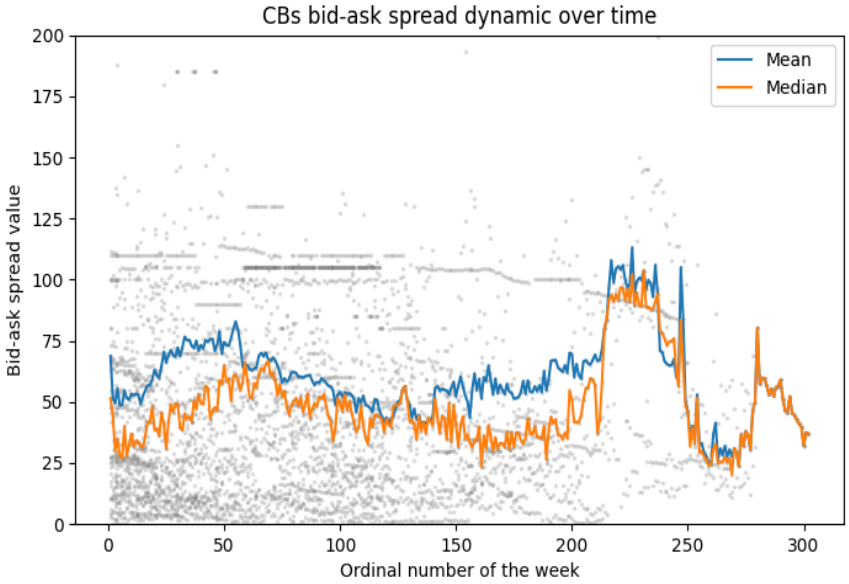


Pic. 15. *CBs bid-ask spread dynamic over time, bps*

To analyse more or less general trends, we will add to the graphs the calculated values of the dynamics of the mean values and median values for each period.



Pic. 16. *GBs bid-ask spread dynamic over time, bps*



Pic. 17. *CBs bid-ask spread dynamic over time, bps*

Since after 200-250 weeks our estimates of the mean and median are strongly biased due to the fact that during this period we have few observations, we will not focus on the dynamics of these periods and later try to estimate them using statistical methods. We will now focus the analysis on timeframes from 0 to 200 weeks.

As we can see, most of the mean values in case of green bonds do not exceed the 50 bps mark. In case of conventional bonds, on the contrary, we see that the average value for each of the periods exceeds 50 base points. Respectively, despite the fact, that GBs bid-ask spreads are more evenly spreaded, while for CBs spreads seems to be more consentrated closer to 0 value,

we can still confirm our idea, that in average, spreads for GBs are lower and more narrow, which indicates higher liquidity than for CBs.

To confirm the idea abot GBs better liquidity let us calculate “Green liquidity”, which refers only GBs. Previously we said, that including in the paired sample bonds with all main identical measures (including issuer, structure, maturity, coupont frequency, currency) we exclude the possibility of ommited variables for the analysis and obtain pairs of GBs and CBs which differenciates from each other only by their based project nature (green or non-green project) and liquidity measure. That is why, as far all other characteristics of the bonds are the same, we can calculate Green liquidity via the following formula:

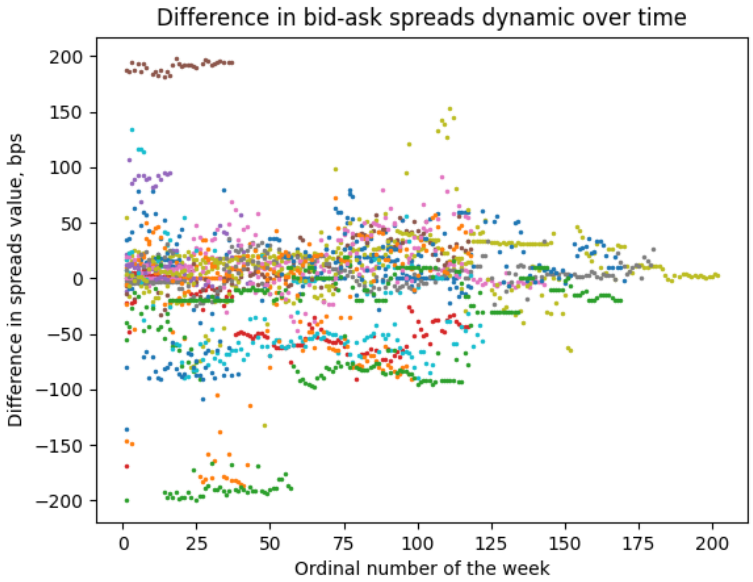
$$Green\ liquidity_{i,t} = Bid\ ask\ spread_{GB,i,t} - Bid\ ask\ spread_{CB,i,t} \qquad (20)$$

Where:

$Bid\ ask\ spread_{GB,i,t}$ – Bid-ask spread for i observation in time t for GBs

$Bid\ ask\ spread_{CB,i,t}$ – Bid-ask spread for i observation in time t for CBs

Resulting we obtain the Green liquidity as one of the 2 main features which can be different for GBs and CBs.

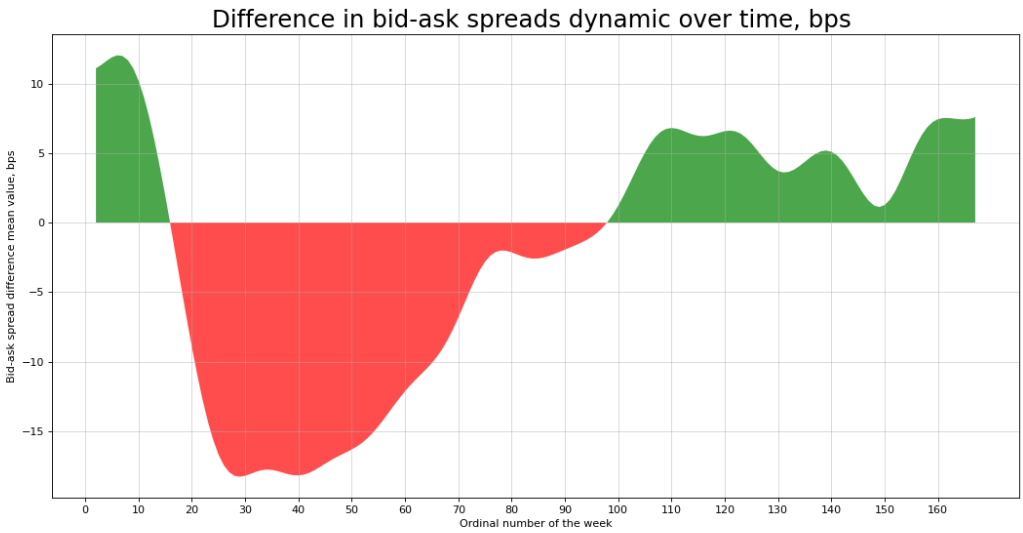


Pic. 18. *Green liquidity dynamic, bps*

The chart above represents dynamic of Green liquidity (difference between GBs bid-ask spreads and CBs bid-ask spreads). As we can see, most of values are concentrated below 0 and demonstrate negative value. Values at the borders of +200 and -200 bps can be assumed as outliers in further analysis. Analyzing the scatterplot, we can see, that at the beginning of life cycle after the issuance a lot of values are positive and relatively high, while after

(approximately after 25 week) become lower and move into negative area with further increase. In other words, our scatterplot shows some periodicity in its trends. To confirm this assumption, we again will calculate mean values for each week period and smooth it via Gaussian method (11) and (12).

Gaussian smoothing will be used to avoid biasedness connected with the extreme low/high values of our data. Moreover, Gaussian smoothing help us to exclude from the sample values which cannot be described by generalized trends with some constant features (mean/standard deviation) and can be detected as white noise. This factor could be useful for our data as far at last weekly observations we have not a lot of variables and should not take into account trends which offer us the graphical representation. The graphic of mean values for green liquidity dynamic is represented in Picture 19.



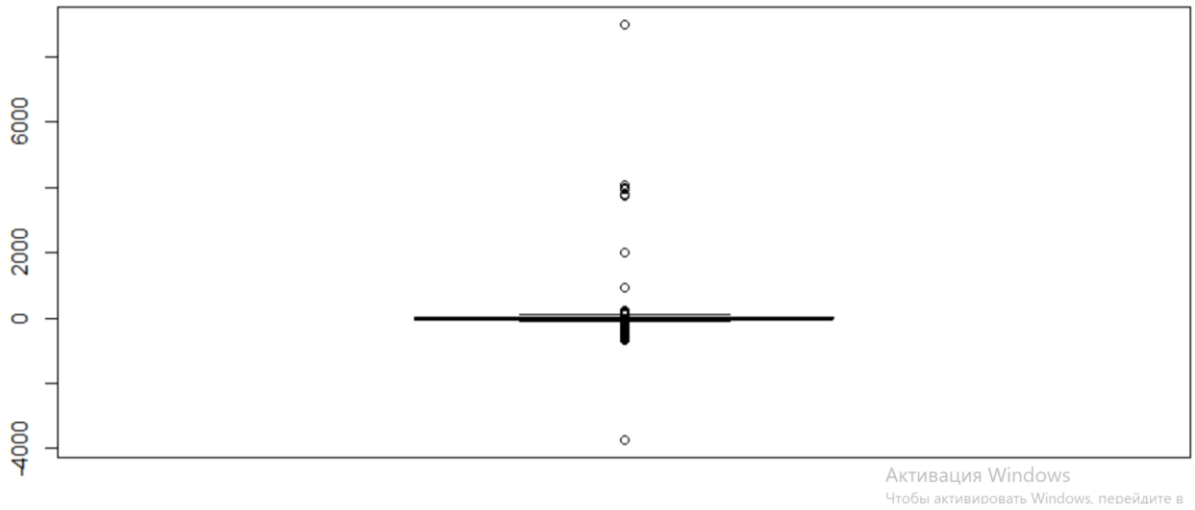
Pic. 19. *Average green liquidity dynamic, bps*

As it was assumed before, observations after 170 weeks were not included in the graphic as far Gaussian smoothing assume these values as white noise and does not find any statistically significant dynamic in it. As for observed results, we can see, that in average most period difference in liquidity is negative and exceeds the mark of -15 bps. The interpretation of the results obtained is as follows: since the graph shows the difference between the bid-ask spread for a green bond and the bid-ask spread for a paired conventional bond, this difference means a difference in the width of the spread. In other words, a negative difference means that the spread for green bonds is narrower and, accordingly, the liquidity is better, and vice versa, a positive value of the difference in spreads means that the spread for a green bond is wider and in this area the liquidity of a green bond is worse. In terms of dynamics, it is important to note here that

according to the average values, in the first weeks after the issue, the liquidity of green bonds is worse than that of paired conventional bonds, however, in the period from about 15 to 100 weeks, this liquidity becomes better than for paired counterparts.

A potential interpretation of the results is as follows: the known fact that the issuance of green bonds is accompanied by an oversubscription on the part of institutional investors. Accordingly, in the first weeks of the life cycle, most of the bonds are concentrated in the hands of large institutional players. However, over time, when more green bonds are released to the secondary market, speculative investors have the opportunity to purchase this type of securities and their liquidity increases. A significant negative area on the chart indicates that in the secondary market, investors are showing significant interest in green bonds.

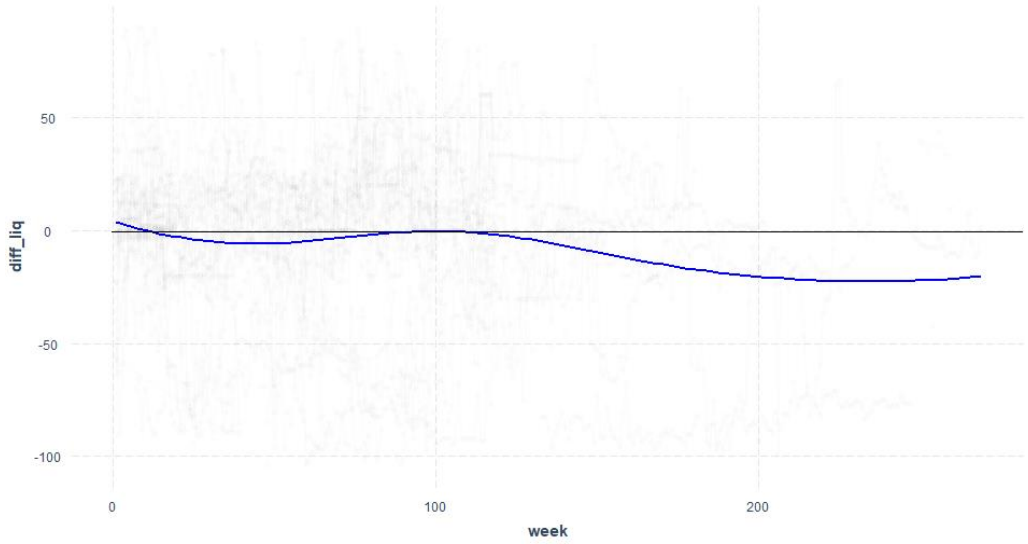
To confirm our hypothesis, we will move from analyzing trends based on mean values to statistical analysis. First, we need to check the sample for outliers and remove them. Previously, we performed clearing of outliers based on specific for a certain bond or a pair of observations. Now, for statistical analysis, we need to conduct an outlier study based on a method that takes into account the homogeneity of the entire sample rather than an individual observation. To check for outliers in our data, let's build a boxplot graph.



Pic. 20. *Box Plot for difference in bid-ask spreads*

As we can see in Picture 20, several statistically significant outliers still are presented in our data. These values were excluded from the sample without any auto fulfillment.

Since our sample is a panel sample, we are severely limited in the methods of analysis. The classical method for analyzing a panel data is linear regression. However, since we want to get away from the linearity of the trends in our data, since we have already obtained evidence of their periodicity, for further analysis we will tune the polynomial fit of our data in Picture 21.



Pic. 21. *Polynomial fit on panel difference in bid-ask spreads for GBs and CBs*

Polynomial fit is necessary for prove of analysis for the following reason: previously, we provided our analysis basing on mean values (in this case mean value of bid-ask difference for GBs and CBs). Now, due to polynomial function, we take into account all trends for each particular observation (pair of GB and CB and their difference in bid-ask spread). This is a good robust test as far we can be sure that observed dynamic is resulted not just skew of several extreme observations but observed trend takes into account all of panel observation trends and approximates them.

However, here we should make a correction that we observed previously: as we already know from Gaussian smoothing all of observations after 170 week seems to be white noise and do not provide any statistically significant trend in data. That is why, during the analysis of our polynomial approximation, we will not take into account trends obtained after 170th week as far we do not have enough number of observations to detect here statistically significant trend.

Overall, our polynomial fit demonstrated approximately the same trends as mean values adjusted for the value of difference in spreads. Again, we see that spreads differences are positive until about week 15, then the differences go into the negative area, demonstrating higher liquidity of green bonds, and around week 100 return to the positive area, demonstrating a decrease in liquidity. Thus, we can consider the results obtained as robust and state that there exists a difference in liquidity between green bonds and their conventional counterparts, this difference is periodic and its frequency can be described as: weaker liquidity of green bonds up to 15 weeks after the issue, higher liquidity from 15 to 100 weeks after the issue and stabilization of the liquidity of green bonds approximately at the level of their usual counterparts after 100 weeks.

In general, if we compare the graphs of the green premium and the difference in the bid-ask spreads of the green and ordinary bonds, we can see a significant pattern - in the period when the liquidity of the green bond is higher, its green premium decreases. This aspect can be explained by the fact that when the liquidity of a green bond increases, the liquidity falls on the speculative part of market players and part of this green premium is destroyed due to an abnormal growth in demand and speculative activity. When speculative interest in green bonds declines, the green premium starts to rise again. However, to make any concrete outcomes first we should investigate the relation between green premium and liquidity.

4.6. Green premium and liquidity relationships analysis

To test our hypothesis about linear relationship between the liquidity level of green bonds and the value of the green premium, we can build a regression model in which:

$$Diff\_midyld_{i,t} = \alpha + \beta Diff\_bidask_{i,t} + u_{i,t} \quad (21)$$

Where

$Diff\_midyld_{i,t}$ – is the difference in mid price YTM between i GB in period t and its paired CB (green premium)

$Diff\_bidask_{i,t}$ – is the difference in bid-ask spread between i GB in period t and its paired CB (liquidity measure)

In this regression α will show us value which is not explained by our model (omitted variable which also can influence on the value of green premium) and β will show us direction of green premium and GBs liquidity relations and sensitivity coefficient of green premium to changes in liquidity of GBs.

For regression analysis on panel data, we will use the pooling regression method, assuming that our section takes into account all possible factors that can affect the green premium and there are no other fixed or random effects between our observations. This logic is based on the need to assess the impact of liquidity on the value of the green premium. The results of the regression model are presented in Picture 22.

As we can see from the table below, the constant and slope coefficients are significant at a significance level of less than 0.01% and, in general, the model is significant at the same confidence level. However, the explanatory power of our model is only 0.2%, which is an extremely low value for capturing an outcome or predicting a dependent variable.

OLS estimation

	Dependent variable:
	diff_yld
diff_liq	-0.0001***
	(0.00003)
Constant	0.093***
	(0.009)
Observations	3,929
R^2	0.002
Adjusted R^2	0.002
Residual Std. Error	0.548 (df = 3927)
F Statistic	8.575*** (df = 1; 3927)
Note:	*p<0.1; **p<0.05; ***p<0.01

Pic. 22. *OLS estimation green premium dependence on liquidity level*

Even though the construction of a linear regression did not give us a significant result and could not show a linear dependence of the premium on liquidity, nevertheless, we can draw two key conclusions. First, the relationship between the variables does exist since the coefficients of the model and the model as a whole are significant. Secondly, the nature of the relationship between the variables is not linear, and accordingly we need to look for alternative ways to describe the nature of this relationship.

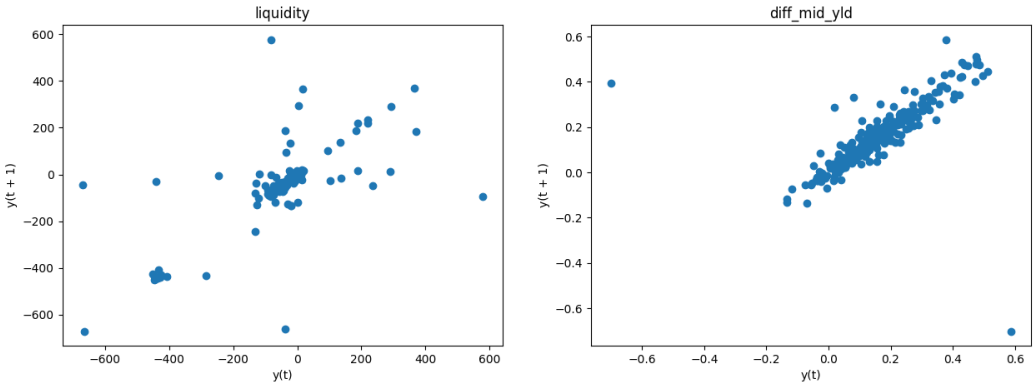
Testing for Granger Causality

If we go back to looking at the polynomial liquidity difference charts and the green premium chart, we can see that there is some offset of the zero-axis intersection in time. Accordingly, we can assume that we have a causal relationship between these variables. We can consider the presence of a causal relationship using Testing for Granger Causality (Granger, 1969). Granger causality is a concept used in econometrics that formalizes the concept of a causal relationship between time series. Granger causality is a necessary but not sufficient condition for causation. Testing based on regression of variables for their past values and past values of the alleged "cause" and testing the hypothesis that the coefficients for the past values of the "cause" are equal to zero at the same time (14) and (15). If the hypothesis is not rejected, then the presence of Granger causality is not recognized. At the same time, the reverse model is tested, when instead of the “cause”, the “effect” is used and vice versa.

Since a prerequisite for testing is the presence of a time series, then we will move from our panel data to a time series of data, that for each time period, the average values for the sample for all observations are calculated. At the output, we have two time series:

1. Liquidity – time series based on mean values of differences in bid-ask spread for GBs and paired CBs for period t
2. Diff_mid_yld – time series based on mean values of differences in YTM on mid price for GBs and paired CBs for period t (green premium or greennium)

One of the main testing conditions is the stationarity of the data series. Therefore, we will begin our analysis by checking the series for stationarity in Picture 23. First, we will visualize out data with 1 lag:



Pic. 23. *Dependence of the liquidity difference and green premium on their lagged values*

As we can see, it seems that that in both cases our data is not stationary and there is direct dependence on the lagged values. To confirm our assumption we will provide ADF and KPSS tests for stationarity:

Table 6. ADF test for liquidity difference time-series

ADF Statistics	-6.919
p-value	0.00
Critical value 1%	-3.45
Critical value 5%	-2.87
Critical value 10%	-2.57

Table 7. KPSS test for liquidity difference time-series

KPSS Statistics	0.1919
p-value	0.1
Number of lags	16
Critical value 1%	0.739
Critical value 5%	0.463
Critical value 10%	0.347

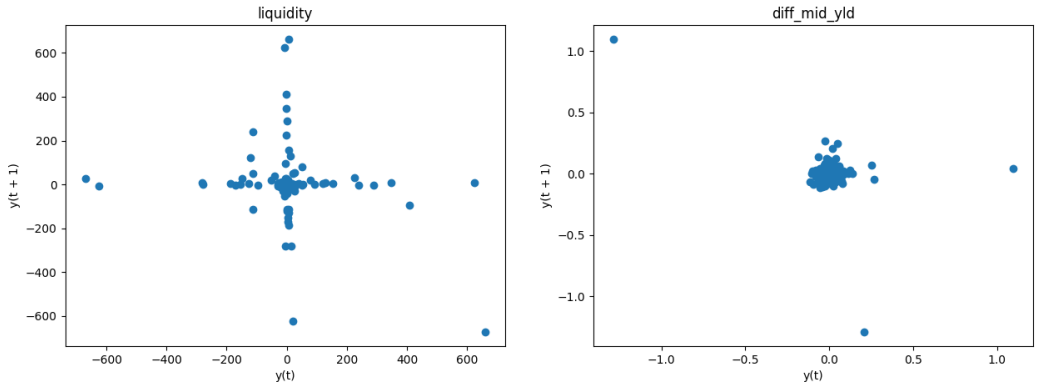
Table 8. ADF test for green premium time-series

ADF Statistics	-3.122
p-value	0.024
Critical value 1%	-3.45
Critical value 5%	-2.87
Critical value 10%	-2.57

Table 9. KPSS test for green premium time-series

KPSS Statistics	0.61
p-value	0.022
Critical value 1%	0.739
Critical value 5%	0.463
Critical value 10%	0.347

According to ADF test our data is not stationary in both cases. That is why we will have to make it stationary we will use differencing approach. After the calculation of first difference lag we created graphs of dependence on lags again in Picture 24:



Pic. 24. *Dependence on lagged values after differencing*

As we can see, differencing procedure with differ order of 1 helped us to make the data stationary and provide further analysis. ADF and KPSS tests results are provided in the appendix.

After we have brought the data to stationarity, we need to determine the lag length for the VAR (Vector Autoregression) model. We will determine the best lag value based on the AIC criterion. The results of comparing models for different lags are presented in the Appendix 5. The best lag for further analysis turned out to be lag = 3. To verify that our VAR model is well

defined, we will test for serial autocorrelation of residuals through Durbin Watson test. Resulting, there is no significant autocorrelation in residuals and the model can be accepted for the further analysis.

After the VAR model specification, we are able to provide test for Granger causality which results are represented in Table 10.

Table 10. Results of Granger causality test

	Diff_mid_yld_x	Liquid_x
Diff_mid_yld_y	1.0	0.16
Liquid_y	0.0	1.0

The rows are the dependent variables, columns are predictors. The values in the table are P-Values. P-Values lesser than the significance level (0.05), implies the Null Hypothesis that the coefficients of the corresponding past values is zero, that is, the X does not cause Y can be rejected.

Resulting, we can state that our assumption that the change in liquidity and the green premium are interrelated has been confirmed. Moreover, we can accept Hypothesis 3 about relations between green premium and liquidity.

However, the test showed that the magnitude of the green premium is the reason for the change in yield, and not vice versa. However, it should be noted that testing shows us causal but not causal-resulting relationships between variables. It is argued that the Granger test only detects "predictable causality." The use of the term "causality" alone is incorrect, since Granger causality is best described as "precedence" or, as Granger himself later argued in 1977, "temporal relationship." Rather than checking if X is causing Y, Granger's causality is checking if X is predicting Y. Thus, we can conclude that the green premium is able to predict the direction and amount of liquidity of green bonds and can be used in classical forecasting models based on the average values and stage of the life cycle of green bonds that we obtained earlier.

In terms of the causal aspect, our results show the following:

1. Green premium declines in period T
2. The liquidity of green bonds in the period T increases relative to their paired counterparts
3. In period T1, when the green premium starts to grow, the liquidity of green bonds decreases
4. While the green premium has a causal relationship with the liquidity of green bonds

The results obtained allow us to conclude that the presence of a green premium precedes liquidity trends and is their root cause. Accordingly, we can state that green premiums are decreasing / increasing not due to trends in liquidity (for example, when speculative investors see relatively high returns and increase trading volumes and, accordingly, liquidity), but, on the contrary, investors are attracted by the nature of green bonds, but not their high liquidity or low volatility, and they show significant interest in green bonds even though the green premium declines in certain time intervals. In addition, the fact that the liquidity of green bonds during a significant time interval is higher than the liquidity of their counterparts signals that investors are ready to invest in a new instrument, despite the presence of identical CBs on the market. Such behavior of investors is a vivid example of investment motivation based on understanding the nature of a financial instrument, projects and assets that are behind this financial instrument.

In turn, the positive green premium, which, as we proved earlier with the Granger test, is not a consequence of low liquidity or high volatility of the green bond. This conclusion is especially significant for us, since it allows us to assume that higher green premiums are the result of market valuation and higher profitability of this financial instrument, despite a longer maturity and a more stable issuer.

Earlier, we discussed that investor interest in green bonds can be explained by quite rational aspects: as a rule, green bonds are issued by more stable, more successful companies, and projects for which investments are directed very often enjoy state support. However, in such a scenario, the yields of such a financial instrument should be lower than its paired analogue, since some of the risks inherent in any bonds (liquidity risk, default risk) are excluded / reduced. However, in the case of green bonds, we see the opposite picture - a green premium exists and the yield of such a bond is on average higher than the yield of a similar financial instrument (CBs in our case). Accordingly, investors see an opportunity to make money on the green bond, including due to the complexity and importance of projects for which investments are attracted.

2.7. Verification of results on real data

The trends in the behavior of the green premium that we have considered earlier allow us to draw a number of conclusions:

- The green premium exists.
- The green premium has both positive and negative value at different times throughout the life cycle.
- Conventionally, these periods can be divided into the following: 1-90 weeks after the issue - a positive green premium, 90-113 weeks after the issue - a negative

green premium (with the lowest value at 100th week), after 113 weeks a positive and relatively high green premium.

Based on the trends described above, we can identify the most profitable (if not optimal) strategy for trading green bonds. In its most general form, we can describe it as follows:

1. Buying a green bond immediately after issue
2. Selling a green bond during a negative green premium between weeks 90 and 113 after issue
3. Buying a green bond after 113 weeks after the issue and holding it until maturity to obtain benefits from higher yields in comparison with CBs holding.

Of course, the strategy described above is its most general and obvious form. Of course, trading green bonds in order to extract the highest yield requires additional analysis of each individual case. However, the essence of a practically applicable strategy remains as follows - it is necessary to get rid of green bonds in a period of approximately 90-113 weeks and a great benefit during this period can be obtained either on alternative conventional bonds or, for example, by restructuring the portfolio and including new green bonds in it, which are already passed the stage of negative green premium and have already begun to demonstrate a high level of yields. To test our strategy in practice, we will apply the above strategy on real data.

Suppose we are private investors who tend to resort to only the simplest trading strategies in their market trading activity. During the zero period, we have the following resources for testing the strategy:

Table 11. Input data for testing of trading strategy

Financial resources	1 000 000 EUR
Number of available GBS with current life cycle duration longer than 120 weeks	25
Strategy 1	Create a GBs portfolio T0 period and keep it until the end of available data (T1 - 31/03/2021)
Strategy 2	Create a GBs portfolio at T0 period, sell GBs at 100th week after issuance (T1), buy these GBs at 113th week after issuance (T2) and keep it until the end of available data (T3 - 31/03/2021)

We have chosen 100th week for portfolio selling because as we previously saw in Gaussian smoothed graph (Picture 11) that at this week green premium is minimal (minimal yield) and, resulting, price should be the highest. We bay back our portfolio at 113th week as far after this week we identified positive green premium (positive yields in comparison with CBs).

Step 1: First, we need to calculate dirty prices of our GBs at every period of time available, where dirty price – is the real price at which buy/selling activity in exchange could be executed. For this purpose, we will use the following formula:

$$Dirty\ price_{i,t} = Clean\ Price_{i,t} + AI_{i,t} \quad (22)$$

Where:

$Clean\ Price_{i,t}$ – is the mid price (Ask price+Bid price)/2 for the bond i in time period t

$AI_{i,t}$ – is the accrued interest for the bond i in time period t

Accrued interest is the amount of interest earned on a debt, such as a bond, but not yet collected. Interest accumulates from the date a loan is issued or when the last bond's coupon was paid. This factor should be included in the analysis as far we are going to calculate financial results of our buying/selling activities during the strategy calculation, and we want to be closer to real results.

Step 2: For each bond in our testing sample, we will calculate nominal and current prices for each period in accordance with exchange rate of this period to provide all calculations in Euro currency as far it is the most numerous currencies in our sample. We will also calculate the annual coupon yield for the bondholder based on the coupon frequency, value, and exchange rate.

Step 3: To complete analysis, we include in the test sample only those green bonds that currently have at least 120 weekly analysis periods. Also, for each observation, we calculate the coupon yield for both strategies that will actually to be received by the holder strictly during the period when the bond is in our portfolio. Finally, we distribute the funds available to us with equal weights among all bonds on the assumption that the dynamics of the green premium is stable from observation to observation, and we do not want to violate the purity of the experiment by skewing the results towards more attractive observation in terms of yield.

Step 4: Calculation of the financial result of strategies.

Strategy 1: We distribute all available funds among 25 green bonds in equal proportions (40,000 euros). This figure is adjusted based on the dirty price of the bond at the time of purchase and resulting obtained in the variable T0 purchase value. Next, we calculate the dirty price at the time the green bond is sold (03/31/2021) for each observation. In this case, our financial result will be calculated as:

$$Profit = -T0\ purchase\ value, EUR + Coupons\ earned, EUR + T1\ selling\ value, EUR$$

Where

$-T0\ purchase\ value, EUR$ – is the dirty price of GBs in time period T0 multiplied by number of bonds bought

$T1\ selling\ value, EUR$ - is the dirty price of GBs in time period T1 multiplied by number of bonds sold

Resulting, for the Strategy 1 we will obtain income of 84 500 EUR.

Strategy 2: We distribute all available funds among 25 green bonds in equal proportions (40,000 euros). This figure is adjusted based on the dirty price of the bond at the time of purchase and resulting obtained in the variable T0 purchase value. Next, we calculate how much income we will obtain from selling our portfolio at 100th week (T1) for each observation. Finally, we calculate how much funds we will have to pay to obtain our portfolio back at 113th week (T2). Next, we calculate the income (T3) at the time the green bond is sold (03/31/2021) for each observation. In this case, our financial result will be calculated as:

$$Profit = -T0\ purchase\ value, EUR + Coupons\ earned, EUR + T1\ selling\ value, EUR - T2\ purchase\ value, EUR + T3\ selling\ value, EUR \quad (23)$$

Resulting, for the strategy 2 we will earn 93 968 EUR as a profit value. Details on calculations are represented in the Appendix.

As we can see, following the Strategy 2 will bring us *11%* higher value than just holding GBs from the issue date till a particular moment of time even where green premium shows high values. Demonstration of theoretical results observed during the research were proved on practice via theoretical portfolio calculation. That is why, we are able to argue that the GBs portfolio management strategy provided by our research demonstrates better results.

2.8. Summary of the research results

The results obtained during the research can be divided into three main groups: the results regarding the green bond premium ("greennium"), the results regarding the liquidity of green bonds and the relationship of these two indicators.

Analysis of green premium

The analysis of the green premium for bonds was provided in order to identify the presence of a green premium, its direction, magnitude and dynamics. The initial assumption that the green premium exists and is periodic has been confirmed. During the analysis, we compared

the difference in the mid-price yield for green bonds and their conventional counterparts. Analysis of sample's means and polynomial fit for panel data proved that the green premium exists, and the premium is periodic. Thus, we can argue that *H1: GBs are traded with a green premium in comparison with paired CBs, ceteris paribus* is accepted.

With our results, we close a significant research gap that has clearly been observed through all previous studies. Some of the studies stated that there is no green premium and that investors are indifferent to invest in green bonds or their classic counterparts, and the returns on green bonds are explained solely by standard market patterns. Another part of previous research stated that the green premium is positive, another part of the researchers said that the green premium is negative. Our research shows that the green premium can be both positive and negative at different time intervals. This study has no predecessors in terms of the analysis of the green premium over the entire life cycle.

During the analysis, we found that at the beginning of the life cycle, green premiums are positive, and the yields of green bonds are higher than those of their conventional counterparts. This result confirms the thesis that since green bonds are a relatively new instrument for the market, its dynamics may differ from the dynamics of a conventional instruments. On the one hand, green bonds are issued by stable issuers with a stable financial position and a positive business reputation. These issuers are characterized by a high rating. As a result, the issues of such issuers are characterized by low volatility, high liquidity, and low market bond yields. However, in the case of green bonds, we see a different picture. After the issuance, the profitability for GBs is higher than that for paired CBs. Accordingly, the market does not yet recognize a high level of reliability for these bonds and evaluate them with lower prices and higher yields than their counterparts, despite all the positive characteristics of the issuer. Thus, we can say, that at the beginning of life cycle GBs are underpriced by the market in comparison with paired CBs.

Further, we see that over time, the green premium declines. We can assume due to the fact that higher yields attract the attention of speculative investors (proof is the simultaneous increase in liquidity due to increased trading volume). In other words, green bonds are not just a tool for better guaranteed income, but also are of interest for speculative trading.

Finally, in the second year of the green bond's life cycle, we again see that its yield begins to rise relative to its paired counterparts. Long-term bonds typically experience declines in yield as they close in maturity. However, in the case of green bonds, we see the opposite dynamic. Accordingly, we can make an assumption that the risk of green bonds is still assessed by the market at a higher level than the risk of conventional paired bonds. This is where the specificity of the projects that underlie the green bonds takes place - as a rule, these are long-

term infrastructure projects or even innovative projects to improve the environment or reduce the impact of production on the environment. Such projects are generally riskier and keep the level of uncertainty at a sufficiently high level for quite a long time, due to which the market estimates the risk of such bonds higher even at later stages of the life cycle.

Analysis of green liquidity and its dependence on green premium

Analysis of green liquidity showed the following: at the beginning of life cycle, bid-ask spread for GBs is wider than for paired CB, which means that liquidity of GBs at this period is worse. However, since 15^{th} week and approximately till 100^{th} weeks liquidity of GBs is better than that for CBs and after if becomes worse again. From this dynamic we can assume that after the GBs issuance they are traded weakly due to possible mistrust from investors to real nature of GBs (if financial investments are really obtained for green projects) or this weak liquidity can be explained by the fact that investors are looking closer to new financial instruments and want to know more about it, where finance will be directed, how it's traded, if it's possible to trust to the issuer etc.

Analysis of liquidity and testing it for causal dependence on the yield of green bonds showed that the dynamics of the green premium is the cause of the dynamics of liquidity, and not vice versa. Accordingly, here we can assume that investor interest in green bonds can come from two main sources: the nature of the green bond (that is, interest in the project) and high yields after the issue. In any case, the green premium, if not independent of liquidity, is in any case not a consequence of it and a simple result of the higher activity of speculative investors. As a result, we can say that we have proven the behavioral aspect in the green bond market, namely the interest of investors in the new instrument and their willingness to accept the higher risk of the green bond instead of accepting the lower risk of its usual paired conventional counterpart of the same issuer and structure.

Possible explanation of green premium dynamic

As far we did not have an opportunity to analyze all possible aspects of GBs (e.g., volatility was not included in the analysis, trading volumes due to lack of information about trading on the OTC market) we are able further only to provide our assumptions on the analysis results and possible explanations of green premium dynamic. Further we will consider each stage of life cycle:

1. The first stage which lays approximately till 88^{th} week is characterized by positive green premium. At this stage yields of GBs are higher than yields of paired CBs while the price of GBs is lower. At the same period of time weal liquidity of GBs become better and exceeds CBs liquidity since 15^{th} week. Taking into account the fact that liquidity is not a cause of green premium according to Granger test

results, but in opposite, green premium predicts changes in liquidity, we can assume, that at this stage information transparency about GBs is not as high as it required by investors in exchange to their needs. Possible, investors assume that GB can become a result of greenwashing[5] procedures and in case of exposing GB will be devalued. That is why GBs yields at this stage are high and liquidity is low due to investor distrust to this new instrument.

2. At the second stage GBs green premium decreases and fall into negative value since approximately 87th till 113th weeks. This could happen because at this stage information asymmetry about GBs decreases and investors have more trust to this instrument. In total with higher yields and lower price GBs attract attention of investors which start more active buy and sell GBs in drive their liquidity as well. Already here all greenwashing projects may be detected, and only true GBs are in demand on investors. Trus price of GBs increases and their yields in opposite decrease.
3. At the final stage when green premium move to the positive area again after 113th week, we can assume that here we see changes in investors nature. Before at the period of negative yields and high liquidity we saw interest of speculative investors which would like to obtain benefits from underpriced and high yield instrument. Thus, driving of prices lad to yield decrease. However now when there are more possibilities for adequate speculative activities when prices are too high and yield are low, speculative investors are being replaced by investors interested in low-risk and stable instruments, such as pension funds etc. Thus, trading activity decrease (and liquidity decrease as well) and yields become higher. Another possible reason of higher yields here is the nature of GBs underlying projects. As we previously mentioned, eco-projects usually relate to long-term and risky infrastructure projects. Now in comparison with CBs where projects are less risky, GBs seems to be a bit more uncertain in terms of successful project realization. Thus, we see higher yields in comparison with paired CBs.

2.9. Managerial implication

Based on the results obtained during the study, firstly, tests were carried out for the robustness and stability of the results through various methods and the independence of the green

[5] Greenwashing – approaches and methods which are aimed to convince the community that bonds investments will be directed into eco-friendly underlying projects, which is not true in reality.

premium from the liquidity of green bonds was proved. Accordingly, we are entitled to speak of higher yields on green bonds over a long period of the life cycle. This result can be applied in practice when choosing an issue in which the investor plans to invest his funds. In the long term, investing in green bonds is more profitable, since they take advantage of the positive effects of the characteristics of their issuer (higher rating, stability, sound financial position and beneficial business reputation), but at the same time, this type of financial instrument offers higher yields compared to peers.

As noted earlier, since green premiums (yields) have relatively less volatility and a more predictable statistical trend, GBs can also be used by investors for portfolio earnings. To prove our results, we proposed a green bond portfolio management strategy whereby green bonds are bought and sold according to the life cycle period dynamic and the direction of the green premium during that time period. Accordingly, the investor receives a higher return on the management of the green portfolio while adhering to the proposed management strategy. Results are confirmed on a random sample of green bonds. Thus, the portfolio manager can rely on the overall trend in green bond yields and make higher returns by reshaping the portfolio approximately at 100 weeks after the issue by excluding bonds that have already reached this maturity indicator and including bonds that have already crossed this stage in the portfolio. Thus, higher management returns will be available to the investor.

Again, in this case, we do not claim the optimality of such a portfolio management strategy, and it is naive to believe that the averaged statistical trends will be valid for any observation of a green bond. However, since GBs have obvious advantages in terms of stability and a lower risk indicator relative to peers, but at the same time shows higher yields, all other things being equal, with similar bonds that are not based on green projects, it seems reasonable to use green bonds not only for “greening” your portfolio to make it less risky and diversify in general, but also build portfolios based on green bonds only, as they show higher overall returns on moderate trends. In this case, we will be better protected from the negative effects that will come from including a small share of green bonds in the portfolio, but at the same time we will be able to rely more on the general market trends inherent in this financial instrument and proven in this study.

If we talk about the results of work from the point of view of the issuing company of green bonds, then here we can also highlight a number of very important remarks.

Earlier, when analyzing the green bond market and analyzing previous studies, we talked a lot about the positive side of green bonds for the issuing company - of course, first of all, this is the reputation side of the issue. The company issuing a green bond to the market demonstrates its stability, care for the environment and, in general, its focus on corporate social responsibility.

However, since there is an opinion that investors do not make much difference between green and ordinary bonds, some companies may refuse to certify their bonds as green or generally refuse to issue them and turn to other sources of funding.

Our research shows that despite the oversubscription during the issue and lower bond prices in the future, investors are really interested in green bonds. A period of higher liquidity with a prior decline in green bond yields for the investor is a clear example of an investor willing to accept lower yields in exchange for greenness bonds and bonds are indeed actively traded in the market showing even better liquidity than their conventional counterparts. Accordingly, a corporation that is considering alternative ways of financing green projects should pay attention to such an instrument as green bonds. That is why we included a large proportion of corporate bonds in the sample to show that the identified trends are also typical for the corporate sector.

Also, our results prove to corporations that investor interest in green bonds is not just a fashion trend and the popularity of the instrument among investors only because of its novelty. Trends inherent in green bonds have patterns that investors understand, investors are interested in these trends and actively trade these bonds.

CONCLUSION

This research aimed to estimate green bonds premium during life cycle of this bond: at the different stages after issuance. For the analysis we moved from the "green bond premium" to "green premium" definition as a difference in yields of GBs and CBs. Moreover, we refused from the regression analysis as far we assumed that green premium is not linear and as far, we work with panel data it would be too rough approximation to try to detect particular equation form for estimation in particular values (% or bps). Thus, we focused on trends and periodicity analysis instead of particle value estimation to keep our results in the most accurate and robust frames. As far we have identified green premium existence, its direction and periodicity, we can argue that the aim of this research was achieved.

Also, to achieve research goal we have settled two research questions:

5. *How the green bond premium changes over its life cycle?*
6. *If the GBs premium changes over life cycle from positive to negative or opposite, when turning point happens?*

In general, we have detected that green premium is periodic and changes from the positive value to negative and opposite. These changing points of moving from positive to negative and opposite are in 87th and 113th weeks. However, we could not detect particular extremums points to answer when turning points happens (in terms when green premium start to fall or increase) as far we could not detect an equation which will describe green premium's behavior with a reasonable degree of accuracy. However still we can argue that research questions were answered.

Further, based on literature review result we have formulated the following hypothesis for analysis:

H1: Green Premium exists in comparison with conventional bonds, ceteris paribus.

H2: Green premium of GBs is non constant over its life cycle.

H3: There exists linear relation between green premium and liquidity for GBs.

Hypothesis 1 and Hypothesis 2 were accepted after Gaussian smoothing analysis and results were tested for robustness via polynomial approximation. Thus, we can argue that green premium exists, and it is periodic. Hypothesis 3 was not accepted as far we could not detect linear relation between green premium and liquidity of GBs, however via Granger test we have identified that there exists causal relation between green premium and "green" liquidity. This fact may us argue that liquidity does not drive yields of GBs but in opposite higher yields of GBs predict changes in GBs liquidity. This is very important outcome as it proves the idea that green

premium is a result of behavioural effects from investors attitude to GBs but not just a market rules where higher liquidity decreases yields and vice versa.

In general, we can say that the main goal of this research was achieved. However, we can detect several limitations on research results. First, during the liquidity analysis we based in on bid-ask spread analysis without considering volumes of trading. We were limited because significant portion of deals are presented in OTC market from which we do not have an opportunity to obtain respective information. Second, our research methodology did not give u an opportunity to measure green premium in a particular value (% or bps) as far our analysis focused on means or polynomial approximation without successful attempts to describe our data with more or less consistent equation for regression analysis. Finally, our analysis was framed by 260 weeks or 5 years interval. We did not take into account GBs with issuance date earlier than 2015 year deliberately as far 2012-2015 years can be characterized as period of becoming for GBs market and tendencies and dynamic during this period could bend our results to the area of lack investors trust to GBs and too low prices of bonds with extremely high yields.

From the limitations mentioned above we can formulate some areas for the future topic development. First, as far we proved that green premium is periodic, it would be useful for practitioners to understand when premium changes it's direction (from increase to decrease). Identification of this extremums will help to speculative investors to understand the most appropriate periods for buying/selling GBs and creation the most profitable trading strategy. However, identification of these extremums is impossible without approximation of green premium dynamic via equational form. It is the second area for development: to understand how the process can be described based on non-linear character of its dynamic in the equational form. Thus, it would be possible to forecast green premium for each particular observation.

APPENDIX 1: RESEARCH ON THE TOPIC

In the table below we consolidate the main research on the topic, which studied GBs premium and their determinants and the main results of these research.

Paper	Main results
Bachelet, M., Becchetti, L., & Manfredonia, S. (2019). The Green Bonds Premium Puzzle: The Role of Issuer Characteristics and Third-Party Verification. Sustainability (11).	In general, GBs have higher yields, higher liquidity and lower volatility in comparison with conventional bonds. Positive green premium was from 2.06 to 5.9 BPS in the overall sample. The authors have found that private issuers GBs without third-party certification have significantly higher premium and lower liquidity.
C. Partridge, F. M. (2020). The evolution of pricing performance of green municipal bonds. Journal of Sustainable Finance & Investment, 10 (1), 44-64.	In general, when we are talking about liquidity, GBs are traded slightly less active, then vanilla bonds. There was identified signal of premium for greenness from yield analysis and benchmark analysis. For the secondary market was identified statistically significant green premium at 4 BPS. For the primary market there was not detected any statistically significant differences.
Karpf, A. M. (2018). The changing value of the 'green' label on the US municipal bond market. Nature Clim Change, 8, 161–165.	The GBs curve is below then for conventional bonds. Green bonds on average pay lower interest rate and that is why providing better financial conditions than conventional bonds. Also it was identified that the spread between GBs and CBs widens with the maturity. However, further analysis did not confirm the assumption that this better conditions can be explained by the nature of GBs.
Larcker, D. F. (2019). Where's the Greenium? SSRN Electronic Journal.	It was identified, that investors are not willing to pay premium to support eco-friendly projects. The difference in yields of GBs and non-green bonds was 0.45 BPS (a slight GBs discount). In general, 85% of observations had zero differential yield. Also, it was identified, that in average the underwriting premium was higher for the certified GBs than for non-green bonds (about 10%). Moreover, there were not observed any difference in liquidity level between GBs and non-green bonds.
M. Nanayakkara, S. C. (2019). Do investors in Green Bond market pay a premium? Global evidence. Applied Economics, 51 (40), 4425-4437.	The results showed that GBs are traded with the premium in comparison with CBs (with a tighter spread of 6.7 BPS). The bonds denominated in local currency tighten the credit spread by 5.6 BPS, compared with a bond denominated in foreign currency. Also, the authors have found positive relations between market risk and OAS, what confirms the hypothesis 5. Moreover, there was identified that 1% increase in US treasury rate will lead to increase of OAS in 1.4 BPS, what confirms H6 (there is no substitution effect).
Q. Wang, Y. Z. (2019). Research on the Factors Affecting the Risk Premium	Green certification has a negative influence on the GBs risk premium. The greater the amount of GBs issuance the higher liquidity of these GBs and lower risk premium. Debt rating has negative correlation with GBs risk premium: the higher

of China's Green Bond Issuance. Sustainability, 11, 63-94.	the rating the lower risks are associated with the bond. The maturity characteristic showed negative correlation with the GBs premiums. The longer maturity the higher level of confidence in the issuer and smaller risk premium
S. Hyuna, D. P. (2020). The price of going green: the role of greenness in green bond markets. Accounting & Finance, 60 , 73–95.	The fact, that the issuer has independent reviewer and a CBI certificate, statistically significant reduces the green bond premium by 6 and 15 BPS respectively. This mean that additional greenness information reduces risks associated with the issuer and reduces investor's information costs. There is no statistically significant difference in bid ask spread between groups (GBs and CBs), however, green bonds have lower coupon rate and issuing amount.
Zerbib, O. (2019). The effect of pro-environmental preferences on bond prices: Evidence from green bonds. Journal of Banking & Finance, 98, 39-60.	In average, the green bond premium is -2.3 BPS. EUR-denominated green bonds have -1.7 BPS premium and USD-denominated green bonds have -2.3 BPS premium. Green bonds with rating AAA on average have premium in -2.9 BPS. Statistically significant difference for other ratings were not detected. Maturity, issue amount and currency do not have any significant influence on the premium value.

APPENDIX 2: DATA DESCRIPTIVE STATISTICS

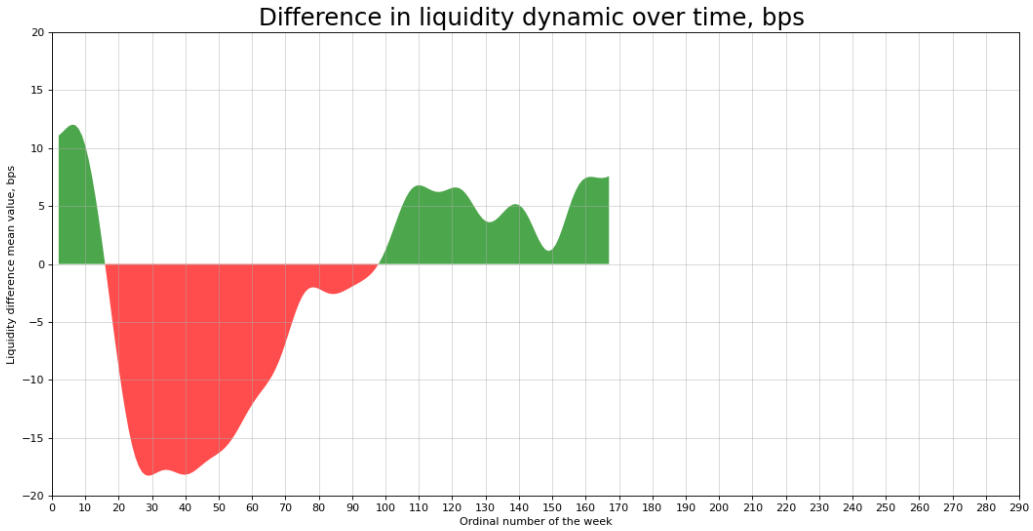
	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Bid_price...	1	33629	102.72	5.17	102.01	102.34	2.97	10.00	135.67	125.67	-2.19	62.32	0.03
Ask_price...	2	33540	103.31	5.27	102.50	102.77	2.94	85.00	200.00	115.00	5.62	82.01	0.03
Bidask_spread..bps	3	33513	59.49	438.41	28.20	37.13	26.98	0.08	16000.00	15999.92	30.97	1008.46	2.39
Avg_price...	4	33540	103.02	4.74	102.22	102.56	2.93	55.50	150.45	94.95	1.46	13.23	0.03
Current.coupon.rate...	5	33629	0.94	0.68	0.75	0.85	0.56	0.01	5.24	5.23	1.31	2.15	0.00
Bid.YTM...	6	33610	0.50	0.81	0.38	0.41	0.60	-0.77	38.16	38.93	10.66	383.06	0.00
Ask.YTM...	7	33534	0.40	0.83	0.29	0.33	0.61	-44.75	4.36	49.11	-11.76	570.12	0.00
Mduration	8	33537	6.74	4.66	6.15	6.17	3.21	0.17	40.18	40.00	3.73	20.70	0.03
G.spread..bps	9	27236	68.60	60.04	61.44	63.87	36.35	-2726.75	1529.91	4256.66	0.82	545.57	0.36

Pic. 25. *Descriptive statistics of GBs*

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Bid_price	1	33286	102.36	5.75	101.61	101.81	2.50	10.01	140.76	130.75	-1.60	34.79	0.03
Ask_price	2	33039	103.33	6.84	102.07	102.39	2.32	88.89	200.00	111.11	7.51	95.20	0.04
Bidask_spread	3	32823	95.75	780.32	35.00	43.97	34.99	0.01	16000.00	15999.99	19.96	399.77	4.31
Avg_price	4	33039	102.85	4.99	101.86	102.12	2.35	80.00	141.08	61.08	2.12	7.50	0.03
Current.coupon.rate...	5	32899	0.95	1.06	0.70	0.73	0.67	0.01	4.60	4.59	1.92	3.35	0.01
Bid.YTM...	6	33273	0.48	1.22	0.30	0.36	0.60	-4.54	47.31	51.85	12.62	247.40	0.01
Ask.YTM...	7	33028	0.30	0.98	0.18	0.25	0.62	-31.42	3.30	34.73	-7.04	124.64	0.01
Mduration	8	33140	6.00	2.86	5.65	5.81	3.07	0.92	20.10	19.19	0.92	1.71	0.02
G.spread..bps	9	26533	64.80	44.59	57.46	60.84	34.11	-1037.78	334.18	1371.96	-1.67	34.57	0.27

Pic. 26. *Descriptive statistics of CBs*

APPENDIX 3: GAUSSIAN SMOOTHING OF LIQUIDITY: FULL PERIOD REPRESENTATION



Pic. 27. *Gaussian smoothed liquidity on the whole period of time observations*

APPENDIX 4: FIXED- AND RANDOM - EFFECTS ESTIMATION OF RELATION BETWEEN GREEN PREMIUM AND LIQUIDITY

Fixed-effects estimation

	Dependent variable:
	diff_yld
diff_liq	-0.0001***
	(0.00002)
Observations	3,929
R^2	0.005
Adjusted R^2	-0.010
F Statistic	19.086*** (df = 1; 3871)
Note:	*p<0.1; **p<0.05; ***p<0.01

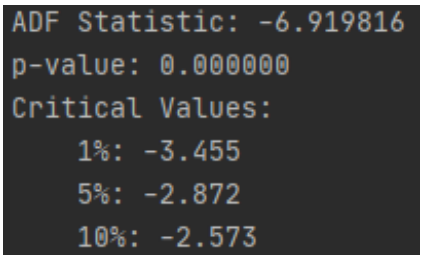
Pic. 28. *Fixed effect estimation of green premium dependence on difference in bid-ask spreads*

Random Effect estimation

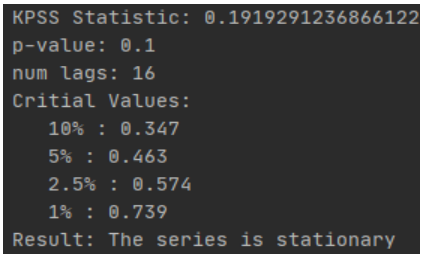
	Dependent variable:
	diff_yld
diff_liq	-0.00001
	(0.00001)
Constant	-0.002
	(0.002)
Observations	3,872
R^2	0.0001
Adjusted R^2	-0.0002
F Statistic	0.384 (df = 1; 3870)
Note:	*p<0.1; **p<0.05; ***p<0.01

Pic. 29. *Random effects estimation of green premium dependence on difference in bid-ask spreads*

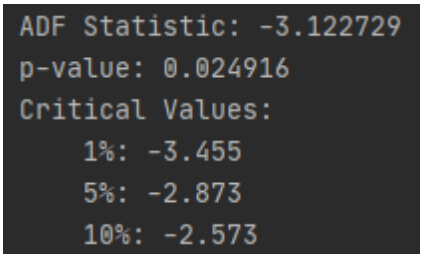
APPENDIX 5: GRAINGER TEST CALCULATION: STATIONARITY TESTS, CHOICE OF VAR, GRAINGER TEST



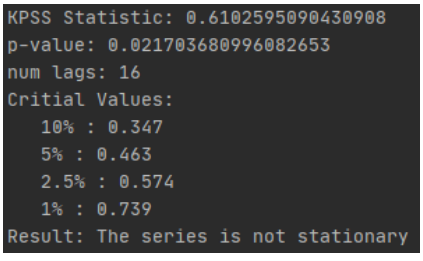
Pic. 30. *ADF test for liquidity before differencing*



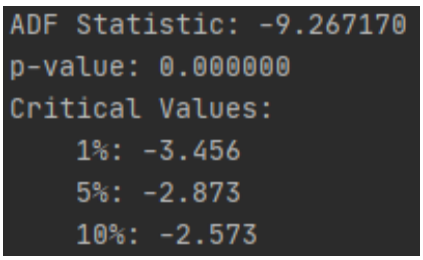
Pic. 31. *KPSS test for liquidity before differencing*



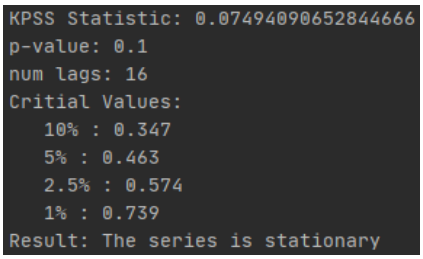
Pic. 32. *ADF test for green premium before differencing*



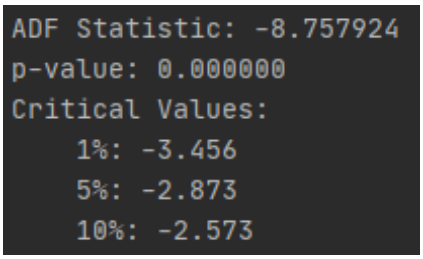
Pic. 33. *KPSS ADF test for green premium before differencing*



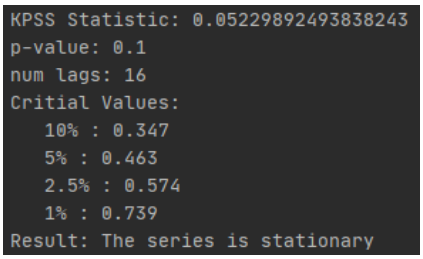
Pic. 34. *ADF test for liquidity after differencing*



Pic. 35. *KPSS test for liquidity after differencing*



Pic. 36. *ADF test for difference green premium after differencing*



Pic. 37. *KPSS test for difference green premium after differencing*

```
Lag Order = 1
AIC :  4.266310560937087
BIC :  4.346705791844046
FPE :  71.25838036008285
HQIC:  4.298601120641141

Lag Order = 2
AIC :  4.118008633955941
BIC :  4.2523625162930285
FPE :  61.437315323892925
HQIC:  4.171977695835437

Lag Order = 3
AIC :  4.063118919133581
BIC :  4.251723988016828
FPE :  58.15682425900056
HQIC:  4.13888893585037

Lag Order = 4
AIC :  4.067135207972158
BIC :  4.310286667850468
FPE :  58.39250106600796
HQIC:  4.164829747028019

Lag Order = 5
AIC :  4.065863170596498
BIC :  4.363858929192024
FPE :  58.32085346739603
HQIC:  4.185606928192058

Lag Order = 6
AIC :  4.080115261918122
BIC :  4.433255964718965
FPE :  59.16182739819054
HQIC:  4.222034077028651

Lag Order = 7
AIC :  4.088684725635954
BIC :  4.49727379095211
FPE :  59.67632831714706
HQIC:  4.252905594308087

Lag Order = 8
AIC :  4.103127913933532
BIC :  4.567471568527294
FPE :  60.5516846613916
HQIC:  4.289779003807078

Lag Order = 9
AIC :  4.128077955555689
BIC :  4.648485270857958
FPE :  62.090932259328895
HQIC:  4.337288620614745

Lag Order = 10
AIC :  4.151851910870984
BIC :  4.728634839795233
FPE :  63.5969456958158
HQIC:  4.383752706428706

Lag Order = 11
AIC :  4.168551328450462
BIC :  4.802024742816332
FPE :  64.68313426395484
HQIC:  4.423274026371892

Lag Order = 12
AIC :  4.159675775109431
BIC :  4.850157503688267
FPE :  64.12986161572222
HQIC:  4.437353379276912
```

Pic. 38. *Detection of the best model for VAR model during Granger testing*

	diff_mid_yld_x	liquid_x
diff_mid_yld_y	1.0	0.1645
liquid_y	0.0	1.0000

Pic. 39. *Granger test results*

APPENDIX 6: PORTFOLIO STRATEGY CALCULATIONS RESULTS

Strategy 1																										
ISIN	BE0002	CA6832	CA7481	CH0373	CH0387	DE000B	DE000B	DE000B	DE000C	DE000D	DE000L	DE000N	DE000N	DE000N	DE000N	DE000N	FR0012	FR0013	FR0013	FR0013	FR0013	LT0000	LT0000	LT0000	LV0000	**Total profit**
T0 purchase value, EUR	39 994	40 287	40 634	40 226	40 070	39 958	39 466	39 941	39 913	40 016	39 990	38 863	39 901	39 511	39 357	40 055	35 136	40 863	39 665	40 216	39 813	40 425	39 906	39 903	40 434	
Current life cycle, weeks	143	219	202	152	175	155	180	237	128	131	173	268	268	229	186	143	268	268	268	215	133	170	170	170	174	
Real yearly coupons, EUR	350	780	660	100	100	600	450	200	500	200	80	200	350	150	200	300	250	700	450	80	200	480	160	320	520	
T1 selling value, EUR	41 264	41 356	40 619	41 294	41 536	43 647	42 355	40 666	41 482	40 882	40 199	41 617	42 805	41 616	42 031	42 957	42 284	47 878	41 134	40 271	41 577	43 829	40 801	42 021	41 253	
Profit	2 232	4 355	2 549	1 361	1 803	5 478	4 446	1 636	2 799	1 370	475	3 785	4 707	2 766	3 389	3 727	8 437	10 622	3 788	386	2 275	4 973	1 418	3 164	2 559	**84 500**

Strategy 2																										
ISIN	BE000 260280	CA683 23ADL	CA748 148RW	CH037 347667	CH038 787903	DE000 BHY0G	DE000 BHY0G	DE000 BHY0G	DE000 CZ40N	DE000 DDA0N	DE000 LB1M2	DE000 NRW0	DE000 NWB0	DE000 NWB0	DE000 NWB0	DE000 NWB0	FR0012 685691	FR0013 054897	FR0013 067170	FR0013 239985	FR0013 365376	LT0000 610305	LT0000 650046	LT0000 670036	LV0000 802353	**Total profit**
T0 purchase value, EUR	39 994	40 287	40 634	40 226	40 070	39 958	39 466	39 941	39 913	40 016	39 990	38 863	39 901	39 511	39 357	40 055	35 136	40 863	39 665	40 216	39 813	40 425	39 906	39 903	40 434	
Current life cycle, weeks	123	199	182	132	155	135	160	217	108	111	153	248	248	209	166	123	248	248	248	195	113	150	150	150	154	
Real yearly coupons, EUR	350	780	660	100	100	600	450	200	500	200	80	200	350	150	200	300	250	700	450	80	200	480	160	320	520	
T1 selling value at 100th week, EUR	38 657	39 147	39 937	41 584	43 114	43 717	42 950	39 970	40 779	40 579	40 541	40 780	41 296	39 329	41 320	42 536	38 174	41 844	42 139	40 577	41 297	43 593	40 718	42 072	41 979	
Coupons earned, EUR	828	2 985	2 310	254	298	1 558	1 385	835	1 038	427	235	954	1 669	603	638	710	1 192	3 338	2 146	300	435	1 385	462	923	1 540	
T2 purchase value at 113th week, EUR	41 238	40 367	40 195	40 983	42 250	43 146	42 675	40 069	41 562	40 944	38 875	40 496	40 536	40 101	41 760	43 536	39 086	25 285	41 357	40 775	43 813	43 201	40 492	41 386	41 809	
T3 selling value, EUR	41 264	41 356	40 619	41 294	41 536	43 647	42 355	40 666	41 482	40 882	40 199	41 617	42 805	41 616	42 031	42 957	42 284	47 878	41 134	40 271	41 577	43 829	40 801	42 021	41 253	
Profit	-484	2 835	2 037	1 923	2 628	5 818	4 549	1 460	1 824	928	2 111	3 992	5 333	1 937	2 872	2 612	7 428	26 912	4 397	157	-318	5 179	1 582	3 728	2 528	**93 968**
Strategy 2 profit is higher by		11%																								

Pic. 40. *Portfolio strategy calculation results*

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