

DETERMINANTE KRETANJA S&P GREEN BOND INDEX-A: EMPIRIJSKA ANALIZA UTICAJA S&P MUNICIPAL BOND INDEX-A I PRINOSA NA AMERIČKE DRŽAVNE OBVEZNICE

Prof. Almir Alihodžić, redovni profesor, Ekonomski fakultet Univerziteta u Zenici,
imejl: almir.dr2@gmail.com
ORCID: <https://orcid.org/0009-0007-7082-1487>

Rezime: Zelene obveznice predstavljaju jedan od najznačajnijih instrumenata održivog finansiranja i imaju sve važniju ulogu u mobilizaciji kapitala za ekološke i klimatske projekte. Cilj ovog istraživanja je analizirati uticaj prinosa municipalnih obveznica i prinosa na desetogodišnje američke državne obveznice na prinose zelenih obveznica u SAD-u tokom perioda: 2016 – 2025. godine. U istraživanju su korišćeni podaci o indeksima S&P Green Bond Index, S&P Municipal Bond Index te prinos na desetogodišnje američke državne obveznice (U.S. 10Y Treasury Yield). Metodološki okvir obuhvata deskriptivnu statistiku, korelacionu analizu, regresionu analizu primenom metode najmanjih kvadrata (OLS), Augmented Dickey – Fuller (ADF) test stacioniranosti i Engle – Granger test kointegracije. Rezultati istraživanja ukazuju na statistički značajnu pozitivnu povezanost između S&P Green Bond Index-a i S&P Municipal Bond Index-a, dok prinos na desetogodišnje američke državne obveznice ostvaruje statistički značajan negativan uticaj na prinose zelenih obveznica. Engle-Granger test potvrdio je postojanje dugoročne ravnotežne veze (kointegracije) između analiziranih varijabli. Dobijeni rezultati ukazuju na značaj tradicionalnih tržišta obveznica i kretanja kamatnih stopa u objašnjenju performansi tržišta zelenih obveznica.

Ključne reči: Zelene obveznice, municipalne obveznice, američke državne obveznice, kointegracija, OLS regresija, održive finansije.

JEL klasifikacija: G12, G15, Q56

Uvodna razmatranja

Zelene obveznice su donedavna inovacija u održivim finansijama. Dakle, zelene obveznice su dužnički instrumenti čiji je prihod namenjen finansiranju projekata sa niskom emisijom ugljenika, prihvatljivih za klimu. Emitenti zelenih obveznica su korporacije, opštine, vladini subjekti, i nadnacionalne institucije. U ovom radu termin „municipalne obveznice“ koristi se za obveznice koje izdaju savezne države, lokalne jedinice vlasti i njihove agencije u Sjedinjenim Američkim Državama. Radi terminološke doslednosti, ovaj termin koristi se u celom radu. Takođe, može se reći da zelene municipalne obveznice predstavljaju nov način da se otključaju finansije za ulaganja u održivu i urbanu infrastrukturu u SAD. Emisija zelenih obveznica kasni zbog negativnih percepcija viših troškova, nižih prinosa i većeg rizika (Chiang, 2017). Zelene obveznice su u suštini identične redovnim municipalnim obveznicama kako po strukturi, riziku i prinosu. Snažna investiciona potražnja za zelenim obveznicama može omogućiti emitentima da se finansiraju uz niže troškove kapitala, jer povećana potražnja smanjuje zahtevani prinos investitora (Zerbib, 2019).

Zelene obveznice se u nekim situacijama porede sa klimatskim obveznicama (engl. Climate Bonds). I pored toga da se u pojedinim situacijama ove dve vrste obveznica mogu izjednačiti, ipak zelene obveznice predstavljaju širi pojam. Sredstva prikupljena emisijom klimatskih obveznica usmerena su pre svega na smanjenje emisije ugljen-dioksida, te ublažavanje i otklanjanje negativnih efekata klimatskih promena, dok zelene obveznice mogu biti usmerene na sve projekte sa pozitivnim implikacijama na životnu sredinu. Dakle, zelene obveznice su instrumenti posvećeni održivosti, poništenju negativnih efekata klimatskih promena i ekološki orijentisanim projektima. Kako zajmovi koje daju finansijske institucije predstavljaju u većini zemalja najvažniji izvor finansiranja, s tim u vezi obveznice imaju značajnu ulogu u finansiranju i refinansiranju kreditnih aktivnosti finansijskih institucija. U poslednje vreme izdavanje od strane finansijskih institucija je u stalnom porastu. Veliki porast emisija zelenih obveznica u 2016. godini, proizišao je iz velikog obima emisija banaka u Kini, gde su zelene obveznice banaka činile oko 76% ukupnog iznosa kineskih emisija u datoj godini. Na osnovu procene OECD – a izdavanje zelenih obveznica finansijskog sektora ima potencijal da nastavi značajan rast u vrednosti od preko 1,7 biliona dolara do 2035. godine (Janković, 2024).

Oblasti na koje se usmerava emisija zelenih obveznica su sledeće: uvećanje energetske efikasnosti, smanjenje postojećeg i prevencija budućeg zagađenja, održivo šumarstvo, poljoprivredu i ribarstvo, zaštita ekosistema na kopnu i u vodi, ekološki vid transporta i saobraćaja, prečišćavanje i održivo upravljanje vodama, itd. (Janković, 2024) Slika 1 prikazuje ključne oblasti zelenog investiranja.

Slika 1: Ključne oblasti zelenog investiranja



IZVOR: Janković, I. (2024). Zelene obveznice, Univerzitet u Beogradu – Ekonomski fakultet, Centar za izdavačku delatnost, str. 22.

Privlačnost zelenih obveznica u velikoj meri proizilazi iz njihove jednostavnosti u pogledu strukture, ključnih elemenata i postupaka koji definišu ovu vrstu dužničkih hartija od vrednosti, te stoga bi trebalo da omoguće jasan i transparentan prenos informacija do investitora u vezi sa korišćenjem sredstava prikupljenih njihovom emisijom i njihovim ekološkim karakteristikama. Formalno posmatrano, proces izdavanja zelenih obveznica je vrlo sličan izdavanju klasičnih obveznica, gde zelene obveznice podležu istim propisima i zahtevima koji se tiču pravnog okvira i prateće dokumentacije kao i finansijskog izveštavanja. Ono što čini dodatak je da prilikom izdavanja zelene obveznice od emitenta se očekuje da će uključiti u procedure i prateći Okvir zelenih obveznica koji obezbeđuje dodatne informacije i procedure usmerene na uveravanje investitora o ekološki usmerenoj upotrebi prikupljenih finansijskih sredstava (Janković, 2024).

Iako je u dosadašnjoj literaturi značajna pažnja posvećena karakteristikama i performansama zelenih obveznica, ograničen broj istraživanja analizira međusobni odnos tržišta zelenih i municipalnih obveznica uz istovremeno uključivanje promena kamatnih stopa kao makroekonomskog faktora. Posebno su retka istraživanja koja koriste tržišne indekse kao reprezentativne pokazatelje kretanja ovih segmenata tržišta kapitala. Cilj ovog istraživanja je ispitati odnos između S&P Green Bond Index-a i S&P Municipal Bond Index-a, te analizirati uticaj prinosa na desetogodišnje američke državne obveznice na kretanje vrednosti indeksa zelenih obveznica. U istraživanju se primenjuju deskriptivna statistika, korelaciona analiza, OLS regresija, i Engle-Granger test kointegracije. U skladu sa definisanim ciljem istraživanja, u radu se razmatraju sledeća istraživačka pitanja:

1. Da li S&P Municipal Bond Index značajno utiče na dnevne vrednosti S&P Green Bond Index-a?
2. Da li prinos na desetogodišnje američke državne obveznice značajno utiče na dnevne vrednosti S&P Green Bond Index-a?
3. Da li između analiziranih varijabli postoji dugoročna ravnotežna veza (kointegracija)?

Kako bi se odgovorilo na postavljena istraživačka pitanja, u empirijskom delu rada primenjene su odgovarajuće statističke i ekonometrijske metode, uključujući regresionu analizu, testove stacioniranosti i Engle-Grangerov test kointegracije, s ciljem ispitivanja kratkoročnih i dugoročnih odnosa između analiziranih varijabli.

Rad je strukturiran na sledeći način. Nakon uvodnih razmatranja, u drugom delu dat je pregled relevantne literature iz oblasti zelenih i municipalnih obveznica. Treći deo rada posvećen je analizi globalnih trendova na tržištu zelenih obveznica. U četvrtom delu prikazani su metodologija istraživanja, model i korišćeni podaci. Peti deo sadrži empirijske nalaze dobijene primenom deskriptivne statistike, korelacione i regresione analize, kao i testovi stacioniranosti i kointegracije. Na kraju rada iznešeni su zaključci, ključni nalazi istraživanja i njihove implikacije za investitore i kreatore ekonomskih politika.

Pregled relevantne literature

Početak poslednje decenije tržište zelenih obveznica beleži snažan rast usled povećane potrebe za finansiranjem projekata održivog razvoja i energetske tranzicije. Poseban značaj imaju municipalne zelene obveznice koje omogućavaju lokalnim zajednicama finansiranje ekoloških infrastrukturnih projekata. Dakle, zelene obveznice su finansijski instrumenti sa fiksnim prihodom koje se izdaju radi prikupljanja sredstava za ekološki prihvatljive projekte. Njihova svrha je internalizacija svih ekoloških eksternalija i podsticanje investicija u zelene projekte radi održivog razvoja (Ehlers i Packer, 2017). Državne zelene obveznice su relativno novi finansijski instrument osmišljen za prikupljanje kapitala za osnovne vladine infrastrukturne projekte koji su u skladu sa održivim programom. Ove obveznice takođe mogu smanjiti troškove kapitala za ekološki prihvatljive projekte. Međutim, izdavanje zelenih obveznica je obično skuplje od konvencionalnih obveznica zbog dodatnih administrativnih, pravnih i marketinških troškova (Doronzo i ostali, 2021). Pored toga, postoje dokazi da zelene obveznice imaju niži prinos od konvencionalnih obveznica prilikom emisije, poznat kao „premijska cena“ (engl. greenium) (Liaw, 2020). Istraživanje grinijuma posebno na tržištu suverenih zelenih obveznica je ograničeno, ali su Grzegorzcyk i Wolff (2022) ukazali na prisustvo malog i negativnog grinijuma na tržištu suverenih obveznica EU. Negativan grinijum znači da su investitori spremni da prihvate niži prinos na državne zelene obveznice u poređenju sa konvencionalnim obveznicama. Jedan od razloga za to je što zelene obveznice pružaju investitorima priliku da ulažu u zelene i održive projekte.

Larcker i Watts (2020) upoređivali su municipalne zelene obveznice sa ekvivalentnim običnim municipalnim obveznicama i otkrili su veoma mali popust na prinos bez dokaza koji podržavaju negativnu premiju na municipalne zelene obveznice. S tim u vezi, došli su do zaključka da je zelena premija de facto nula.

Istorijski gledano, zelene obveznice su bile kažnjene na tržištu municipalnih promena, trgujući se po nižim cenama i višim prinosima, nego što se očekivalo na osnovu njihovih kreditnih profila. Poslednjih godina, kreditni kvalitet municipalnih zelenih obveznica se povećao, a premija je postala pozitivna. S tim u vezi, zelene obveznice postaju sve atraktivnija investicija u cilju premošćavanja jaza u finansiranju klimatskih promena za ublažavanje i prilagođavanje.

Partridge i Medda (2020) analizirali su tržište zelenih municipalnih obveznica u SAD- u i pronašli preliminarne dokaze o postojanju greenium-a. Njihovi rezultati pokazuju da su investitori bili spremni prihvatiti nešto niže prinose na zelene municipalne obveznice u odnosu na uporedive konvencionalne municipalne obveznice. Autori zaključuju da takvi nalazi odražavaju rastuću potražnju za održivim investicijama te ukazuju na sve veću povezanost između tržišta zelenih i municipalnih obveznica.

Tang i Zhang (2020) analizirali su efekte emisije zelenih obveznica na finansijska tržišta koristeći uzorak kompanija iz 28 zemalja u periodu: 2007. – 2017. Njihovi rezultati su pokazali da tržište pozitivno reaguje na emisiju zelenih obveznica, dok se nakon emisije povećavaju institucionalno vlasništvo i likvidnost akcija, što potvrđuje rastući značaj zelenih finansijskih instrumenata na globalnom tržištu kapitala. Asness (2000) analizirao je odnos prinosa akcija i obveznica te objasnio premiju rizika na tržištu akcija.

Reboredo i Ugolini (2020) su među prvima koji su ispitivali vezu između zelenih obveznica i finansijskih tržišta. Autori su razmatrali model strukturne vektorske autoregresije (SVAR) i otkrili su da je tržište zelenih obveznica značajno povezano sa tržištem trezorskih zapisa i valuta. Takođe, su došli do zaključka da postoji slaba veza između zelenih obveznica i tržišta akcija i energije. Hammoudeh i ostali (2020) su takođe koristili pristup uzročnosti preko vremenske promenljive kako bi ispitali uzročnu vezu između tržišta zelenih obveznica i drugih finansijskih indikatora od 2016 do 2020. godine. Autori su došli do zaključka da su prinosi 10- godišnjih američkih trezorskih obveznica primarni faktor koji određuje prinose zelenih obveznica.

Pham i Nguyen (2021) su takođe istraživali zavisnost repa distribucije između zelenih obveznica i energetskih, akcijskih i tradicionalnih tržišta obveznica koristeći metod unakrsnog kvantilograma od oktobra 2014 do februara 2021. godine. Autori su dobili pomešane dokaze, jer se prelivanje između finansijskog i tržišta zelenih obveznica značajno menjalo u različitim kvantilima.

Flammer (2021) analizira korporativne zelene obveznice i utvrđuje da investitori pozitivno reaguju na njihovu emisiju. Takođe, rezultati istraživanja pokazuju da emitenti nakon emisije ostvaruju bolje ekološke performanse, smanjuje se emisija CO₂, te privlače dugoročni investitori, što potvrđuje značaj zelenih obveznica kao instrumenta održivog finansiranja.

Nguyen i Le (2025) analizirali su uticaj emisije zelenih obveznica na tranziciju prema obnovljivim izvorima energije u 192 zemlje tokom perioda: 2007– 2021. Rezultati istraživanja su pokazali da emisija zelenih obveznica značajno doprinosi finansiranju projekata obnovljive energije i ubrzaava energetsku tranziciju.

Sojoudi i ostali (2026) utvrdili su postojanje značajnog greenium-a na tržištu američkih municipalnih obveznica, pri čemu su investitori bili spremni prihvatiti niže prinose na zelene obveznice radi podrške ekološki održivih projekata. Autori takođe ističu da se intenzitet greenium-a menja kroz vreme i zavisi od karakteristika samih obveznica.

Pored toga novija istraživanja ukazuju na postojanje greenium-a na tržištu zelenih i municipalnih obveznica, što dodatno potvrđuje specifičnost tržišnog vrednovanja zelenih finansijskih instrumenata. Iako su prethodna istraživanja analizirala povezanost zelenih obveznica sa različitim segmentima finansijskog tržišta, rezultati prethodnih istraživanja nisu uvek jednoznačni, a nalazi se razlikuju u zavisnosti od posmatranog tržišta, vremenskog perioda i primenjene metodologije. Pored toga, prethodna istraživanja primenjivala su različite metodološke pristupe, uključujući panel analizu, modele vremenskih serija i druge ekonometrijske modele, dok se u ovom radu primenjuje kombinacija regresione analize, ADF testa stacionarnosti i Engle – Grangerovog testa kointegracije. Takav metodološki pristup omogućava ispitivanje kratkoročnih efekata S&P Municipal Bond Indexa i prinosa na desetogodišnje američke državne obveznice na performanse S&P Green Bond Indexa, kao i utvrđivanje postojanja dugoročne ravnotežne veze između analiziranih varijabli. Na osnovu pregleda relevantne literature, identifikovanog istraživačkog jaza i definisanog cilja istraživanja, formulisane su sledeće istraživačke hipoteze:

H1: Postoji dugoročna ravnotežna veza (kointegracija) između analiziranih varijabli.

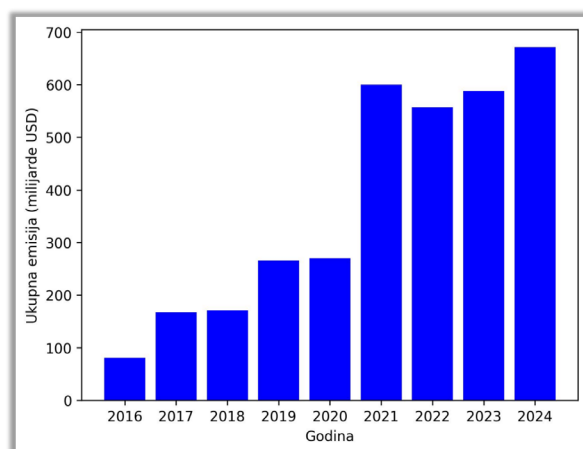
H2: Postoji statistički značajna veza između S&P Municipal Bond Index-a i S&P Green Bond Index-a.

H3: Postoji statistički značajan uticaj prinosa na američku 10 – godišnju državnu obveznicu na S&P Green Bond Index.

Globalni trendovi na tržištu zelenih obveznica

Prvu zelenu obveznicu emitovala je Evropska investiciona banka (EIB) 2007. godine, za finansiranje projekata obnovljive energije i energetske efikasnosti. Od tada, zelene obveznice postaju sve popularniji oblik finansiranja. Ilustracije radi, u 2008. godini, ukupna emisija zelenih obveznica bila je manja od milijardu dolara, da bi do kraja 2018. godine, skočila na 143 milijarde dolara. Ovaj trend stručnjaci iz prakse nazivaju bumom zelenih obveznica koji će se verovatno nastaviti u narednim godinama (Morgan Stanley, 2017). Takođe, mnogi komentatori vide zelene obveznice kao alat za rešavanje klimatskih promena. Rast značaja zelenih obveznica na globalnom finansijskom tržištu potvrđuje i kontinuirano povećanje vrednosti njihovih emisija, što prikazuje Slika 2.

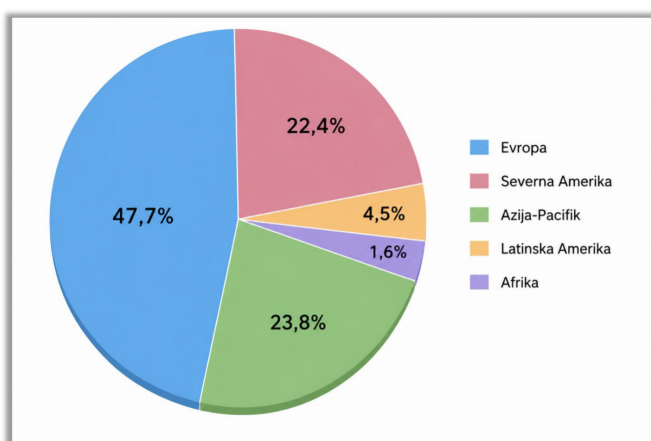
Slika 2: Vrednost emisija zelenih obveznica (u milijardama USD)



IZVOR: Climate Bonds Initiative. (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

Ukupna emisija zelenih obveznica u svetu povećana je sa oko 80 milijardi USD u 2016. godini na oko 670 milijardi USD u 2024. godini, što predstavlja povećanje za oko 737%. Značajan rast emisije zelenih obveznica u periodu od 2016. do 2024. godine, može se obrazložiti jačanjem regulatornog okvira u oblasti održivih finansija, rastućom potražnjom investitora za ESG instrumentima, aktivnijim učešćem država kroz izdavanje suverenih zelenih obveznica, povoljnijim uslovima finansiranja u periodu niskih kamatnih stopa pre 2022. godine. Takođe, povećana svest o klimatskim rizicima i potrebi energetske tranzicije usmerila je kapital prema projektima obnovljivih izvora energije, energetske efikasnosti i održive infrastrukture. Isto tako, standardizacija tržišta kroz razvoj međunarodnih principa i taksonomija dodatno je povećala kredibilitet i transparentnost tržišta što je doprinelo ubrzanom rastu ovog segmenta finansijskog tržišta.

Grafikon 1: Emisija zelenih obveznica prema regionu u 2024. godini (u %)



IZVOR: Climate Bonds Initiative (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

Regionalno posmatrano, Evropa u 2024. godini učestvuje sa 47,7% u ukupnoj globalnoj emisiji zelenih obveznica, dok Azija-Pacifik učestvuje sa 23,8%, Severna Amerika sa 22,4%, Latinska Amerika sa 4,5% i Afrika sa 1,6%. Ovi podaci pokazuju da Evropa, Azija-Pacifik i Severna Amerika zajedno učestvuju sa 93,9% ukupne globalne emisije zelenih obveznica, dok Latinska Amerika i Afrika imaju znatno manje učešće, što ukazuje na potencijal za dalji razvoj tržišta održivog finansiranja u tim regionima. Rast tržišta zelenih obveznica nije ravnomerno raspoređen među zemljama, već je koncentrisan u određenim razvijenim ekonomijama koje imaju značajnu ulogu u finansiranju projekata održivog razvoja. Radi detaljnijeg sagledavanja geografske distribucije tržišta zelenih obveznica, u Tabeli 1 prikazani su podaci o vrednostima emitovanih zelenih obveznica i njihovom procentualnom učešću po odabranim zemljama u prvom polugodištu 2024. godine.

Tabela 1: Emisija zelenih obveznica po zemljama u prvom polugodištu 2024. godine

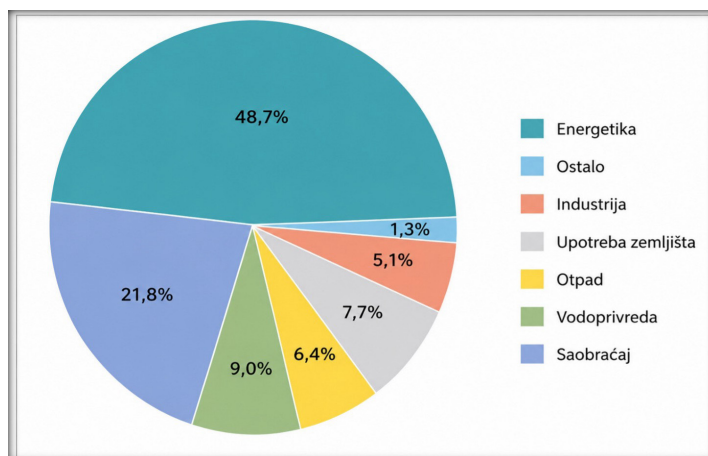
Naziv zemlje	Zelene obveznice (u mlrd USD)	Procentualno učešće
Japan	10,6	11,69%
Italija	12,1	13,35%
Francuska	11,6	12,80%
Australija	4,7	5,18%
Austrija	7,2	7,95%
Nemačka	14,0	15,45%
Kanada	2,9	3,20%
Rumunija	2,2	2,43%
Singapur	1,9	2,09%
Mađarska	1,6	1,77%
Island	0,8	0,88%
Kina	0,8	0,88%
Indija	1,2	1,32%
Velika Britanija	10,1	11,15%
Holandija	2,3	2,54%
Španija	2,1	2,32%
Belgija	1,7	1,87%
Novi Zeland	0,8	0,88%
Danska	0,6	0,66%
Irska	0,6	0,66%
Indonezija	0,5	0,60%
Švajcarska	0,2	0,22%
Peru	0,1	0,11%
Ukupno	90,6	100,00%

IZVOR: Climate Bonds Initiative. (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

Podaci prikazani u Tabeli 1 odnose se na odabrane zemlje emitente zelenih obveznica u prvom polugodištu 2024. godine, pri čemu kolona procentualno učešće predstavlja učešće pojedine zemlje u ukupnoj vrednosti emisija prikazanih u tabeli (90,6 mlrd USD). Prikazani podaci u Tabeli 1 ukazuju na značajnu koncentraciju emisija zelenih obveznica u razvijenim ekonomijama tokom prvog polugodišta 2024. godine. Najveći obim emisija zabeležen je u Nemačkoj (14,0 mlrd USD), Italiji (12,1 mlrd USD) i Francuskoj (11,6 mlrd USD) koje zajedno čine deo ukupne emisije zelenih obveznica. S druge strane, najmanje emisije evidentirane su u Peruu, Švajcarskoj i Indoneziji. Ovi podaci potvrđuju da je tržište zelenih obveznica dominantno razvijeno u ekonomski snažnijim zemljama koje aktivno promovišu održivo finansiranje i zelenu tranziciju.

Pored geografske distribucije emisija zelenih obveznica, značajno je analizirati i sektorsku usmerenost prikupljenih sredstava. Struktura emisije zelenih obveznica prema sektorima prikazana je na Grafikonu 2.

Grafikon 2: Sektorska raspodela globalne emisije zelenih obveznica u 2024. godini (u%)



IZVOR: Climate Bonds Initiative. (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

Sektorska raspodela emisije zelenih obveznica u 2024. godini, pokazuje dominantno učešće energetskeg sektora sa oko 49%, što potvrđuje ključnu ulogu investicija u obnovljive izvore energije i dekarbonizaciju. Takođe, značajan procenat ima i saobraćaj od oko 22%, dok su sektori poput vodoprivrede, upravljanja otpadom i upotreba zemljišta umereno zastupljeni. Ovakva struktura ukazuje da se kapital primarno usmerava ka sektorima sa najvećim potencijalom za smanjenje emisija i ubrzanje klimatske tranzicije.

Metodologija i podaci

Model

Metod običnih najmanjih kvadrata (eng. ordinary least squares - OLS) jedna je od najosnovnijih i najšire korišćenih tehnika procene u statistici i ekonometriji. On pruža relativno jednostavan, ali moćan metod za procenu odnosa među promenljivim, minimiziranjem zbira kvadrata reziduala, tj. razlike

između posmatranih i predviđenih vrednosti zavisne promenljive (Nosheen i ostali, 2025). Klasičan model linearne regresije pod OLS metodom pretpostavlja linearnost parametara, slučajno uzorkovanje, odsustvo savršene multikolinearnosti, egzogenost regresora i homoskedastičnost (Hansen, 2022). U cilju testiranja međusobnih odnosa između tržišta zelenih obveznica, tržišta konvencionalnih municipalnih obveznica i prinosa na desetogodišnje američke državne obveznice, u ovom istraživanju primenjen je model najmanjih kvadrata. Klein i Weill (2018) ukazuju da OLS regresija nije samo korisna metoda za opisivanje podataka, već i pružanje prve pristrasne procene koeficijenata.

U empirijskoj analizi korišćene su dnevne vrednosti S&P Green Bond Indexa i S&P Municipal Bond Indexa za period: 2016 – 2025., dok je prinos na desetogodišnje američke državne obveznice (U.S. 10 – Year Treasury Yield) korišćen kao zasebna objašnjavajuća varijabla. U istraživanju nisu korišćeni dnevni prinosi navedenih indeksa, već njihove dnevne vrednosti, što predstavlja osnovu za procenu modela i interpretaciju dobijenih rezultata. S&P Green Bond Index predstavlja reprezentativan pokazatelj širokog segmenta globalnog tržišta zelenih obveznica i obuhvata državne, supranacionalne, agencijske, korporativne, finansijske i municipalne zelene obveznice. Shodno tome, rezultati ovog istraživanja trebaju se tumačiti u kontekstu tržišta zelenih obveznica obuhvaćenih S&P Green Bond Indexom, te se ne mogu tumačiti isključivo u kontekstu zelenih municipalnih obveznica. Pored regresione analize primenom metode najmanjih kvadrata, u istraživanju su primenjeni Augmented Dickey-Fuller (ADF) test stacioniranosti i Engle – Granger test kointegracije. ADF test korišćen je za ispitivanje stacioniranosti i utvrđivanje reda integracije analiziranih vremenskih serija, dok je Engle-Granger test primenjen radi ispitivanja postojanja dugoročne ravnotežne veze između dnevnih vrednosti S&P Green Bond Index-a, S&P Municipal Bond Index-a i prinosa na desetogodišnje američke državne obveznice. Primena Engle-Granger testa opravdana je u slučaju kada su analizirane varijable integrisane istog reda, odnosno I(1). Svi statistički testovi provedeni su na nivou značajnosti od 5%.

Specifikacija modela definisana je na sledeći način:

$$GB_t = \alpha + \beta_1 MB_t + \beta_2 U.S.10Y_Y_t + \varepsilon_t$$

Gde je:

GB_t – dnevna vrednost S&P Green Bond Indexa;

MB_t – dnevna vrednost S&P Municipal Bond Indexa;

$U.S.10Y_Y_t$ – prinos na američku 10-godišnju državnu obveznicu;

β_1 i β_2 – predstavljaju regresione koeficijente;

ε_t – slučajna greška.

Svi proračuni obično koriste nivo značajnosti od 5%. Stoga je test značajnosti izvršen za sve promenljive korišćenjem t – testa na nivou značajnosti od 95% (Chmelarova, 2007).

Podaci

U ovom istraživanju korišćeni su sekundarni podaci prikupljeni iz relevantnih finansijskih baza podataka. Analiza se zasniva na dnevnim podacima za period od 29. januara 2016. godine do 31. decembra

2025. godine, što obuhvata ukupno 2.481 opservaciju. Kao zavisna varijabla korišćen je S&P Green Bond Index (GB), koji prati performanse globalnog tržišta zelenih obveznica čiji su prihodi namenjeni finansiranju projekata sa pozitivnim ekološkim efektima. Glavna nezavisna varijabla je S&P Municipal Bond Index (MB), koji predstavlja referentni pokazatelj performansi američkog tržišta municipalnih obveznica. Ovaj indeks obuhvata širok spektar obveznica koje emituju savezne države, lokalne zajednice i njihove agencije. Pored toga u model je uključena i druga nezavisna varijabla U.S. 10 - Year Treasury Yield (U.S.10Y), koja predstavlja prinos na desetogodišnje državne obveznice SAD-a i često se koristi kao referentna bezrizična kamatna stopa na finansijskim tržištima. Podaci za S&P Green Bond i S&P Municipal Bond Index preuzeti su iz baze podataka S&P Dow Jones Indices (2025), dok su podaci o prinosu na desetogodišnje američke državne obveznice preuzeti iz Federal Reserve Economic Data (FRED) baze podataka. Nakon usklađivanja datuma trgovanja formiran je jedinstveni skup podataka koji je korišćen za provođenje ekonometrijske analize.

Empirijski nalazi

Deskriptivna statistika

U cilju sagledavanja osnovnih karakteristika analiziranih varijabli, u Tabeli 2 prikazani su rezultati deskriptivne statistike prinosa S&P Green Bond Indexa, S&P Municipal Bond Indexa i prinosa na američku desetogodišnju državnu obveznicu.

Tabela 2: Deskriptivna statistika prinosa S&P Green Bond Indexa, S&P Municipal Bond Indexa i prinosa na američku desetogodišnju državnu obveznicu (U.S. 10-Year Treasury Yield) (%) za period: 29.01.2016.- 31.12.2025.

Opis	S&P Green Bond index	S&P Municipal Bond Index	U.S.10Y_Y
Srednja vrednost	0,00981	0,00954	0,0738
Medijana	0,01573	0,01688	0,000
Standardna devijacija	0,21507	0,21989	2,9384
Max	1,1112	3,3943	40,740
Min	-1,5517	-2,5897	-27,027
Mera asimetrije	-0,4674	-0,4804	1,4053
Spljoštenost	7,7804	62,068	39,309
Verovatnoća	0,000	0,000	0,000
Broj opservacija	2.481	2.481	2.481

IZVOR: Proračun autora na osnovu podataka preuzetih sa:
<https://www.spglobal.com/spdji/en/index-family/fixed-income/us-municipal/#overview>

Rezultati prikazani u Tabeli 2 pokazuju da S&P Green Bond Index i S&P Municipal Bond Index imaju vrlo slične prosečne vrednosti prinosa tokom posmatranog perioda. Nasuprot tome, prinos na američku desetogodišnju državnu obveznicu beleži nešto višu prosečnu vrednost i veću volatilnost, što ukazuje na različitu dinamiku kretanja u odnosu na tržište zelenih i municipalnih obveznica. Ovakav rezultat upućuje na postojanje klasičnog odnosa između prinosa i rizika na finansijskim tržištima. Drugim rečima, viši prinos na desetogodišnje američke državne obveznice predstavlja kompenzaciju investitorima za preuzimanje kamatnog i inflacionog rizika, koji su izraženiji kod dugoročnih dužničkih instrumenata. Promene u monetarnoj politici, posebno kretanje referentnih kamatnih stopa i inflaciona očekivanja, značajno utiču na volatilnost prinosa ovih obveznica, što se odražava kroz veću standardnu devijaciju. Ovakav rezultat potvrđuje ulogu prinosa na desetogodišnje američke državne obveznice kao referentne bezrizične kamatne stope na globalnom finansijskom tržištu, čije promene utiču na vrednovanje i atraktivnost različitih segmenata tržišta obveznica.

Posmatrano sa druge strane, niži prinosi i manja kolebljivost zelenih i municipalnih obveznica mogu se objasniti karakteristikama ovih tržišta. Municipalne obveznice uglavnom uživaju poreske olakšice, dok kod zelenih obveznica postoji stabilna i rastuća potražnja investitora motivisanih ESG principima, što doprinosi relativno stabilnijim kretanjima prinosa. Slične prosečne vrednosti prinosa i relativno niska volatilnost ukazuju na mogućnost postojanja dugoročne povezanosti između tržišta zelenih i municipalnih obveznica, što će biti dodatno ispitano primenom Engle-Granger testa kointegracije. Meszaros i ostali (2023) su istražili svojstva volatilnosti zelenih suverenih obveznica evropskih malih otvorenih ekonomija za period između 2016. i 2021. godine, sa akcentom razlika između zelenih suverenih obveznica i konvencionalnih suverenih obveznica tokom posmatranog perioda. Oni su posmatrali tržišta u dve zemlje članice EU tj. Poljsku i Mađarsku te uporedili sa zrelim tržištem Nemačke kao referentnom zelenom tržištu. Rezultati studije su pokazali da zelene suverene obveznice imaju veću volatilnost od tradicionalnih što ukazuje na to da je tržište još uvek sumnjičavo u ovom mladom stanju, te da je ova imovina više reagovala na šokove. Međutim, ove razlike nisu bile toliko velike, što dalje znači da dublje tržište zelenih obveznica može imati slične statističke karakteristike kao tradicionalno tržište.

Tabela 3: Proračun godišnjih prinosa S&P indeksa municipalnih obveznica, S&P indeksa zelenih obveznica i prinosa na desetogodišnje državne američke obveznice za period: 2016.- 2025. godine (u%)

Godina	S&P Municipal Bond Index	S&P U.S. Green Bond Index	U.S.10Y_Y
2016.	0,55%	-0,30%	1,82%
2017.	4,82%	6,56%	2,33%
2018.	1,35%	0,26%	2,91%
2019.	6,89%	8,07%	2,14%
2020.	4,97%	4,77%	0,89%
2021.	1,71%	2,26%	1,45%
2022.	-8,32%	-11,92%	2,95%
2023.	5,64%	6,61%	3,96%
2024.	1,92%	1,41%	4,21%
2025.	4,13%	6,75%	4,29%
Prosek	2,37%	2,45%	2,69%

IZVOR: Proračun autora

Iz prethodne tabele je evidentno da je indeks municipalnih obveznica imao najnižu stopu prinosa u 2022. godini (-8,32%), najvišu stopu prinosa u 2019. godini od oko 6,89% te prosečnu stopu od oko 2,37%. Za razliku od indeksa municipalnih obveznica, berzanski indeks konvencionalnih zelenih obveznica je najnižu vrednost prinosa zabeležio u 2022. godini (-11,92%), najveću vrednost prinosa je ostvario u 2019. godini od oko 8,07%, te prosečnu vrednost od oko 2,45%. Najveća stopa prinosa na desetogodišnje državne američke obveznice je ostvarena u 2025. godini oko 4,29%, najniža vrednost je zabeležena u 2020. godini (0,89%) i prosečna vrednost od oko 2,69%.

Prinos na desetogodišnje državne američke obveznice reflektuje očekivanja investitora u pogledu buduće inflacije i kretanja referentnih kamatnih stopa. U periodima izražene inflacije i restriktivne monetarne politike, kao što je bio slučaj u posmatranom periodu, dolazi do rasta prinosa na državne obveznice, jer investitori zahtevaju višu kompenzaciju za gubitke realne vrednosti novca. I pored toga što su u tabeli 3 prikazane neznatne razlike u prosečnim prinosima između S&P Municipal Bond Index i S&P Green Bond Index, statistički testovi brojnih autora nisu potvrdili postojanje značajnog prinosnog popusta ili premije cena (engl. greenium) za zelene obveznice. Janković i ostali (2022) su otkrili vrlo mali popust na prinos municipalnih zelenih obveznica i zaključili su da je zelena premija faktički jednaka nuli. Kako nema značajnih razlika u prinosima zelenih i konvencionalnih obveznica, investitori mogu odlučiti u koju obveznicu investirati na osnovu drugih faktora kao što su etički ili ekološki faktori, kao i rizik i likvidnost. Navedeni nalazi ukazuju da tržišta zelenih i municipalnih obveznica pokazuju slične karakteristike prinosa, što opravdava dalje ispitivanje njihove međusobne povezanosti primenom korelacione, regresione i kointegracione analize.

Korelaciona analiza

U cilju preliminarne ispitivanja međusobnih odnosa između S&P Green Bond Index-a, S&P Municipal Bond Index-a i prinosa na desetogodišnje američke državne obveznice, primenjena je Pearsonova korelaciona analiza. Korelaciona analiza omogućava identifikovanje smera i intenziteta linearne povezanosti između posmatranih varijabli. Prema Cohen-u (1988) ukoliko se koeficijent korelacije kreće od 0,10 do 0,29 onda je reč o maloj korelaciji. Takođe, ukoliko se koeficijent korelacije kreće od 0,30 do 0,49 onda je prisutna srednja korelacija. I ukoliko koeficijent korelacije poprima vrednosti od 0,50 do 1,0 onda je evidentno da je korelacija velika.

Tabela 4: Korelaciona analiza (Pearson koeficijent korelacije) između S&P indeksa zelenih obveznica, S&P indeksa municipalnih obveznica i prinosa na desetogodišnje državne američke obveznice za period: 2016.- 2025.

		S&P Green Bond U.S. Dollar Select Index	S&P Municipal Bond Index	U.S.10Y_Y
S&P Green Bond U.S. Dollar Select Index	Pearson Correlation	1,000	0,906	-0,069
	Sig. (2-tailed)	-	0,000	0,001
	N	2,481	2,481	2,481
S&P Municipal Bond Index	Pearson Correlation	0,906	1,000	0,203
	Sig. (2-tailed)	0,000	-	0,000
	N	2,481	2,481	2,481
U.S.10Y_Y	Pearson Correlation	-0,069	0,203	1,000
	Sig. (2-tailed)	0,001	0,000	1,000
	N	2.481	2.481	2.481

IZVOR: Proračun autora

Iz prethodne tabele je evidentno da Pearsonov koeficijent korelacije između S&P Green Bond i S&P Municipal Bond Index-a iznosi 0,906 što ukazuje na veoma jaku pozitivnu povezanost dnevnih promena prinosa između posmatranih indeksa, što sugerise da se posmatrani indeksi u velikoj meri kreću u istom smeru. Dobijeni rezultat ukazuje da promene prinosa na municipalne obveznice u velikoj meri prate promene prinosa na zelene obveznice, što potvrđuje visok stepen integrisanosti posmatranih tržišta. Dakle, ovi rezultati upućuju na zaključak da investitori koji razmatraju da ulažu u zelene municipalne obveznice mogu očekivati slične trendove kao i kod konvencionalnih municipalnih obveznica. I pored toga što zelene obveznice imaju specifičnu namenu za finansiranje ekoloških projekata, njihovo tržište je u velikoj meri integrisano sa tradicionalnim tržištem obveznica. Dobijeni rezultati su u skladu sa nalazima Gorelicka i ostalih (2024), koji ističu da zelene municipalne obveznice dele brojne karakteristike sa tradicionalnim municipalnim obveznicama, uključujući slične obrasce formiranja prinosa i ponašanja investitora. Mnoge zelene obveznice izdaju iste institucije koje izdaju i klasične obveznice, gde ih investitori posmatraju kao deo šireg tržišta fiksnog prihoda.

¹Predstavlja pojam u finansijama koji označava situaciju kada investitori prihvataju niži prinos na zelene obveznice u poređenju sa sličnim konvencionalnim obveznicama istog emitenta, ročnosti i rizika.

Inverzna veza između kamatnih stopa i cena obveznica potvrđena je u literaturi, gde se ističe da postoji negativan odnos između cene obveznice i kamatne stope (Litvinovs i Raiko, 2017). Dakle, rast kamatnih stopa povezan je sa padom cena obveznica što objašnjava negativnu korelaciju između prinosa na državne obveznice i vrednosti prinosa indeksa zelenih i municipalnih obveznica (-0,069). Iako je negativnog predznaka, intenzitet ove korelacije je nizak, što ukazuje da kretanje prinosa na desetogodišnje američke državne obveznice nije snažno linearno povezano sa promenama prinosa analiziranih indeksa.

Svaka varijabla u modelu koja ima VIF vrednost veću od 3 smatra se multikolinearnom, te je time odbačena iz modela. U slučaju multikolinearnosti, koeficijenti varijabli postali su nestabilni, a standardne greške precenjene. Tabela 5 prikazuje dobijene rezultate multikolinearne analize između posmatranih varijabli u modelu.

Tabela 5: Multikolinearna analiza putem faktora inflacije varijanse (VIF)

Variable	VIF	1/VIF
S&P Municipal Bond Index	1,04	0,959028
U.S.10Y_Y	1,04	0,959028
Mean VIF	1,04	

IZVOR: Proračun autora

Rezultati prikazani u Tabeli 5 pokazuju da su VIF vrednosti za sve nezavisne varijable značajno ispod granične vrednosti od 3. Navedeni rezultati ukazuju na odsustvo problema multikolinearnosti, što potvrđuje pouzdanost procenjenog regresionog modela i omogućava dalju interpretaciju dobijenih koeficijenata.

Test stacioniranosti vremenskih serija (ADF test)

Rezultati Augmented Dickey-Fuller (ADF) testa prikazanog u tabeli 6 pokazuju da niti jedna od analiziranih varijabli nije stacionirana u nivou, budući da su $p > 0,05$.

Tabela 6: Rezultati Augmented Dickey – Fuller (ADF) testa stacioniranosti varijabli

Variable	ADF statistika	p-vrednost	ADF statistika (prva diferencija)	p-vrednost	Zaključak
S&P Green Bond Index	1,8016	0,983	-41,555	$p < 0,001$	I(1)
S&P Municipal Bond Index	1,4161	0,961	-26,588	$p < 0,001$	I(1)
U.S.10Y_Y	0,4204	0,804	-49,649	0,001	I(1)

IZVOR: Proračun autora

Nakon primene prve diferencije, sve varijable postaju stacionirane, što potvrđuju ADF statistike i $p < 0,05$. Na osnovu dobijenih rezultata može se zaključiti da su sve analizirane varijable integrisane reda jedan, odnosno $I(1)$. Budući da su sve analizirane varijable integrisane reda jedan, odnosno $I(1)$, ispunjen je osnovni preduslov za primenu Engle-Granger testa kointegracije i ispitivanja postojanja dugoročne ravnoteže između posmatranih varijabli.

Engle-Granger test kointegracije

S obzirom da su sve varijable integrisane istog reda, u narednom koraku izvršen je Engle-Granger test kointegracije kako bi se ispitalo postojanje dugoročne ravnotežne veze između posmatranih varijabli.

Tabela 7: Rezultati Engle-Granger testa kointegracije

Reziduali	ADF statistika	p-vrednost	Zaključak
RESID01	-5,1183	$p < 0,001$	Varijable su kointegrisane

IZVOR: Proračun autora

Rezultati Engle-Granger testa prikazani u Tabeli 7 pokazuju da su reziduali procenjenog regresionog modela stacionirani, što potvrđuje ADF statistika od -5,1183 i $p < 0,05$. Dobijeni rezultat ukazuje na postojanje dugoročne ravnoteže između analiziranih varijabli. Na osnovu dobijenih rezultata može se zaključiti da između analiziranih varijabli postoji dugoročna ravnotežna veza, odnosno da su S&P Green Bond Index, S&P Municipal Bond Index i U.S. 10Y međusobno kointegrisani. Ovaj nalaz je u skladu sa istraživanjem Rehmana i ostali (2024) koji su primenom Johansenovog testa kointegracije utvrdili postojanje dugoročne povezanosti između tržišta zelenih obveznica i međunarodnih finansijskih tržišta. Njihovi rezultati pokazali su postojanje dve kointegracione veze, što potvrđuje da se tržišta dugoročno kreću zajedno. Sličan zaključak proizilazi i iz rezultata Engle-Granger testa provedenog u ovom istraživanju, čime je potvrđena prva istraživačka hipoteza (H1).

Rezultati regresione analize (OLS)

Nakon provere pretpostavki modela, uključujući odsustvo multikolinearnosti i postojanja kointegracione veze između analiziranih varijabli, u nastavku se prezentuju rezultati regresione analize zasnovane na metodi najmanjih kvadrata. Tabela 8 ilustruje rezultate regresione analize zasnovane na modelu najmanjih kvadrata između nezavisnih varijabli i dnevne vrednosti berzanskog indeksa zelenih obveznica S&P Green Bond U.S. Vrednost F – statistike kod metode najmanjih kvadrata iznosi 9.831,14 kao i $p < 5\%$ što ukazuje na to da je model statistički visoko značajan (tabela 8).

Tabela 8: Koeficijenti nezavisnih promenljivih pri regresiji najmanjih kvadrata za period: 2016. – 2025.

Regresioni model	Metod najmanjih kvadrata (OLS)		
Zavisna varijabla - S&P Green Bond U.S. Dollar Select Index			
Nezavisne varijable	Koef.	Std. Greška	Verovatnoća
C	5,6097	0,80989	p<0,001
S&P Municipal Bond Index	0,4446	0,00318	p<0,001
U.S.10Y_Y	-1,7534	0,04554	p<0,001
Koeficijent determinacije	0,88807	-	-
Prilagođeni koeficijent determinacije	0,88798	-	-
F-Statistic	9.831,14	-	-
Prob (F-statistic)	p<0,001	-	-

IZVOR: Proračun autora

Primenom jednačine (1) na dobijene podatke po metodi najmanjih kvadrata u tabeli 8 dolazimo do sledećeg prognozirano modela:

$$GB_t = 5,6097 + 0,4446 * MB - 1,7534 * U.S.10Y_Y$$

Prilagođeni koeficijent determinacije (Adjusted R²) kod modela najmanjih kvadrata iznosi 0,88798 što ukazuje da je približno 88,8% varijacija dnevne vrednosti S&P Green Bond Index-a objašnjeno promenama dnevnih vrednosti S&P Municipal Bond Index-a i prinosa na američku 10 - godišnju državnu obveznicu (U.S. 10Y_Y). Preostalih 11,2% varijacije može se pripisati drugim faktorima koji nisu uključeni u model. Vrednost F statistike iznosi 9.831,14 uz verovatnoću p<0,001, što potvrđuje da je regresioni model statistički značajan na nivou značajnosti od 5%. Kod metode najmanjih kvadrata vrednost koeficijenta MB i U.S.10Y_Y iznosi 0,4446 i - 1,7534 respektivno. Koeficijent uz varijablu MB je pozitivan, što ukazuje da povećanje prinosa S&P Municipal Bond Index-a za jednu jedinicu povezano je sa povećanjem vrednosti S&P Green Bond Index-a za oko 0,4446 jedinice, uz pretpostavku da ostale varijable ostaju nepromenjene. S druge strane, koeficijent uz varijablu U.S. 10Y_Y je negativan, što ukazuje da povećanje prinosa na američku 10 - godišnju državnu obveznicu za jednu jedinicu povezano je sa smanjenjem vrednosti S&P Green Bond Index-a za oko 1,7534 jedinice, uz nepromenjene ostale uslove. Na osnovu dobijenih rezultata može se zaključiti da postoji statistički značajna pozitivna veza između S&P Municipal Bond Index-a i S&P Green Bond Index-a, čime je potvrđena druga istraživačka hipoteza (H2). Dobijeni nalazi su u skladu sa rezultatima Janković i ostali (2022) koji su takođe utvrdili snažnu povezanost između tržišta zelenih i konvencionalnih municipalnih obveznica. Takođe, Marszalek i Sekula (2024) utvrdili su statistički značajne razlike između prinosa zelenih i konvencionalnih municipalnih obveznica, ali su te razlike uglavnom bile male i promenljive tokom vremena. Njihovi rezultati ukazuju da investitori zelene i konvencionalne obveznice često posmatraju kao slične finansijske instrumente, što potvrđuje visok stepen povezanosti između ova dva segmenta tržišta. Ovakvi nalazi pružaju teorijsku osnovu za očekivanje pozitivne veze između S&P Municipal Bond Index -a i S&P Green Bond Index-a. Dobijeni rezultati dodatno potvrđuju da se tržište zelenih

obveznica ne razvija izolovano, već u značajnoj meri prati dinamiku tradicionalnog tržišta obveznica. Nadalje, rezultati pokazuju da prinos na američke 10 – godišnje državne obveznice (U.S.10Y_Y) ima statistički značajan negativan uticaj na S&P Green Bond Index, čime je potvrđena treća istraživačka hipoteza (H3). Ovaj nalaz je u skladu sa istraživanjem Gozgora i Karakasa (2023), koji su utvrdili negativnu povezanost između prinosa američkih državnih obveznica i prinosa zelenih obveznica.

Slične zaključke iznosi i Tomczak (2024), koja navodi da su prinosi zelenih obveznica značajno određeni kretanjem prinosa na konvencionalne državne obveznice, te opštim nivoom kamatnih stopa. Navedeni rezultati potvrđuju da promene na tržištu državnih obveznica predstavljaju važan faktor koji utiče na performanse tržišta zelenih obveznica. Naime, rast prinosa na američke državne obveznice povećava atraktivnost ulaganja u sigurne državne hartije od vrednosti, zbog čega jedan deo investitora preusmerava sredstva iz zelenih obveznica prema državnim obveznicama. Istovremeno, više kamatne stope povezane su sa višom diskontnom stopom koja se koristi pri vrednovanju obveznica, kao i sa nižom tržišnom vrednošću postojećih zelenih obveznica i njihovih indeksa. Provedena analiza pokazuje da su tržište municipalnih obveznica i kretanje prinosa na američke državne obveznice među ključnim determinantama performansi tržišta zelenih obveznica u posmatranom periodu. Iako analizirani period (2016-2025) obuhvata različite tržišne režime, uključujući pandemiju COVID-19, promene monetarne politike i ciklus rasta kamatnih stopa, cilj ovog istraživanja bio je ispitivanje ukupnih odnosa između analiziranih varijabli tokom celokupnog posmatranog perioda. Buduća istraživanja mogu uključiti analizu podperioda, primenu dummy varijabli za ključne tržišne događaje, kao i testove stabilnosti koeficijenata, čime bi se dodatno proverila robusnost dobijenih rezultata.

Zaključak

Tržište zelenih obveznica poslednjih godina beleži značajan rast, te predstavlja jedan od najvažnijih segmenata održivih finansija. Povećana potreba za finansiranjem projekata iz oblasti zaštite životne sredine, obnovljivih izvora energije i energetske efikasnosti doprinela je većem interesu investitora, finansijskih institucija i kreatora ekonomskih politika za ovaj finansijski instrument. Istovremeno, razvoj tržišta zelenih obveznica sve je više povezan sa kretanjima na tradicionalnim tržištima obveznica i promenama u makroekonomskom okruženju, posebno u pogledu kamatnih stopa. Cilj ovog rada bio je ispitati povezanost između S&P indeksa zelenih obveznica, S&P indeksa municipalnih obveznica i prinosa na desetogodišnje državne obveznice Sjedinjenih Američkih Država u periodu od 2016. do 2025. godine. U svrhu realizacije postavljenog cilja primenjene su metode deskriptivne statistike, korelacione analize, regresione analize primenom metode najmanjih kvadrata (OLS), Augmented Dickey – Fuller (ADF) test stacionarnosti i Engle-Granger test kointegracije.

Rezultati deskriptivne analize ukazuju da su posmatrane varijable pokazivale različitu dinamiku prinosa tokom analiziranog perioda. Najniže stope prinosa i indeks municipalnih i indeks zelenih obveznica ostvarili su tokom 2022. godine, iako su i u pojedinim prethodnim godinama zabeleženi pozitivni prinosi. Istovremeno je tokom 2022. godine evidentiran rast prinosa na američke desetogodišnje državne obveznice. Nakon 2022. godine nisu ostvarene negativne stope prinosa, već je usledio oporavak oba tržišna segmenta, što ukazuje na njihovu međusobnu povezanost i osetljivost na promene kamatnih stopa.

Rezultati korelacione analize pokazali su postojanje veoma snažne pozitivne veze između S&P indeksa zelenih obveznica i S&P indeksa municipalnih obveznica, gde koeficijent korelacije između datih indeksa iznosi 0,906. Dobijeni rezultati regresione analize potvrđuju da indeks municipalnih obveznica ima pozitivan i statistički značajan uticaj na indeks zelenih obveznica, dok prinos na desetogodišnje državne američke obveznice ostvaruje negativan i statistički značajan uticaj. Takođe, visoka vrednost koeficijenta determinacije ($R^2=0,888$) ukazuje na značajnu objašnjavajuću moć postavljenog modela. Dobijeni empirijski rezultati potvrđuju da tržište municipalnih obveznica predstavlja značajan faktor u objašnjenju kretanja S&P Green Bond Indexa, dok prinos na desetogodišnje američke državne obveznice ima statistički značajan negativan uticaj. Ovi nalazi su u skladu sa postavljenim ciljem istraživanja i potvrđuju postojanje značajne povezanosti između analiziranih tržišnih varijabli.

Rezultati ADF testa pokazali su da su sve analizirane varijable integrisane reda jedan, odnosno $I(1)$. Nakon primene Engle-Granger testa utvrđeno je postojanje dugoročne ravnotežne veze između posmatranih varijabli. Na osnovu navedenog može se zaključiti da su tržište zelenih obveznica, tržište municipalnih obveznica i dugoročne kamatne stope međusobno povezani ne samo kratkoročno već i dugoročno.

Ovo istraživanje ima određena ograničenja koja je potrebno uzeti u obzir prilikom interpretacije rezultata. Prvo, analiza je fokusirana isključivo na američko tržište zelenih i municipalnih obveznica, zbog čega se dobijeni rezultati ne mogu u potpunosti generalizirati na druga finansijska tržišta. Drugo, model uključuje ograničen broj varijabli, odnosno S&P Green Bond Index, S&P Municipal Bond Index i prinos na desetogodišnje državne obveznice SAD-a, dok drugi potencijalno značajni faktori, poput inflacije, referentnih kamatnih stopa, makroekonomskih pokazatelja i ESG faktora, nisu bili obuhvaćeni analizom. Treće istraživanje se zasniva na dnevnim podacima za period 2016.- 2025. godine, što može ograničiti mogućnost sagledavanja dugoročnih strukturnih promena na tržištu obveznica. Četvrto, S&P Green Bond Index predstavlja reprezentativan pokazatelj širokog segmenta globalnog tržišta zelenih obveznica i obuhvata državne, supranacionalne, agencijske, korporativne, finansijske i municipalne zelene obveznice. Zbog toga se rezultati ovog istraživanja odnose na tržište zelenih obveznica obuhvaćenih ovim indeksom, a ne isključivo na segment zelenih municipalnih obveznica. Buduća istraživanja mogu koristiti odgovarajuće indekse ili podatke na nivou pojedinačnih emisija zelenih municipalnih obveznica radi detaljnije analize specifičnosti ovog segmenta tržišta.

Uprkos navedenim ograničenjima, ovo istraživanje pruža vredan doprinos razumevanju odnosa između tržišta zelenih i municipalnih obveznica. Dobijeni rezultati ukazuju na postojanje značajne povezanosti između analiziranih varijabli, pri čemu tržište municipalnih obveznica i kretanje dugoročnih kamatnih stopa imaju važnu ulogu u objašnjavanju kretanja na tržištu zelenih obveznica. Navedeni nalazi mogu biti korisni investitorima, kreatorima ekonomskih politika, i drugim učesnicima na finansijskim tržištima prilikom donošenja investicionih odluka i procene rizika. Imajući u vidu rastući značaj održivih finansija, buduća istraživanja trebala bi biti usmerena na identifikaciju dodatnih faktora koji utiču na razvoj i dugoročnu stabilnost tržišta zelenih obveznica.

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DETERMINANTS OF THE S&P GREEN BOND INDEX: AN EMPIRICAL ANALYSIS OF THE IMPACT OF THE S&P MUNICIPAL BOND INDEX AND THE U.S. 10 – YEAR TREASURY YIELD

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Prof. Almir Alihodžić, Tenured Professor, Faculty of Economics,
University of Zenica,
Email: almir.dr2@gmail.com
ORCID: <https://orcid.org/0009-0007-7082-1487>

Abstract: *Green bonds represent one of the most important instruments of sustainable finance and play an increasingly significant role in mobilizing capital for environmental and climate-related projects. The aim of this study is to examine the impact of the S&P Municipal Bond Index and the U.S. 10-Year Treasury Yield on the performance of the S&P Green Bond Index over the period 2016–2025. The analysis is based on data for the S&P Green Bond Index, the S&P Municipal Bond Index, and the U.S. 10-Year Treasury Yield. The methodological framework includes descriptive statistics, correlation analysis, ordinary least squares (OLS) regression, the Augmented Dickey–Fuller (ADF) unit root test, and the Engle–Granger cointegration test. The empirical results indicate a statistically significant positive relationship between the S&P Green Bond Index and the S&P Municipal Bond Index, while the U.S. 10-Year Treasury Yield has a statistically significant negative effect on green bond performance. The Engle–Granger test confirms the existence of a long-run equilibrium relationship (cointegration) among the analysed variables. The findings highlight the importance of traditional bond markets and interest rate movements in explaining the performance of the green bond market.*

Keywords: Green bonds, municipal bonds, U.S. Treasury bonds, cointegration, OLS regression, sustainable finance.

JEL classification: G12, G15, Q56.

Introduction

Green bonds are a relatively recent innovation in sustainable finance. They are debt instruments whose proceeds are earmarked for financing low-carbon and climate-friendly projects. Green bonds may be issued by corporations, municipalities, governments, and supranational institutions. Furthermore, municipal green bonds represent a new way of unlocking finance for sustainable and urban infrastructure investments in the United States. In this paper, the term “municipal bonds” refers to bonds issued by U.S. states, local government units, and their agencies. For the sake of terminological consistency, this term is used throughout the paper. The issuance of green bonds initially lagged due to perceptions of higher costs, lower returns, and greater risk (Chiang, 2017). In essence, green bonds are comparable to conventional municipal bonds in terms of their structure, risk, and return. Strong investor demand for green bonds may enable issuers to obtain financing at lower costs of capital, as increased demand reduces investors’ required rate of return (Zerbib, 2019).

Green bonds are sometimes compared with climate bonds. Although these two types of bonds may overlap in certain situations, green bonds represent a broader concept. Proceeds raised through the issuance of climate bonds are primarily allocated to reducing carbon dioxide emissions and mitigating the adverse effects of climate change, whereas green bonds may finance a wider range of projects with positive environmental impacts. Therefore, green bonds are financial instruments dedicated to sustainability, climate change mitigation, and environmentally oriented projects. Since loans provided by financial institutions represent the primary source of financing in most countries, bonds play an important role in financing and refinancing the lending activities of financial institutions. In recent years, bond issuance by financial institutions has increased steadily. The significant growth in green bond issuance in 2016 was largely driven by substantial issuances from banks in China, where bank-issued green bonds accounted for approximately 76% of the total value of Chinese green bond issuances in that year. According to OECD estimates, green bond issuance by the financial sector has the potential to continue expanding significantly, exceeding USD 1.7 trillion by 2035 (Janković, 2024).

The main areas targeted by green bond issuance include improving energy efficiency, reducing existing pollution and preventing future pollution, sustainable forestry, agriculture and fisheries, protecting terrestrial and aquatic ecosystems, environmentally friendly transport, wastewater treatment, and sustainable water management, among others (Janković, 2024). Figure 1 illustrates the key areas of green investment.

Figure 1: Key Areas of Green Investment



Source: Janković, I. (2024). Zelene obveznice, Belgrade University – Faculty of Economics, Publishing Centre, p. 22.

The attractiveness of green bonds largely stems from their simplicity in terms of structure, key features, and procedures that define this type of debt security, thereby ensuring a clear and transparent flow of information to investors regarding the use of proceeds and the environmental characteristics of financed projects. From a formal perspective, the issuance process of green bonds is very similar to that of conventional bonds, as green bonds are subject to the same legal and regulatory requirements, documentation standards, and financial reporting obligations. The main additional requirement is that issuers are expected to comply with the Green Bond Framework, which provides additional information and procedures designed to assure investors that the funds raised will be used for environmentally sustainable purposes (Janković, 2024).

Although considerable attention has been devoted in the existing literature to the characteristics and performance of green bonds, only a limited number of studies have examined the relationship between the green bond market and the municipal bond market while simultaneously incorporating interest rate changes as a macroeconomic factor. Studies using market indices as representative indicators of the performance of these capital market segments are particularly scarce. The aim of this study is to examine the relationship between the S&P Green Bond Index and the S&P Municipal Bond Index and to analyse the impact of the U.S. 10-Year Treasury yield on movements in the value of the green bond index. The study employs descriptive statistics, correlation analysis, OLS regression, and the Engle–Granger cointegration test. In line with the stated research objective, the following research questions are addressed:

1. Does the S&P Municipal Bond Index have a statistically significant effect on the daily values of the S&P Green Bond Index?
2. Does the U.S. 10-Year Treasury Yield have a statistically significant effect on the daily values of the S&P Green Bond Index?
3. Is there a long-run equilibrium relationship (cointegration) between the analyzed variables?

To address the stated research questions, the empirical part of the study employs appropriate statistical and econometric methods, including regression analysis, stationarity tests, and the Engle–Granger cointegration test, in order to examine both the short-run and long-run relationships among the analysed variables. The remainder of the paper is organized as follows. Following the introduction, the second section provides a review of the relevant literature on green and municipal bonds. The third section presents an analysis of global trends in the green bond market. The fourth section describes the research methodology, the empirical model, and the data used in the analysis. The fifth section reports the empirical findings obtained through descriptive statistics, correlation analysis, OLS regression, and stationarity and cointegration tests. Finally, the paper concludes by summarizing the main findings and discussing their implications for investors and policymakers.

Review of Relevant Literature

At the beginning of the last decade, the green bond market experienced strong growth driven by the increasing need to finance sustainable development and energy transition. Municipal green bonds are of particular importance, as they enable local communities to finance environmentally sustainable infrastructure projects. Green bonds are fixed-income financial instruments issued to raise capital for environmentally friendly projects. Their primary purpose is to internalize environmental externalities and promote investment in green projects that support sustainable development (Ehlers & Packer, 2017). Sovereign green bonds are a relatively new financial instrument designed to raise capital for government infrastructure projects aligned with sustainable development objectives. These bonds may also reduce the cost of capital for environmentally sustainable projects. However, issuing green bonds is generally more expensive than issuing conventional bonds due to additional administrative, legal, and marketing costs (Doronzo et al., 2021). Furthermore, evidence suggests that green bonds are issued at lower yields than conventional bonds, a phenomenon known as the greenium (Liaw, 2020). Research on the greenium in the sovereign green bond market remains limited; however, Grzegorzczuk and Wolff (2022) documented the presence of a small negative greenium in the EU sovereign bond market. A negative greenium indicates that investors are willing to accept lower yields on sovereign green bonds compared with conventional bonds, reflecting their willingness to invest in green and sustainable projects. One of the reasons for this is that green bonds provide investors with the opportunity to invest in green and sustainable projects.

Larcker and Watts (2020) compared municipal green bonds with equivalent conventional municipal bonds and found only a very small yield discount, with no evidence supporting a negative premium on municipal green bonds. Accordingly, they concluded that the green premium was de facto zero. Historically, green bonds were penalized in the municipal bond market, trading at lower prices and higher yields than would be expected based on their credit profiles. In recent years, however, the credit quality of municipal green bonds has improved, and the green premium has turned positive. Consequently, green bonds have become an increasingly attractive investment for bridging the financing gap associated with climate change mitigation and adaptation.

Partridge and Medda (2020) analyzed the U.S. municipal green bond market and found preliminary evidence of the existence of a greenium. Their findings indicate that investors were willing to accept slightly lower yields on green municipal bonds compared with comparable conventional municipal bonds. The authors concluded that these findings reflect the growing demand for sustainable investments and indicate an increasingly strong relationship between the green bond market and the municipal bond market.

Tang and Zhang (2020) examined the effects of green bond issuance on financial markets using a sample of companies from 28 countries over the period 2007–2017. Their results showed that financial markets respond positively to green bond issuance, while institutional ownership and stock liquidity increase following issuance, confirming the growing importance of green financial instruments in global capital markets. In addition, Asness (2000) analysed the relationship between stock and bond returns and explained the equity risk premium.

Reboredo and Ugolini (2020) were among the first researchers to examine the relationship between green bonds and financial markets. Using a Structural Vector Autoregression (SVAR) model, they found that the green bond market is significantly linked to the Treasury bill and foreign exchange markets. They also concluded that the relationship between green bonds and the stock and energy markets is relatively weak. Hammoudeh et al. (2020) likewise employed a time-varying causality approach to investigate the causal relationship between the green bond market and other financial indicators over the period 2016–2020. Their findings indicate that the U.S. 10-Year Treasury Yield is the primary factor determining green bond yields.

Pham and Nguyen (2021) also examined tail dependence between green bonds and the energy, equity, and conventional bond markets using the cross-quantilogram approach over the period from October 2014 to February 2021. The authors reported mixed evidence, as the spillover effects between the financial market and the green bond market varied significantly across different quantiles.

Flammer (2021) analysed corporate green bonds and found that investors respond positively to their issuance. Furthermore, the results indicate that, following bond issuance, issuers achieve better environmental performance, reduce CO2 emissions, and attract long-term investors, confirming the importance of green bonds as an instrument of sustainable finance.

Nguyen and Le (2025) examined the impact of green bond issuance on the transition toward renewable energy sources across 192 countries over the period 2007–2021. Their findings indicate that green bond issuance makes a significant contribution to financing renewable energy projects and accelerating the energy transition.

Sojoudi et al. (2026) found evidence of a significant greenium in the U.S. municipal bond market, with investors willing to accept lower yields on green bonds in support of environmentally sustainable projects. The authors also emphasized that the magnitude of the greenium changes over time and depends on the characteristics of the bonds themselves.

Furthermore, recent studies provide additional evidence of the existence of a greenium in the green and municipal bond markets, further confirming the distinctive market valuation of green financial instruments. Although previous studies have examined the relationship between green bonds and

various segments of the financial market, their findings have not always been consistent and vary depending on the market analysed, the observation period, and the methodology employed. Moreover, earlier research has applied a variety of methodological approaches, including panel data analysis, time-series models, and other econometric techniques, whereas this study employs a combination of OLS regression, the Augmented Dickey-Fuller (ADF) unit root test, and the Engle-Granger cointegration test. This methodological framework enables the examination of the short-run effects of the S&P Municipal Bond Index and the U.S. 10-Year Treasury Yield on the performance of the S&P Green Bond Index, as well as the identification of a long-run equilibrium relationship among the analysed variables. Based on the review of the relevant literature, the identified research gap, and the defined research objective, the following research hypotheses are formulated:

H1: There is a long-run equilibrium relationship (cointegration) among the analysed variables.

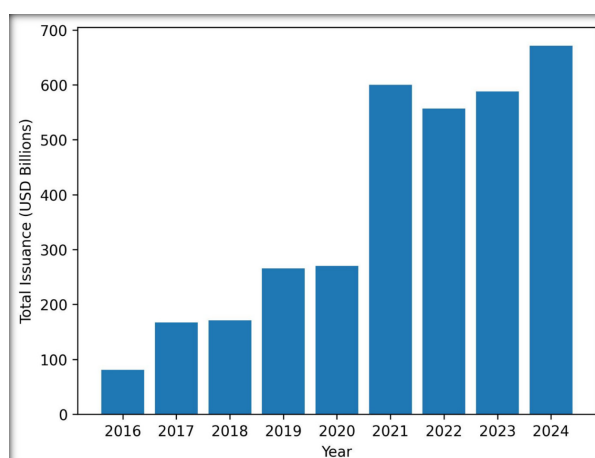
H2: There is a statistically significant relationship between the S&P Municipal Bond Index and the S&P Green Bond Index.

H3: The U.S. 10-Year Treasury Yield has a statistically significant effect on the S&P Green Bond Index.

Global Trends in the Green Bond Market

The first green bond was issued by the European Investment Bank (EIB) in 2007 to finance renewable energy and energy efficiency projects. Since then, green bonds have become an increasingly popular financing instrument. For illustration, in 2008 the total volume of green bond issuance amounted to less than USD 1 billion, but by the end of 2018 it had increased to USD 143 billion. Market practitioners refer to this trend as the green bond boom, which is expected to continue in the coming years (Morgan Stanley, 2017). Furthermore, many commentators regard green bonds as an important instrument for addressing climate change. The growing importance of green bonds in global financial markets is further evidenced by the continuous increase in their issuance volume, as illustrated in Figure 2.

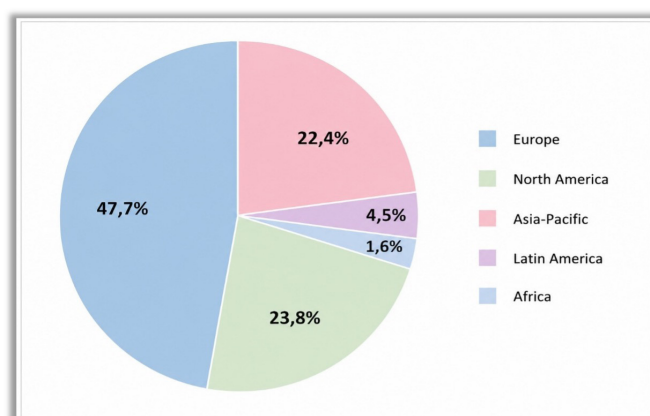
Figure 2: Global Green Bond Issuance Volume (USD billions)



Source: Climate Bonds Initiative. (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

Global green bond issuance increased from approximately USD 80 billion in 2016 to around USD 670 billion in 2024, representing an increase of approximately 737%. The substantial growth in green bond issuance over the 2016–2024 period can be attributed to the strengthening of the regulatory framework for sustainable finance, growing investor demand for ESG instruments, increased sovereign participation through the issuance of sovereign green bonds, and more favourable financing conditions during the period of low interest rates prior to 2022. Furthermore, heightened awareness of climate risks and the need for energy transition have directed capital toward renewable energy projects, energy efficiency, and sustainable infrastructure. In addition, the standardization of the market through the development of international principles and taxonomies has further enhanced the credibility and transparency of the market, thereby contributing to the accelerated growth of this segment of the financial market.

Graph 1: Green Bond Issuance by Region in 2024 (in %)



Source: Climate Bonds Initiative (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

From a regional perspective, Europe accounts for 47.7% of total global green bond issuance in 2024, followed by the Asia-Pacific region with 23.8%, North America with 22.4%, Latin America with 4.5%, and Africa with 1.6%. These figures indicate that Europe, the Asia-Pacific region, and North America together account for 93.9% of total global green bond issuance, whereas Latin America and Africa have considerably smaller shares, suggesting substantial potential for the further development of sustainable finance markets in these regions. The growth of the green bond market is not evenly distributed across countries but is concentrated in certain developed economies that play a significant role in financing sustainable development projects. To provide a more detailed overview of the geographical distribution of the green bond market, Table 1 presents data on the value of green bond issuance and their percentage shares across selected countries during the first half of 2024.

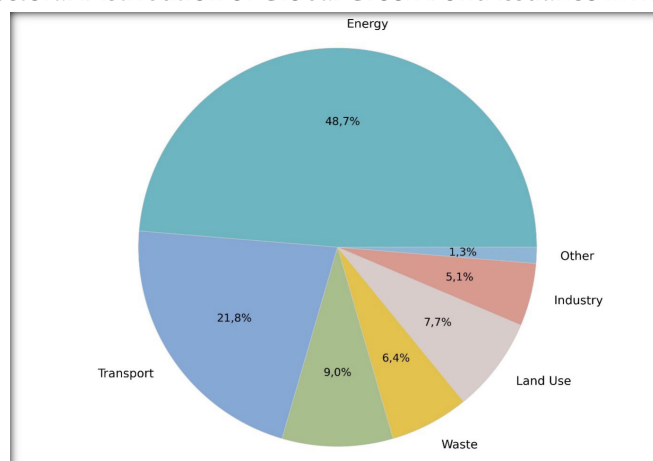
Table 1: Green Bond Issuance by Country in the First Half of 2024

Country	Green Bonds (USD billion)	Percentage Share
Japan	10.6	11.69%
Italia	12.1	13.35%
France	11.6	12.80%
Australia	4.7	5.18%
Austria	7.2	7.95%
Germany	14.0	15.45%
Canada	2.9	3.20%
Romania	2.2	2.43%
Singapore	1.9	2.09%
Hungary	1.6	1.77%
Iceland	0.8	0.88%
China	0.8	0.88%
India	1.2	1.32%
United Kingdom	10.1	11.15%
Netherlands	2.3	2.54%
Spain	2.1	2.32%
Belgium	1.7	1.87%
New Zealand	0.8	0.88%
Denmark	0.6	0.66%
Ireland	0.6	0.66%
Indonesia	0.5	0.60%
Switzerland	0.2	0.22%
Peru	0.1	0.11%
Total	90.6	100.00%

Source: Climate Bonds Initiative. (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

The data presented in Table 1 refer to selected countries issuing green bonds during the first half of 2024. The percentage share column indicates each country's contribution to the total value of green bond issuance presented in the table (USD 90.6 billion). The data shown in Table 1 reveal a significant concentration of green bond issuance in developed economies during the first half of 2024. The largest issuance volumes were recorded in Germany (USD 14.0 billion), Italy (USD 12.1 billion), and France (USD 11.6 billion), which together account for a substantial share of total green bond issuance. In contrast, the lowest issuance volumes were recorded in Peru, Switzerland, and Indonesia. These findings confirm that the green bond market is predominantly developed in economically stronger countries that actively promote sustainable finance and the green transition. In addition to the geographical distribution of green bond issuance, it is also important to analyse the sectoral allocation of the funds raised. The sectoral structure of green bond issuance is presented in Graph 2.

Graph 2: Sectoral Distribution of Global Green Bond Issuance in 2024 (in %)



Source: Climate Bonds Initiative. (2024). Interactive data platform.
<https://www.climatebonds.net/market/data/>

The sectoral distribution of green bond issuance in 2024 indicates the dominant share of the energy sector, accounting for approximately 49%, confirming the crucial role of investments in renewable energy sources and decarbonization. In addition, the transport sector represents a significant share of around 22%, while sectors such as water management, waste management, and land use are moderately represented. This structure suggests that capital is primarily directed toward sectors with the greatest potential to reduce emissions and accelerate the climate transition.

Methodology and Data

Model

The ordinary least squares (OLS) method is one of the most fundamental and widely used estimation techniques in statistics and econometrics. It provides a relatively simple yet powerful approach for estimating relationships between variables by minimizing the sum of squared residuals, i.e., the differences between the observed and predicted values of the dependent variable (Nosheen et al., 2025). The classical linear regression model estimated using the OLS method assumes parameter

linearity, random sampling, the absence of perfect multicollinearity, exogeneity of the regressors, and homoscedasticity (Hansen, 2022). To examine the relationships between the green bond market, the conventional municipal bond market, and the yield on the 10-year U.S. Treasury bond, the OLS model was applied in this study. Klein and Weill (2018) point out that OLS regression is not only a useful method for describing data but also for providing the first unbiased estimates of the coefficients. In the empirical analysis, daily values of the S&P Green Bond Index and the S&P Municipal Bond Index for the period 2016–2025 were used, while the yield on the 10-year U.S. Treasury bond (U.S. 10-Year Treasury Yield) was included as a separate explanatory variable. In this study, the daily values of the selected indices, rather than their daily returns, were used, providing the basis for model estimation and the interpretation of the obtained results. The S&P Green Bond Index is a representative indicator of a broad segment of the global green bond market and includes sovereign, supranational, agency, corporate, financial, and municipal green bonds. Accordingly, the findings of this study should be interpreted within the context of the green bond market represented by the S&P Green Bond Index and should not be interpreted exclusively in the context of municipal green bonds. In addition to the ordinary least squares (OLS) regression analysis, the Augmented Dickey–Fuller (ADF) unit root test and the Engle–Granger cointegration test were employed. The ADF test was used to examine stationarity and determine the order of integration of the analyzed time series, whereas the Engle–Granger test was applied to assess the existence of a long-run equilibrium relationship between the S&P Green Bond Index, the S&P Municipal Bond Index, and the yield on the 10-year U.S. Treasury bond. The application of the Engle–Granger test is appropriate when the analyzed variables are integrated of the same order, i.e., $I(1)$. All statistical tests were conducted at the 5% significance level.

The model specification is defined as follows:

$$GB_t = \alpha + \beta_1 MB_t + \beta_2 U.S. 10Y_Y_t + \varepsilon_t$$

Where:

GB_t – daily value of the S&P Green Bond Index;

MB_t – daily value of the S&P Municipal Bond Index;

$U.S. 10Y_Y_t$ – yield on the 10-year U.S. Treasury bond;

β_1 i β_2 – regression coefficients

ε_t – error term.

Statistical analyses are commonly conducted using a 5% significance level. Accordingly, the significance of all variables was assessed using the t-test at the 95% confidence level (Chmelarova, 2007).

Data

This study is based on secondary data collected from relevant financial databases. The analysis relies on daily data covering the period from January 29, 2016, to December 31, 2025, comprising a total of 2,481 observations. The dependent variable is the S&P Green Bond Index (GB), which tracks the performance of the global green bond market, whose proceeds are allocated to financing projects with positive environmental impacts. The main independent variable is the S&P Municipal Bond Index

(MB), which serves as a benchmark indicator of the performance of the U.S. municipal bond market. This index covers a broad range of bonds issued by U.S. states, local governments, and their agencies. In addition, the model includes a second independent variable, the U.S. 10-Year Treasury Yield (U.S.10Y), representing the yield on the 10-year U.S. Treasury bond, which is widely used as a benchmark risk-free interest rate in financial markets. Data for the S&P Green Bond Index and the S&P Municipal Bond Index were obtained from the S&P Dow Jones Indices database (2025), while data on the 10-year U.S. Treasury yield were obtained from the Federal Reserve Economic Data (FRED) database. After aligning the trading dates, a unified dataset was constructed and used for the econometric analysis.

Empirical Findings

Descriptive Statistics

To provide an overview of the main characteristics of the analyzed variables, Table 2 presents the results of the descriptive statistics for the S&P Green Bond Index, the S&P Municipal Bond Index, and the yield on the 10-year U.S. Treasury bond.

Table 2: Descriptive Statistics of the S&P Green Bond Index, S&P Municipal Bond Index, and the U.S. 10-Year Treasury Yield (%) for the period: January 29, 2016 – December 31, 2025

Description	S&P Green Bond index	S&P Municipal Bond Index	U.S.10Y_Y
Mean	0.00981	0.00954	0.0738
Median	0.01573	0.01688	0.000
Standard Deviation	0.21507	0.21989	2.9384
Maximum	1.1112	3.3943	40.740
Minimum	-1.5517	-2.5897	-27.027
Skewness	-0.4674	-0.4804	1.4053
Kurtosis	7.7804	62.068	39.309
Probability	0.000	0.000	0.000
Number of Observations	2,481	2,481	2,481

Source: Calculations by author based on data obtained from:
<https://www.spglobal.com/spdji/en/index-family/fixed-income/us-municipal/#overview>

The results presented in Table 2 indicate that the S&P Green Bond Index and the S&P Municipal Bond Index recorded very similar average returns over the observed period. In contrast, the yield on the U.S. 10-year Treasury bond exhibited a slightly higher average value and greater volatility, indicating a different pattern of movement compared to the green and municipal bond markets. These findings point to the existence of the classical risk–return relationship in financial markets. In other words, the higher yield on U.S. 10-year Treasury bonds represents compensation to investors for assuming interest rate and inflation risks, which are more pronounced in long-term debt instruments. Changes in monetary policy, particularly movements in benchmark interest rates and inflation expectations, significantly affect the yield volatility of these bonds, as reflected in their higher standard deviation. These findings confirm the role of the yield on U.S. 10-year Treasury bonds as the benchmark risk-free interest rate in global financial markets, whose fluctuations influence the valuation and attractiveness of different segments of the bond market. On the other hand, the lower returns and lower volatility of green and municipal bonds can be explained by the characteristics of these markets. Municipal bonds generally benefit from tax advantages, while green bonds are supported by stable and growing demand from investors motivated by ESG principles, contributing to relatively more stable yield movements. The similar average returns and relatively low volatility also suggest the possibility of a long-term relationship between the green and municipal bond markets, which will be further examined using the Engle–Granger cointegration test. Meszaros et al. (2023) examined the volatility characteristics of sovereign green bonds issued by small open European economies over the period from 2016 to 2021, focusing on the differences between sovereign green bonds and conventional sovereign bonds. They analyzed the markets of two EU member states, Poland and Hungary, and compared them with the mature German green bond market used as a benchmark. The results showed that sovereign green bonds exhibited higher volatility than traditional sovereign bonds, suggesting that this market remains in an early stage of development and that these instruments are more sensitive to shocks. However, these differences were not substantial, indicating that, as the green bond market matures, it may eventually exhibit statistical characteristics similar to those of the conventional bond market.

Table 3: Annual Returns of the S&P Municipal Bond Index, the S&P U.S. Green Bond Index, and the U.S. 10 – Year Treasury Bond Yield for the period: 2016 – 2025 (in%)

Year	S&P Municipal Bond Index	S&P U.S. Green Bond Index	U.S.10Y_Y
2016	0.55%	-0.30%	1.82%
2017	4.82%	6.56%	2.33%
2018	1.35%	0.26%	2.91%
2019	6.89%	8.07%	2.14%
2020	4.97%	4.77%	0.89%
2021	1.71%	2.26%	1.45%
2022	-8.32%	-11.92%	2.95%
2023	5.64%	6.61%	3.96%
2024	1.92%	1.41%	4.21%
2025	4.13%	6.75%	4.29%
Average	2.37%	2.45%	2.69%

Source: Author's calculations

It is evident from the previous table that the Municipal Bond Index recorded its lowest annual return in 2022 (-8.32%), its highest annual return in 2019 (approximately 6.89%), and an average annual return of approximately 2.37%. In contrast, the S&P U.S. Green Bond Index recorded its lowest annual return in 2022 (-11.92%), its highest annual return in 2019 (approximately 8.07%), and an average annual return of approximately 2.45%. The yield on the U.S. 10-year Treasury bond reached its highest level in 2025 (approximately 4.29%), while the lowest yield was recorded in 2020 (0.89%), with an average value of approximately 2.69%. The yield on the U.S. 10-year Treasury bond reflects investors' expectations regarding future inflation and changes in benchmark interest rates. During periods of elevated inflation and restrictive monetary policy, as was the case over the observed period, Treasury bond yields tend to increase because investors demand higher compensation for the loss of the real value of money. Although Table 3 shows only minor differences in the average returns of the S&P Municipal Bond Index and the S&P U.S. Green Bond Index, empirical evidence reported by numerous authors has not confirmed the existence of a significant yield discount or price premium (known as the greenium) associated with green bonds. Janković et al. (2022) identified only a very small yield discount for municipal green bonds and concluded that the green premium was effectively equal to zero. Since there are no significant differences in the returns of green and conventional bonds, investors may base their investment decisions on other factors, such as ethical and environmental considerations, as well as risk and liquidity. These findings suggest that the green and municipal bond markets exhibit similar return characteristics, thereby justifying further investigation of their interrelationship through correlation, regression, and cointegration analyses.

Correlation Analysis

To preliminarily examine the relationships among the S&P Green Bond Index, the S&P Municipal Bond Index, and the yield on the U.S. 10-year Treasury bond, Pearson correlation analysis was employed. Correlation analysis enables the identification of the direction and strength of the linear relationship between the observed variables. According to Cohen (1988), a correlation coefficient ranging from 0.10 to 0.29 indicates a weak correlation. Similarly, a correlation coefficient ranging from 0.30 to 0.49 indicates a moderate correlation, whereas a correlation coefficient ranging from 0.50 to 1.00 indicates a strong correlation.

Table 4: Correlation Analysis (Pearson Correlation Coefficient) between the S&P Green Bond Index, the S&P Municipal Bond Index, and the Yield on the U.S. 10-Year Treasury Bond for the period: 2016 - 2025

		S&P Green Bond U.S. Dollar Select Index	S&P Municipal Bond Index	U.S.10Y_Y
S&P Green Bond U.S. Dollar Select Index	Pearson Correlation	1.000	0.906	-0.069
	Sig. (2-tailed)	-	0.000	0.001
	N	2.481	2.481	2.481
S&P Municipal Bond Index	Pearson Correlation	0.906	1.000	0.203
	Sig. (2-tailed)	0.000	-	0.000
	N	2.481	2.481	2.481
U.S.10Y_Y	Pearson Correlation	-0.069	0.203	1.000
	Sig. (2-tailed)	0.001	0.000	1.000
	N	2.481	2.481	2.481

Source: Author's calculations

As shown in the previous table, the Pearson correlation coefficient between the S&P Green Bond Index and the S&P Municipal Bond Index is 0.906, indicating a very strong positive relationship between the daily return movements of the two indices. This suggests that the observed indices tend to move in the same direction to a considerable extent. The results indicate that changes in municipal bond returns largely follow changes in green bond returns, confirming a high degree of integration between the two markets. Therefore, these findings suggest that investors considering investments in green municipal bonds can expect return patterns similar to those observed in conventional municipal bonds. Although green bonds are specifically intended to finance environmentally sustainable projects, their market remains highly integrated with the traditional bond market. These findings are consistent with those reported by Gorelick et al. (2024), who argue that green municipal bonds share many characteristics with conventional municipal bonds, including similar return dynamics and investor behaviour. Many green municipal bonds are issued by the same institutions that issue conventional bonds, leading investors to view them as part of the broader fixed-income market. The inverse relationship between interest rates and bond prices has been well documented in the literature, which emphasizes the

¹In finance, the term *greenium* refers to a situation in which investors are willing to accept a lower yield on green bonds compared with comparable conventional bonds issued by the same issuer and having similar maturity and risk characteristics.

existence of a negative relationship between bond prices and interest rates (Litvinovs & Raiko, 2017). Accordingly, an increase in interest rates leads to a decline in bond prices, explaining the negative correlation between the yield on the U.S. 10-year Treasury bond and the returns of the green and municipal bond indices (-0.069). Although the correlation coefficient is negative, its magnitude is relatively low, indicating that movements in the yield on the U.S. 10-year Treasury bond are not strongly linearly associated with changes in the returns of the analysed indices.

Each variable in the model with a VIF value greater than 3 is considered to exhibit multicollinearity and is therefore excluded from the model. In the presence of multicollinearity, the estimated coefficients become unstable and their standard errors are inflated. Table 5 presents the results of the multicollinearity analysis for the variables included in the model.

Table 5: Multicollinearity Analysis Using the Variance Inflation Factor VIF

Variables	VIF	1/VIF
S&P Municipal Bond Index	1.04	0.959028
U.S.10Y_Y	1.04	0.959028
Mean VIF	1.04	

Source: Author's calculations

The results presented in Table 5 indicate that the VIF values for all independent variables are well below the threshold value of 3. These findings suggest the absence of multicollinearity, confirming the reliability of the estimated regression model and allowing for a reliable interpretation of the estimated coefficients.

Stationarity Test of Time Series (ADF Test)

The results of the Augmented Dickey-Fuller (ADF) test presented in Table 6 indicate that none of the analysed variables is stationary at the level, as all $p > 0.05$.

Table 6: Results of the Augmented Dickey-Fuller (ADF) Test for Variable Stationarity

Variables	ADF Statistic	p-value	ADF Statistic (First Difference)	p-value	Conclusion
S&P Green Bond Index	1.8016	0.983	-41.555	$p < 0.001$	I(1)
S&P Municipal Bond Index	1.4161	0.961	-26.588	$p < 0.001$	I(1)
U.S.10Y_Y	0.4204	0.804	-49.649	0.001	I(1)

Source: Author's calculations

Following the first differencing, all variables become stationary, as confirmed by the ADF statistics and $p < 0.005$. Based on these results, it can be concluded that all analysed variables are integrated of order one, i.e., $I(1)$. Since all analysed variables are integrated of order one, $I(1)$, the main prerequisite for applying the Engle–Granger cointegration test and examining the existence of a long-run equilibrium relationship among the observed variables is satisfied.

Engle–Granger Cointegration Test

Since all variables are integrated of the same order, the Engle–Granger cointegration test was conducted in the next step to examine the existence of a long-run equilibrium relationship among the observed variables.

Table 7: Results of the Engle–Granger Cointegration Test

Residuals	ADF Statistic	p-value	Conclusion
RESID01	-5.1183	$p < 0.001$	Variables are cointegrated

Source: Author's calculations

The results of the Engle–Granger test presented in Table 7 indicate that the residuals of the estimated regression model are stationary, as confirmed by the ADF statistic of -5.1183 and a $p < 0.05$. These findings indicate the existence of a long-run equilibrium relationship among the analysed variables. Based on the obtained results, it can be concluded that the S&P Green Bond Index, the S&P Municipal Bond Index, and the U.S. 10-Year Treasury bond yield are cointegrated. These findings are consistent with the study by Behlman et al. (2024), who, using the Johansen cointegration test, confirmed the existence of a long-run relationship between the green bond market and international financial markets. Their results revealed the presence of two cointegrating relationships, confirming that these markets move together over the long run. A similar conclusion is reached based on the results of the Engle–Granger test conducted in this study, thereby confirming the first research hypothesis (H1).

Results of the Regression Analysis (OLS)

After verifying the model assumptions, including the absence of multicollinearity and the existence of a cointegration relationship between the analyzed variables, the results of the Ordinary Least Squares (OLS) regression analysis are presented below. Table 8 presents the results of the OLS regression model examining the relationship between the independent variables and the S&P Green Bond U.S. Dollar Select Index. The F-statistic is statistically significant (Table 8), with $p < 0.05$, indicating that the overall model is highly statistically significant.

Table 8: Coefficients of the independent variables in the Ordinary Least Squares (OLS) regression for the period 2016–2025

Regression Model	Ordinary Least Squares (OLS) Method		
Dependent variable - S&P Green Bond U.S. Dollar Select Index			
Independent variables	Koef.	Std. Greška	Verovatnoća
C	5.6097	0.80989	p<0.001
S&P Municipal Bond Index	0.4446	0.00318	p<0.001
U.S.10Y_Y	-1.7534	0.04554	p<0.001
Coefficient of Determination (R) ²	0.88807	-	-
Adjusted Coefficient of Determination (Adjusted R ²)	0.88798	-	-
F-Statistic	9,831.14	-	-
Prob (F-statistic)	p<0.001	-	-

IZVOR: Proračun autora

By applying Equation (1) to the data obtained using the Ordinary Least Squares method presented in Table 8, the following estimated model is derived:

$$GB_t = 5,6097 + 0,4446 * MB - 1,7534 * U.S. 10Y_Y$$

The adjusted coefficient of determination (Adjusted R²) for the Ordinary Least Squares (OLS) model is 0.88798, indicating that approximately 88.8% of the variation in the daily values of the S&P Green Bond Index is explained by changes in the daily values of the S&P Municipal Bond Index and the yield on the U.S. 10-year Treasury bond (U.S. 10Y_Y). The remaining 11.2% of the variation can be attributed to other factors not included in the model. The F-statistic is 9,831.14, with a p<0.000, confirming that the regression model is statistically significant at the 5% significance level. In the OLS model, the estimated coefficients for the MB and U.S. 10Y_Y variables are 0.4446 and -1.7534, respectively. The positive coefficient of the MB variable indicates that a one-unit increase in the daily value of the S&P Municipal Bond Index is associated with an increase of approximately 0.4446 units in the daily value of the S&P Green Bond Index, holding all other variables constant. Conversely, the coefficient of the U.S. 10Y_Y variable is negative, indicating that a one-unit increase in the yield on the U.S. 10-year Treasury bond leads to a decrease of approximately 1.7534 units in the daily value of the S&P Green Bond Index, ceteris paribus. Based on the obtained results, it can be concluded that there is a statistically significant positive relationship between the S&P Municipal Bond Index and the S&P Green Bond Index, thereby confirming the second research hypothesis (H2). These findings are consistent with the results of Janković et al. (2022), who also identified a strong relationship between the green bond market and the conventional municipal bond market. Furthermore, Marszałek and Sekuła (2024) found statistically significant differences between the returns on green and conventional municipal bonds, however, these differences were generally small and varied over time. Their findings suggest that investors often perceive green and conventional bonds as similar financial instruments, confirming a high degree of

interconnectedness between these two market segments. These findings provide a theoretical basis for expecting a positive relationship between the S&P Municipal Bond Index and the S&P Green Bond Index. The obtained results further confirm that the green bond market does not develop in isolation but rather closely follows the dynamics of the conventional bond market. Furthermore, the results indicate that the yield on the U.S. 10-year Treasury bond (U.S. 10Y_Y) has a statistically significant negative effect on the daily value of the S&P Green Bond Index, thereby confirming the third research hypothesis (H3).

This finding is consistent with the study by Gozgor and Karakas (2023), who identified a negative relationship between U.S. Treasury bond yields and green bond returns. Similar conclusions were reached by Tomczak (2024), who reported that green bond returns are significantly influenced by the performance of conventional government bonds as well as by the overall level of interest rates. These findings confirm that developments in the government bond market represent an important factor affecting the performance of the green bond market. Specifically, an increase in U.S. Treasury bond yields enhances the attractiveness of investing in safe government securities, leading some investors to reallocate funds from green bonds to government bonds. At the same time, higher interest rates increase the discount rate used in bond valuation, resulting in a decline in the market value of outstanding green bonds and their corresponding indices. The conducted analysis indicates that the municipal bond market and movements in U.S. Treasury bond yields were among the key determinants of green bond market performance during the observed period. Although the analyzed period (2016–2025) covers different market regimes, including the COVID-19 pandemic, changes in monetary policy, and the interest rate tightening cycle, the primary objective of this study was to examine the overall relationship between the analyzed variables throughout the entire observation period. Future research may include sub-period analyses, the application of dummy variables for major market events, and coefficient stability tests in order to further assess the robustness of the obtained results.

Conclusion

The green bond market has experienced significant growth in recent years and has become one of the most important segments of sustainable finance. The increasing need to finance projects related to environmental protection, renewable energy sources, and energy efficiency has contributed to growing interest in this financial instrument among investors, financial institutions, and policymakers. At the same time, the development of the green bond market has become increasingly associated with developments in traditional bond markets and changes in the macroeconomic environment, particularly with respect to interest rates. The aim of this study was to examine the relationship between the S&P Green Bond Index, the S&P Municipal Bond Index, and the yield on the 10-year U.S. Treasury bond over the period from 2016 to 2025. To achieve this objective, the study employed descriptive statistics, correlation analysis, ordinary least squares (OLS) regression analysis, the Augmented Dickey–Fuller (ADF) unit root test, and the Engle–Granger cointegration test.

The results of the descriptive analysis indicate that the observed variables exhibited different yield dynamics over the analyzed period. The lowest yields were recorded for both the S&P Municipal Bond Index and the S&P Green Bond Index in 2022, although positive yields had also been observed in certain earlier years. At the same time, 2022 was characterized by a significant increase in the yield on the 10-year U.S. Treasury bond. Following 2022, neither market segment recorded negative yields;

instead, both experienced a recovery, indicating their close interrelationship and sensitivity to changes in interest rates.

The results of the correlation analysis revealed a very strong positive relationship between the S&P Green Bond Index and the S&P Municipal Bond Index, with a correlation coefficient of 0.906. The regression analysis confirmed that the S&P Municipal Bond Index exerts a positive and statistically significant effect on the S&P Green Bond Index, whereas the yield on the 10-year U.S. Treasury bond has a negative and statistically significant effect. Furthermore, the high coefficient of determination ($R^2 = 0.888$) indicates the substantial explanatory power of the estimated model. The empirical findings confirm that the S&P Municipal Bond Index is a significant determinant of movements in the S&P Green Bond Index, while the yield on the 10-year U.S. Treasury bond has a statistically significant negative impact. These findings are consistent with the stated research objective and confirm the existence of a significant relationship among the analyzed market variables.

The results of the ADF test indicated that all analyzed variables are integrated of order one, i.e., $I(1)$. The application of the Engle–Granger cointegration test confirmed the existence of a long-run equilibrium relationship among the observed variables. Based on these findings, it can be concluded that the green bond market, the municipal bond market, and long-term interest rates are interconnected not only in the short run but also in the long run.

This study has several limitations that should be considered when interpreting the findings. First, the analysis focuses exclusively on the U.S. green bond and municipal bond markets; therefore, the results cannot be fully generalized to other financial markets. Second, the model includes a limited number of variables, namely the S&P Green Bond Index, the S&P Municipal Bond Index, and the yield on the 10-year U.S. Treasury bond, while other potentially important determinants, such as inflation, benchmark interest rates, macroeconomic indicators, and ESG factors, were not incorporated into the analysis. Third, the study is based on daily data covering the period from 2016 to 2025, which may limit the ability to capture long-term structural changes in the bond market. Fourth, the S&P Green Bond Index represents a broad segment of the global green bond market, encompassing sovereign, supranational, agency, corporate, financial, and municipal green bonds.

Therefore, the findings of this study apply to the green bond market represented by this index rather than exclusively to the segment of green municipal bonds. Future research may employ more specialized indices or issue-level data on green municipal bonds to provide a more comprehensive analysis of the specific characteristics of this market segment.

Despite these limitations, this study makes a valuable contribution to the understanding of the relationship between the green bond and municipal bond markets. The findings indicate the existence of significant relationships among the analyzed variables, with the municipal bond market and long-term interest rates playing an important role in explaining developments in the green bond market. These results may be useful for investors, policymakers, and other participants in financial markets when making investment decisions and assessing risk. Given the growing importance of sustainable finance, future research should focus on identifying additional factors that influence the development and long-term stability of the green bond market.

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