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Finanza sostenibile

Greenwashing alert system for EU green bonds

The CONSOB–University of Trento prototype

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Abstract

The demand for green bonds – financial instruments used to fund environmentally sustainable projects – has recently registered an increasing trend by remaining on high levels since 2021. At the same time, concerns about greenwashing have risen as well, potentially undermining investor confidence, harming market integrity, and slowing down the transition to a sustainable economy.

According to ESMA, identifying greenwashing cases could be challenging due to misleading financial disclosure or omission of information. Indeed, sustainability claims could suffer from absence of substantial backing or evidence, cheap talk, inconsistency (*i.e.*, mismatch between the company's sustainability claims and its actual practices), cherry-picking, complexity and lack of transparency. In addition, market pressure due to consumer demands or investor expectations could lead companies to overstate their environmental credentials and expertise. Lastly, the absence of a specific and unique regulation on this topic at both national and EU levels could undermine greenwashing detection as well. Similarly, academic literature underlines various but somewhat interrelated interpretations of greenwashing such as 'selective disclosure', 'unsubstantiated or misleading claims', 'gap between environmental information disclosed and actual environmental performance' and 'overly positive beliefs about an organization's environmental performance'. All these definitions refer to firms manipulating communication with the aim of creating a favourable, social and eco-friendly company image.

JEL Classifications: Q01, Q56, G18, G20, G38, C63, O31.

Keywords: sustainable finance, green bonds, SupTech tools, machine learning, Artificial Intelligence.

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The aim of our research is to develop a first prototype that should be grounded in Artificial Intelligence (AI), which could support supervision activity by providing alerts for potential cases of greenwashing (*i.e.*, greenwashing alert system). Financial authorities increasingly recognize the need for supervisory technology tools (SupTech) to enhance their oversight capabilities. SupTech leverages advanced technologies such as AI and machine learning (ML) to improve the efficiency and effectiveness of regulatory supervision. These tools enable authorities to quickly process vast amounts of data, potentially identifying risks early, and supporting compliance with regulatory standards.

The developed prototype relies on large language models such as ClimateBERT and ESGBERT, combined with a proprietary dictionary that maps a defined set of keywords to each Sustainable Development Goal (SDG), based on the alignment of the Green Bond Principles (GBP) with the SDG framework. First, the prototype can identify environmental phrases and environmental claims in selected documents such as sustainability reports, tagging them accordingly as 'environmental' or 'environmental claim'. Second, the prototype highlights the sentiment of statements and classifies them into three categories: risk, opportunity, or neutral, depending on the tone of the content. Third, the prototype performs a dictionary-based search to extract SDG-related phrases, assigns them to the corresponding SDG and then computes an SDG mismatch measure that quantifies discrepancies between the declared and the detected SDGs. The overall system provides structured insights that can support regulatory and supervisory efforts. By automating these processes, the prototype can significantly reduce the time which analysts need to manually review sustainability reports and mitigate potential biases that can arise from subjective interpretation. This systematic approach could not only improve efficiency but also strengthen the reliability and transparency of analyses. The prototype has not yet been fully validated and tested, primarily due to the limited number of confirmed greenwashing cases; nonetheless, it shows potential for future implementation as a greenwashing alert system.

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This paper stems from the collaboration between CONSOB and the University of Trento, developed within the framework of a *Training on the Job* programme. The conceptual design of the prototype was the result of joint work by S. Paterlini and A. Nicolodi (University of Trento), together with CONSOB officers: M. Gentile, V. Foglia Manzillo, M.R. Sancilio and P. Deriu.

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Contents

1 Introduction

Climate change stands as one of the most pressing challenges of our time, requiring coordinated efforts from various sectors, including the financial industry, to drive meaningful change. Within this context, green bonds have emerged as a pivotal financial instrument aimed at financing projects that facilitate the transition to a sustainable and low-carbon economy. Over the past decade, the issuance of green bonds has grown significantly, reflecting their increasing adoption and investor demand. Alongside this growth, innovative financial products, such as sustainability-linked bonds, have been developed to provide additional flexibility and incentives for meeting sustainability goals.

However, the rapid expansion of these markets also brings challenges, with greenwashing being one of the most critical concerns. Notably, there is no universally agreed-upon definition of greenwashing, which makes the issue complex and multifaceted. Broadly speaking, greenwashing refers to the practice of misleading stakeholders – such as investors, regulators, or the public – by exaggerating, omitting, or falsely claiming the environmental benefits of financial products, corporate activities, or projects. This could involve presenting a product as 'green' or 'sustainable' without sufficient evidence, overstating the impact of funded projects, or selectively disclosing favourable information while concealing activities that harm the environment. In the context of green bonds, such practices can erode investor's trust, misallocate resources, and undermine the credibility of financial instruments designed to contrast climate change.

At the same time, advancements in AI, particularly through large language models (LLMs), provide innovative and powerful tools to tackle challenges such as greenwashing. These technologies enable sophisticated analysis of textual data, facilitating the identification of environmental sentences, claims and their sentiment. In this study, we explore how AI and LLMs can be leveraged to develop a prototype for a greenwashing alert system tailored to the European green bond market. Beyond utilizing pre-trained models such as ESGBERT and ClimateBERT to identify environmental sentences and claims and the tone of the conversation, we enhance our approach by creating a proprietary dictionary-based tool. This tool systematically scans sustainability reports to identify and evaluate references to Sustainable Development Goals (SDGs) declared by green bond issuers, offering an additional layer of verification and transparency.

While Natural Language Processing (NLP) offers significant potential in addressing greenwashing, it also comes with certain limitations. One of its key advantages is its ability to process vast amounts of textual data efficiently, extracting relevant information and identifying patterns that may not be immediately apparent to human analysts. By leveraging NLP, regulators can systematically analyse sustainability reports to detect environmental sentences and claims, SDGs sentences and the tone of the conversation.

However, NLP also presents challenges. The accuracy of these models depends heavily on the quality and comprehensiveness of the training data. Since sustainability

disclosures often contain ambiguous language, subjective terminology, or industry-specific jargon, NLP models may struggle to differentiate between genuine commitments and misleading statements. Additionally, AI-based systems can sometimes reinforce biases related to historical data, potentially leading to the risk of false positives and negatives in detecting greenwashing. Another limitation is interpretability, while NLP models can flag potentially misleading statements, they may not always provide clear explanations for why a claim is classified as flawed. This fact underscores the importance of complementing AI-driven approaches with expert judgment and robust validation methods.

Given the increasing complexity of financial markets and the growing regulatory focus on green finance, developing SupTech tools for regulators is becoming increasingly important. SupTech solutions powered by AI and NLP can enhance regulatory oversight by automating the screening of sustainability-related disclosures, reducing the manual workload, and improving the consistency of greenwashing detection. By integrating AI-driven tools into supervisory procedures, authorities can more effectively monitor compliance with sustainability standards, identify emerging risks, and ensure that green bond issuers adhere to their stated environmental commitments. Moreover, these tools can help regulators keep pace with the rapid evolution of sustainable finance, enabling data-driven decision-making and more targeted interventions where necessary.

Ultimately, while NLP is not a flawless solution, its integration into SupTech frameworks represents a significant step toward improving transparency and accountability in the green bond market. By combining AI-driven automation with human expertise, regulators can develop more effective mechanisms for greenwashing alerts, ensuring that sustainable finance truly contributes to the fight against climate change.

The paper is structured as follows. In Section 2, we review greenwashing definition as provided in the financial regulatory framework while Section 3 focuses on the academic literature review. Section 4 reports on the main trends in the green bond market world-wide and describes the sample of green bonds domiciled in Europe. Furthermore, Section 5 presents the developed prototype and illustrates selected use cases, while Section 6 discusses possible implications for supervisory activities. Finally, the conclusions summarize key insights of our research.

2 Greenwashing definition in the financial regulatory framework

The lack of an applicable and binding definition of greenwashing within the EU regulatory financial framework has made it challenging to precisely assess the extent of this phenomenon in recent years.

The question of how to define greenwashing and identify its core characteristic has been the subject of in-depth studies first by regulation. In this context, it has been emphasized that the multifaceted nature of greenwashing — which

can manifest in various forms — makes it difficult to define it in a clear-cut way. A rigid definition may, in fact, fail to capture the full complexity of the phenomenon. Nevertheless, efforts have been made to at least reconstruct its essential core and identify its defining elements.

Greenwashing is subject to a specific regulatory framework when it comes to financial products and issuers.

In the financial field several regulatory instruments, including EU financial regulatory instruments and one EU regulatory guidance, refer to greenwashing in specific contexts.

References to the definition of greenwashing can be found in the Taxonomy Regulation[1], in the SFDR[2], in the MiFID II Regulation[3] as well as in the IDD Regulation[4]. In these dossiers, the legislator focuses on the disclosure and advice of financial products, while as clarified by ESMA[5], greenwashing can occur at different stages of the product life cycle and can also concern statements or actions at the entity level (*i.e.*, the so-called entity level financial market participants), rather than only at the product level.

The absence of a common notion of greenwashing in European legislation makes supervision more complex and fuels the risk of divergences in EU regulatory and supervisory approaches, which can generate arbitrage phenomena and damage

1 The Regulation (EU) 2020/852 (Taxonomy Regulation) states in its recital 11: «*In the context of this Regulation, greenwashing refers to the practice of gaining an unfair competitive advantage by marketing a financial product as environmentally friendly, when in fact basic environmental standards have not been met.*»

2 The Commission Delegated Regulation (EU) 2022/1288 supplementing Regulation (EU) 2019/2088 (SFDR) states in its recital 16: «*It is therefore necessary to address concerns about 'greenwashing', that is, in particular, the practice of gaining an unfair competitive advantage by recommending a financial product as environmentally friendly or sustainable, when in fact that financial product does not meet basic environmental or other sustainability-related standards*».

3 The Commission Delegated Regulation (EU) 2021/1253, amending MiFID II Delegated Regulation (EU) 2017/565 as regards the integration of sustainability factors, risks and preferences into certain organizational requirements and operating conditions for investment firms, clarifies the following in its recital 7: «*It is necessary to address concerns about 'greenwashing', that is, in particular, the practice of gaining an unfair competitive advantage by recommending a financial instrument as environmentally friendly or sustainable, when in fact that financial instrument does not meet basic environmental or other sustainability-related standards. In order to prevent mis-selling and greenwashing, investment firms should not recommend or decide to trade financial instruments as meeting individual sustainability preferences where those financial instruments do not meet those preferences. Investment firms should explain to their clients or potential clients the reasons for not doing so and keep records of those reasons*».

4 The Commission Delegated Regulation (EU) 2021/1257, amending IDD Delegated Regulations (EU) 2017/2358 and (EU) 2017/2359 as regards the integration of sustainability factors, risks and preferences into the product oversight and governance requirements for insurance undertakings and insurance distributors and into the rules on conduct of business and investment advice for insurance-based investment products, states the following: «*It is necessary to address concerns about 'greenwashing', that is, in particular, the practice of gaining an unfair competitive advantage by recommending an insurance-based investment product as environmentally friendly or sustainable, when in fact that insurance-based investment product does not meet basic environmental or other sustainability-related standards. In order to prevent mis-selling and greenwashing, insurance intermediaries and insurance undertakings distributing insurance-based investment products should not recommend insurance-based investment products as meeting individual sustainability preferences where those products do not meet those preferences*».

5 This position was confirmed by ESMA in the Progress Report on Greenwashing of 31 May 2023. On this point, see the document available on the https://www.esma.europa.eu/sites/default/files/2023-06/ESMA30-1668416927-2498_Progress_Report_ESMA_response_to_COM_RfI_on_greenwashing_risks.pdf website.

industry and investors (also considering the availability in Italy of products engineered by foreign intermediaries).

In the absence of an unambiguous definition of greenwashing at the legislative level, the supervisory authorities in the financial sector have so far played an important interpretative role, with a view to application convergence.

ESMA has set out an initial definition of greenwashing in its Sustainable Finance Roadmap 2022-2024[6], in which it has identified the fight against this phenomenon as one of the three priority areas of intervention for the three-year reference period; priorities also confirmed in its strategy 2023-2028[7]. In particular, the ESMA Sustainable Finance Roadmap defined greenwashing as «*market practices, both intentional and unintentional, whereby the publicly disclosed sustainability profile of an issuer, and the characteristics and/or objectives of a financial instrument or a financial product either by action or omission do not properly reflect the underlying sustainability risks and impacts associated to that issuer, financial instrument or financial product. The greenwashing phenomenon could be generally identified as a misrepresentation, mislabelling, mis-selling and / or mis-pricing phenomenon*».

According to ESMA's first conceptualisation, greenwashing would take the form of a phenomenon of misrepresentation of information relating to ESG phenomena or the incorrect attribution of a sustainability label to a product or service and, ultimately, in the event of mis-selling (*i.e.*, the sale of an asset that does not correspond to the actual interest of the customer/investor).

In order to understand how the risks of greenwashing can be better controlled, on May 23, 2022 the European Commission has mandated the European Supervisory Authorities (ESAs - EBA, EIOPA and ESMA), (in an individual, but coordinated form) to provide their respective contributions in order to understand and define the phenomenon of greenwashing; assess the state of implementation and application of sustainable finance measures; assess whether the powers and mandates of the authorities, their tools and practices, experience and capabilities, as well as their supervisory and enforcement responses are adequate. The European Commission, therefore, has identified the need to define a general notion of greenwashing, identifying the main characteristics of the phenomenon, covering the main nodes of the sustainable investment value chain as well as the channels of transmission of greenwashing in the financial sector.

During the course of the work of ESAs, starting from the aforementioned definition of greenwashing provided in the ESMA Sustainable Finance Roadmap (where

6 The document is available at: https://www.esma.europa.eu/sites/default/files/library/esma30-379-1051_sustainable_finance_roadmap.pdf.

7 It should be noted that ESMA has placed particular emphasis on the importance of combating greenwashing also in its Strategy for 2023-2028, cf. https://www.esma.europa.eu/sites/default/files/library/esma_strategy_2023-2028.pdf. In addition, improving the transparency and comprehensibility of ESG disclosure - in the area of collective management, the provision of investment services and issuers' reporting - is one of the Union's strategic supervisory priorities ('Union Supervisory Strategic Priority' or 'USSP') that CONSOB, like the other authorities of the Member States, is called upon to integrate into its supervisory programmes for the three-year period 2023-2025 in order to protect investors and support the development of a credible ESG market.

different facets of the phenomenon are identified such as, for example, «*misrepresentation*, *mislabelling*, *mis-selling and / or mis-pricing phenomenon*»), a series of way sustainability claims, statements or disclosures may be misleading: from the omission of information that investors or consumers would need to make informed decisions (including, but not limited to, biased, selective, unclear or unintelligible, inconsistent, vague, overly simplistic, ambiguous, outdated or unsubstantiated claims) to the provision of information, relevant for the purposes of the aforementioned decisions, which are false or (potentially) misleading for investors and consumers (including mislabelling, misclassification, mis-targeted marketing)[8].

The ESAs recognize that greenwashing is a complex phenomenon and could emerge throughout the sustainable investment chain, both at the level of entity and product or service, not only in specific disclosures required by sustainable finance legislation but also for the violation of general principles of financial regulation, concerning, for example, the clear, fair and non-misleading nature of disclosure to investors.

In the Progress Report on Greenwashing, published on May 31, 2023, the three ESAs developed the common high-level understanding that «*greenwashing is a practice where sustainability-related statements, declarations, actions, or communications do not clearly and fairly reflect the underlying sustainability profile of an entity, a financial product or financial service. This practice may be misleading to consumers, investors, or other market participants*».

With regard to the main constituent elements of the phenomenon, it is observed that it can: i) derive from both the omission of information and misleading information; ii) derive from declarations/omissions or actions; iii) be intentional or unintentional; iv) occur both at the entity level (*i.e.*, relating to an entity's sustainability strategy; or performance), at financial product level (*i.e.*, relating to a product's sustainability strategy or performance) and «*at financial service level including advice (i.e., relating to the integration of sustainability-related preferences to the provision of financial advice)*»; as well as in relation to different stages of the product life cycle or the sustainable investment value chain (SIVC); v) occur both in regulated documents (or in relation to general principles) and in relation to entities that do not fall within the current scope of sustainable finance regulations; vi) be carried out by the entity to which the information refers or by a third party (*i.e.*, an ESG rating provider)[9].

8 In the call for evidence (launched in November 2022 https://www.esma.europa.eu/sites/default/files/library/esas_call_for_evidence_on_greenwashing.pdf.), it is noted that greenwashing can also occur where the element of intentionality does not occur («*e.g. resulting from negligence or from misinterpretation of the sustainable finance regulatory framework requirements*») and also in relation to «*entities that are currently outside of the remit of the EU sustainable finance legislation as it currently stands (e.g. ESG ratings)*». It should also be noted that, if not addressed, greenwashing undermines trust in markets and sustainable finance policies, even where there is no immediate damage to the investor or consumer or the achievement of an undue competitive advantage.

9 In particular, the ESAs also agreed that «*sustainability-related misleading claims can occur and spread either intentionally or unintentionally and that greenwashing does not require investors being actually harmed. Moreover, greenwashing can occur in relation to entities and products that are either under or outside the remit of the EU regulatory framework*».

The Report assesses the «*risk of greenwashing – namely the risk that misleading sustainability claims occur and mislead investors in their decisions – across the sustainable investment value chain (SIVC)*».

The ESAs assess the risk of greenwashing for financial market participants in their three main roles of trigger, spreader and receiver of a sustainability-related claim; recognizing how greenwashing can operate both at the entity level and at the product or service level and can affect the fundamental aspects of the sustainability profile such as «*ESG governance and resources; ESG strategy, policies and credentials; ESG performance metrics and targets; and sustainability impact*». The ESAs noted that the most frequently encountered misleading claims take the form of 'cherry-picking' [*i.e.*, when formulating a sustainability claim by selecting only certain characteristics of the social activity or product or service, not mentioning other aspects of the same that are not sustainable], «*omission, ambiguity, empty claims (including exaggeration), misleading use of ESG terminology such as naming and irrelevance*» and that «*while regulatory documents appear less exposed to greenwashing risks than marketing materials, labels and voluntary reporting, they should not be overlooked*».

The ESAs understand greenwashing as a practice where sustainability related statements, declarations, actions, or communications do not clearly and fairly reflect the underlying sustainability profile of an entity, a financial product, or financial services. This practice may be misleading to consumers, investors, or other market participants; in particular, practice misleading due to the omission of information or misleading due to the actual provision of information or direct claim but in misleading actions.

Greenwashing (at entity or product level) can be a source of direct financial risks for the companies involved, as well as reputational and legal risks with indirect financial consequences for the companies. Such risks can potentially affect both financial and non-financial undertakings.

The progress report explains that the realization of these risks may fuel financial risks and adverse impacts for the system, due to the cross-cutting nature of sustainability issues. In addition, the main transmission channels through which the adverse effects of greenwashing can fuel 'traditional' financial risks (liquidity, credit, market and contagion risk) are described. The progress report notes that financial markets do not seem to correctly price the greenwashing risks incurred by companies, with consequent distorting effects on the incentives that drive the latter's action.

Greenwashing risk related financial risk to market participants can stem from the materialisation of reputational risk or legal financial different risk categories (Table 1).

Table 1 – Transmission channels of greenwashing-related financial risks to EU markets and investors, by risk category

liquidity risk	• lower trading volumes or higher bid-ask spreads or longer time to unwind positions due to reduced willingness to trade with specific counterparties • stranded assets
credit risk	• higher borrowing costs • increased credit default swap spreads due to higher risk perceptions • reduced creditworthiness, credit rating downgrades • stranded assets
market risk	• lower asset valuation due to decreasing investor demand • increased volatility and lower resilience to adverse market movements
contagion risk	• sell-off within the sector • market losses on passive investments • outflows from investment products

Source: ESMA Progress Report on Greenwashing, 2023.

Under adverse market conditions, greenwashing-related financial risks may spread to the broader financial system. Greenwashing may also have non-financial, system-wide, implications (Figure 1).

Greenwashing is characterized based on five main dimensions:

i) the role that the different participants in the financial markets can play (trigger, spreader, receiver of misleading sustainability claims);

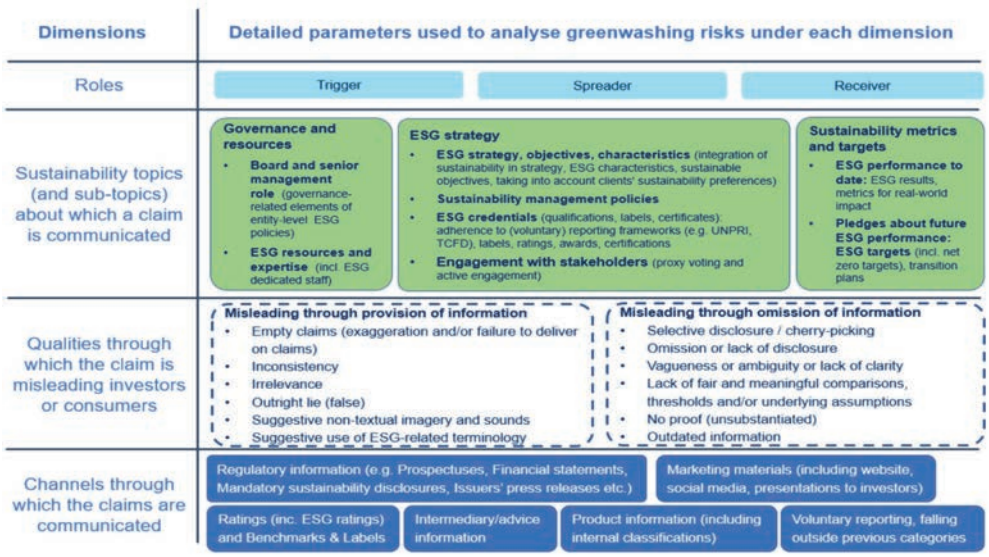
ii) the topics subject to greenwashing (claims about impact; engagement; present and future ESG performance such as net zero or more broad transition; ESG strategy, objectives and characteristics; ESG qualifications, labels and certificates and ESG governance, corporate resources and expertise);

iii) the ways in which a statement can be misleading;

iv) the qualities which make them misleading (*i.e.*, naming issues, cherry-picking, empty claims, etc.);

v) the different channels of communication of misleading statements (*i.e.*, marketing materials, voluntary reporting, labels, ESG ratings, etc.); misleading claims could be linked to provision or omission of information.

Figure 1 – Dimensions used to analyse greenwashing risks



Source: ESMA Progress Report on Greenwashing, 2023.

The report outlines the various channels through which misleading claims can be communicated.

The report focuses on four sectors under ESMA's remit and identifies areas more exposed to greenwashing risks and relevant potential remediation actions:

i) with regards to issuers, «*forward-looking information and pledges about future ESG performance appear to be particularly exposed to greenwashing risk. Enhanced transparency on underlying assumptions and parameters appears necessary to help investors make informed investment decisions taking into account the ambition and the credibility of sustainability commitments*»;

ii) sustainability claims appear particularly exposed to greenwashing risks in relation to investment_managers (*i.e.*, fund's or the manager's engagement with investee companies; ESG strategy, policies and credentials; ESG governance as well as claims on sustainability impact; fund names); «*mitigating these risks would require clarifications regarding the concept of contribution to a sustainable objective, standardized disclosures in particular for engagement and addressing the misuse of the Sustainable Finance Disclosures Regulation as a labelling regime*»;

iii) benchmarks are a key transmission channel for sustainability claims and data produced by issuers and ESG data providers. «*In terms of mitigation, enhancing the Benchmark Regulation's interaction with more recent pieces of the sustainable finance framework would be important as well as the introduction of a reliable label for ESG benchmarks and of naming conventions*»;

iv) for investment service providers, «*particularly exposed to greenwashing risks are claims about the extent to which advice offered to retail investors takes sustainability into account and situations where an advisor may not provide*

suitable personalized advice when presenting the sustainability features of products. In order to mitigate these risks, the regulatory framework could be strengthened concerning the concept of sustainability preferences, financial advisors' expertise improved and at the same time the ESG literacy of retail investors increased».

On 4 June 2024, the three ESAs published their respective Final Reports on greenwashing[10] which, confirming the analysis of the Progress Report, contain indications on the strengthening of supervision and the improvement of market practices related to sustainability statements.

The ESAs developed the common high-level understanding that «*greenwashing is a practice where sustainability-related statements, declarations, actions, or communications do not clearly and fairly reflect the underlying sustainability profile of an entity, a financial product or financial service. This practice may be misleading to consumers, investors, or other market participants*».

The ESAs also agreed that sustainability-related misleading claims can occur and spread either intentionally or unintentionally and that «*greenwashing does not require investors being actually harmed*».

The ESAs stressed that financial market participants must be responsible for the sustainability information provided, which must be fair, clear and not misleading. ESMA's Final report also highlights the areas of the sustainable investment value chain most exposed to the risk of greenwashing, identifying preliminary monitoring and remediation actions. ESMA found that misleading claims can relate to all key aspects of a product or entity's sustainability profile such as: ESG governance and resources, strategy, ESG policies and credentials, ESG performance objectives, and sustainability impact.

The Final Report recommends that National Competent Authorities (NCAs) continue to develop an integrated approach to sustainability supervision while strengthening and promoting the financial literacy of retail investors and explore the use SupTech and NLP tools to facilitate the examination of sustainability-related information.

It is highlighted that effective supervision relies on NCAs' access to relevant, high-quality and comparable data; the use of SupTech tools can enhance the efficiency of supervision, without replacing the professional judgement of the supervisors.

From a comparative point of view, though the FCA UK does not have a formal definition of greenwashing, its consultation on Sustainability Disclosure Requirements (SDR) and investment labels (CP22/20)[11] describes greenwashing as in relation to firms making exaggerated, misleading or unsubstantiated sustainability related claims about their products; claims that do not stand up to closer scrutiny. The FCA UK also noted

10 ESMA 36-287652198-2699, Response to the European Commission's request for input on 'greenwashing' risks and the supervision of sustainable finance policies, 4 June 2024.

11 CP22/20: Sustainability Disclosure Requirements (SDR) and investment labels.

that greenwashing may also occur at corporate level (about the entity, including its business relationships and counterparties).

In Guidance published in 2021, the Swiss FINMA referred to greenwashing as «*the risk that investors and clients will be consciously or unconsciously misled about the sustainable characteristics of financial products and services*». On 16 December 2022, the Federal Council of Switzerland published its position[12] on the prevention of greenwashing in the financial sector, mentioning that «*greenwashing occurs in the financial sector when, for example, a financial instrument or service is portrayed as having sustainable characteristics or pursuing sustainability goals, and this portrayal does not adequately reflect reality*». Greenwashing is not legally defined under the Securities and Futures Ordinance (SFO) in Hong Kong. However, the SFC Hong Kong mentioned in its Strategic Framework for Green Finance[13], issued in September 2018 that greenwashing refers to asset managers marketing themselves as 'green' or 'sustainable' but do not fully integrate these factors into the investment process.

3 Academic literature review and ESMA greenwashing research and analysis

3.1 Greenwashing in academic literature

The term greenwashing, first introduced by Jay Westerveld in 1986, lacks a universally accepted definition within academic literature. Indeed, as highlighted by Inês *et al.* (2023), greenwashing has a multifaceted nature and can be analysed from various perspectives. Aronczyk *et al.* (2024) emphasize that, at its core, it involves companies deliberately misleading stakeholders about their sustainability commitments to enhance their reputation, attract funding, or obscure controversial practices.

Researchers underline different but somewhat interrelated meanings of greenwashing such as 'selective disclosure', 'unsubstantiated or misleading claims', 'gap between environmental information disclosed and actual environmental performance' and 'overly positive beliefs about an organisation's environmental performance'. All these definitions refer to firms manipulating communication with the aim of creating a favourable, social and eco-friendly company image. According to this approach, researchers propose to assess the misalignment between two likely uncoherent behaviours: symbolic and substantive actions (Walker *et al.*, 2012; Donia *et al.*, 2016), reputational intention and real sustainability performance (Steiner *et al.*, 2018), symbolic communication and non-substantive actions (Lyon *et al.*, 2011), fake and real behaviour (Delmas *et al.*, 2011), low Corporate Social Responsibility (CSR) performance and high communication standards (Contreras-Pacheco *et al.*, 2017), sustainability behaviour and sustainability communication (Palazzo *et al.*, 2006). In addition, Lyon *et al.*, (2015) identify a non-exhaustive list of greenwashing behaviours

12 The Federal Council's position on the prevention of greenwashing in the financial sector.

13 SFC Strategic Framework for Green Finance, 21 September 2018.

such as selective disclosure, empty green claims and policies, dubious certifications and labels, ineffective public voluntary programs, misleading narrative and discourse and misleading visual imagery.

Most of the empirical analysis's focuses, indeed, on firms' ESG disclosure and pays attention to the discrepancies between what companies claim and their real ESG performance. In this regard, Dorfleitner *et al.* (2023) define greenwashing as 'selective disclosure', that is when firms hide negative information regarding firm's CSR and highlight only positive information. They are in line with Mahoney *et al.* (2013), who consider greenwashing as a selective positive disclosure which aims to impress stakeholders and mislead them. They develop a conceptual framework to measure greenwashing which is based on the difference between real green performance (*i.e.*, amount of CO2 emissions and number of ESG controversies) and apparent green performance (*i.e.*, if a sustainability board is in place textual self-representation, green marketing expenses and company joining some green voluntary initiative). Their measure is adjusted based on the firm's size and industry.

A similar approach is chosen by Yu *et al.* (2020) who measure greenwashing as the difference between the amount of ESG disclosure (measured by Bloomberg ESG disclosure scores) and ESG performance (identified by ESG scores provided by LSEG). The indicator is high when the company makes a big effort to reveal a large amount of ESG data, even if ESG performance is weak.

Ruiz-Blanco *et al.* (2022) measure the so-called CSR disclosure performance gap (Font *et al.*, 2012; Marquis *et al.*, 2016; Unerman, 2000; Wang *et al.*, 2018, Wiseman, 1982) as the distance between what is reported, based on the firms' disclosure through sustainability reports, and the company's commitment to sustainability evaluated by external parties (Bloomberg ESG scores). Wang *et al.* (2018) by referring to a sample of US companies, highlight that higher performing firms use highly readable narrative to disclose their CSR achievements, while lower performance companies use complex and less understandable language.

Birindelli *et al.* (2024) focuses on the relation between greenwashing and financial performance in the banking sector and investigates the moderating role of gender diversity. They measure greenwashing as the discrepancy between environmental disclosure, which is based on the Bloomberg Environmental disclosure score and effective environmental performance, which relies on the LSEG Eikon Environmental performance. Kathan *et al.* (2025) identify greenwashing cases related to the constituents of Stoxx Europe 600 from 2015 to 2023 and find that the highest number of greenwashing accusations occur among companies with high ESG scores (provided by LSEG and Bloomberg) and large sizes. Indeed, based on empirical evidence provided by the authors, these evaluations of firms' sustainable profile are negatively correlated with real green performance, thus highlighting the possibility that these scores may not reflect the actual environmental performance of companies.

Aronczyk *et al.* (2024) analyse the presence of greenwashing in the net-zero plans of the Canadian company 'Pathways Alliance'. They carried out a case study on the firm's documentation regarding net-zero plans and identify instances of

greenwashing due to the presence of selective disclosure and omission, misalignment of claim and action, displacement of responsibility, non-credible claims, specious comparisons, non-standard accounting and inadequate reporting.

Mateo-Márquez *et al.* (2022) examine voluntary corporate environmental disclosure on a sample of companies which participate in the 2015 Carbon Disclosure Project (CDP) report making their data public (444 firms from 12 countries at the global level operating in several sectors). They identify cases of greenwashing measuring the misalignment between carbon disclosure (CDP score) and environmental performance of firms and analyse, through an econometric model, the impact of climate change related regulative pressures on the likelihood of greenwashing. Their findings highlight that companies belonging to countries with robust climate regulations and rigorous monitoring of firms' compliance are less prone to greenwashing practices. Additionally, the probability of engaging in greenwashing rises with risk exposure, profitability and size of the firms.

Lastly, Rodriguez *et al.* (2024) analyse Colombian manufacturing companies and build up, by applying several machine learning techniques, measures which signal when environmental certifications do not correspond with tangible actions and eco-friendly programs leading to possible greenwashing cases. Deceptive manipulation occurs when certifications create misleading perceptions without concrete actions. The study highlights the vulnerability of some eco-labels and shows the need for substantial measurable actions to validate sustainability claims.

In conclusion, greenwashing has become a prominent topic across multiple academic disciplines, with a growing number of literature reviews being published recently, such as Sneideriene *et al.* (2025), who underline that greenwashing is a complex and multifaceted issue.

3.2 AI and greenwashing alert and detection

The complexity and nuance of greenwashing make manual detection both challenging and prone to bias. AI has the potential to issue greenwashing alerts or to detect greenwashing by identifying patterns and trends that may not be immediately apparent to human analysts (Tang *et al.* 2023) and can be used to analyse the language used in sustainability reports of companies accused of greenwashing (De Villiers *et al.* 2024). As a result, NLP techniques have gained traction in recent studies for detecting greenwashing (*i.e.*, Luccioni *et al.*, 2020; Schimanski *et al.*, 2024; Bingler *et al.*, 2022, 2024; Moodaley *et al.*, 2023). We refer to Calamai *et al.* (2025) for a survey on corporate greenwashing detection in text.

Lagasio (2024) quantifies ESG commitments using NLP, developing an ESG-washing severity index to measure discrepancies between corporate claims and actions. The author defines an ESG-washing index which is the difference between sentiment and sustainability score, and it is interpreted as a quantitative measure for the discrepancy between sustainability claims and tangible actions within each report.

Amel-Zadeh *et al.* (2021) combine NLP with machine learning to identify companies that contribute to the United Nations Sustainable Development Goals (UN SDGs). More broadly, NLP has proven to be a powerful tool for analysing corporate sustainability disclosures (Nemes *et al.,* 2022). Zhao *et al.* (2023) apply NLP techniques to measure inconsistencies between ESG sentiment indicators, computed based on companies' disclosure and external sentiment scores, stemming from Twitter. The sample includes 12 large pharmaceutical companies over the period from 2012 to 2022. The absence of a significant correlation between internal and external sentiments could signal potential greenwashing issues. Moreover, an innovative NLP-driven question and answer system is proposed, with the aim of making greenwashing monitoring faster and more accurate.

As research in this area expands (*i.e.*, Henao-Rodríguez *et al.*, 2024; Bingler *et al.*, 2022, 2024; Schimanski *et al.*, 2024; Calamai *et al.*, 2025), NLP continues to offer promising approaches for identifying greenwashing indicators in corporate reports.

Key development in this field is domain-specific pretraining, as proposed by Moodaley *et al.* (2023) and the fine-tuning of large language models (LLMs) like BERT (Bidirectional Encoder Representations from Transformers) for sustainability-related applications.

BERT is a state-of-the-art NLP model developed by Google, designed to capture contextual meaning by analysing word relationships bidirectionally—both left-to-right and right-to-left (Devlin *et al.*, 2018). One of its most significant features is domain adaptation, which allows BERT to be fine-tuned for specialized fields. By training on large text corpora and then optimizing for specific tasks like question-answering and sentiment analysis, BERT has given rise to domain-specific variants that continue to be updated.

Among these, ClimateBERT and ESGBERT have been specifically developed for sustainability-related applications. ClimateBERT focuses on climate-related texts, enhancing NLP applications in environmental science and climate policy analysis. Its training involves datasets centred on climate change discourse, enabling precise sentiment analysis and detection of misinformation (Webersinke *et al.,* 2022; Stammbach *et al.*, 2023). ESGBERT, on the other hand, is tailored for Environmental, Social, and Governance (ESG) data, improving the processing of financial and corporate texts with an ESG focus (Schimanski *et al.*, 2024). It might facilitate better insights into sustainability reporting and strengthen greenwashing alert and detection mechanisms.

Gourier *et al.* (2024) build up a news-implied greenwashing index which measures the fraction of climate-related news mentioning firms' greenwashing. In more detail, they apply NLP techniques on the history of paper-based Wall Street Journal articles between January 1986 and June 2022. The authors find several results based on the innovative measurement which they propose. Firstly, attention to greenwashing has consistently grown above all since 2018; in addition, financial sector has shown to be the main driver of this increasing trend given that it has been the main theme in greenwashing-related articles; other relevant topics are energy and construction sectors. Moreover, the news-implied greenwashing index significantly

impacts investors' behaviour both at institutional and retail levels; an unexpected growth of greenwashing news leads to a reduction of investments in green funds. Lastly, the index impairs the price discovery process because it tends to bias the estimates of climate risk premia.

Bingler *et al.* (2022) analyse the disclosures of companies that officially support the task force on climate-related financial disclosure (TCFD) by evaluating possible cases of 'cherry-picking', The authors apply ClimateBERT to identify climate-related financial information and find that voluntary disclosure commitments seem to suffer from 'cheap talk', which is non-specific, vague, superficial ESG disclosure, and that, notwithstanding the TCFD guidelines framework, companies prefer disclosure on non-material categories. Bingler *et al.* (2024) refined ClimateBERT algorithm by defining an innovative deep-learning tool called ClimateBertCTI which is applied to identify climate related cheap talk. Imprecise or inaccurate claims could be associated, indeed, with misleading information rising greenwashing risk. They also build up a sentiment score which captures the firms' sentiment towards climate change in terms of risk or opportunity.

3.3 Measurements of greenwashing risk in the sustainable debt market

Greenwashing is a relevant topic at corporate debt level given that creditors can trustily assess the company's value, lower their risk compensation and expect return rates, thereby reducing financing costs (Peng *et al.*, 2024; Roggi *et al.*, 2024). To our knowledge there are no academic papers providing empirical evidence on the presence of greenwashing in the green bond market using NLP techniques. Indeed, academic literature mainly relies on the analysis of market data by testing the relevance of the so called green premium or 'greenium', that is the additional cost associated with choosing environmentally friendly products. Gao *et al.* (2022) starting from the assumption that green bonds can constitute a signal of firms' commitments towards the safeguard of environment (Flammer, 2021), build up an adverse selection model which analyses the determinants of green bond premium over conventional bonds. They find that greenium exists when there is asymmetric information between bond issuers and bond buyers with respect to issuers' type, transition risks stemming from carbon pricing and it is costly to engage in greenwashing. Transition risk is the source of higher default risk for brown firms and enhances the value of green bonds leading to higher levels of greenium. Disclosure and reporting requirements could increase greenwashing costs and, therefore, reduce greenwashing.

Asl *et al.* (2024) measure the relationship between different green bond types (*i.e.*, S&P Green Bond Index, S&P Green Bond Select Index, S&P US Municipal Green Bond Index, S&P Green Bond US Dollar Select Index, S&P Global ESG Equity & Green Bond Balanced Index, and S&P Global ESG Equity & Green Bond Balanced 5% Decrement Index) and the so-called green economy[14]. The authors find that some green

14 The authors perform their analysis by using the NASDAQ OMX Green Economy Index.

bond types, like conventional, municipal, and currency-dominated green bonds, may be at risk of greenwashing due to the absence of a thorough permanent causal link with an ecologically sustainable economy.

Baldi *et al.* (2022) analyse green bond market data and find that funding of infrastructure projects with greater impact on the sustainability of target communities or territories are associated with lower yields, while higher greenwashing risk leads to greater returns as investors demand a premium for the increased risk. They carried out an econometric analysis on green bonds issued globally between 2012 and 2020, showing that greenwashing risk is more pronounced in the financial sector and among multinational or sovereign issuers. In addition, Xu *et al.* (2022) analyse the relation between greenwashing and green bond pricing in the Chinese market. They find that credit spreads are higher in the green bond market compared to that of traditional bonds. This difference tends to reduce if there is third-party certification. Green bond credit spreads, however, tend to vary depending on the trading venue and on the ESG performance of issuers.

3.4 ESMA research and analysis on greenwashing

As previously mentioned, ESMA considers investor protection from greenwashing a priority for financial market supervisors, as emphasized in its Progress Report on Greenwashing (2023) and its Final Report on Greenwashing (2024). In response, ESMA is conducting research and developing analytical tools to enhance financial supervision and identify potential cases of greenwashing more effectively. Amzallag *et al.* (2023) analyse all EU-domiciled investment funds investing in transferable securities between 2013 and 2023. The authors find an increasing percentage of funds using ESG language in their names (from 3% in 2013 to approximately 14% at the beginning of 2023). Nearly all funds choosing to use ESG language in their name preferred less specific ESG-related words. In addition, around 5% of actively managed equity bonds and mixed asset funds domiciled have enhanced their name with new words since 2018. Through the analysis of the differences in terms of ESG languages across fund document types (*i.e.*, investment strategies, KIID/KID, marketing documentation), they also reveal that funds with ESG-related language in their name show a wider ESG disclosure[15] in their investment strategy and KIID/KID than other funds. The share of ESG words in fund documents is coherent with the SFDR disclosure type (Article 8 funds use more ESG words than Article 6 funds, but fewer than Article 9 funds). Nevertheless, fund managers adapt their communication strategy to the expected types of clients (*i.e.*, retail investors vs institutional investors).

Mosson (2024) focuses on impact investing, that is investments with the clear goal to realize positive and measurable social and environmental impacts together with a financial return, by referring to the UN SDG framework. In particular, the author develops a methodology to identify SDG funds in the EU market based on the application of NLP techniques by searching for SDG-related terms in the fund's legal

15 ESG disclosure is measured by the number of ESG words.

name, the fund investment strategy and the KID. The paper highlights that SDG funds are few and do not significantly differ from non-SDG peers in terms of alignment with UN SDGs.

ESG controversies can be broadly defined, as they provide information on greenwashing perceptions, but they could be slightly different from greenwashing occurrences. Mazzacurati *et al.* (2023) analyse greenwashing controversies, that are allegations, put forward by stakeholders, regarding to perceived misalignment between sustainability-related communications and corporate actions by measuring impacts on stock returns and firm valuation. The data on allegations stem from RepRisk database, cover the period between 2020 and 2021 and involve European firms from the STOXX Europe 600 index. Misleading communication incidents referring to potential greenwashing behaviour are identified through text-based search. The authors find an increase in greenwashing controversies in recent years which are concentrated in few sectors, including the financial sector. The impact on firms' stock returns and market valuation of greenwashing controversies, however, is not clearly negative highlighting the absence of an effective market-based mechanism to help prevent potential greenwashing behaviour.

4 Green bonds

4.1 Definition and regulatory framework

Green bonds are bond instruments whose proceeds are used for financing or re-financing eligible projects aimed at achieving climate mitigation and adaptation goals, or other environmental goals[16]. Green bonds fall under the notion of financial instrument pursuant to Article 1, paragraph 1-bis, letter b), of Legislative Decree No. 58/1998 and similarly to traditional bonds, investors have a right of credit, equal to the repayment of the principal and the payment of interest accrued periodically, distinguishing themselves for the interest underlying the management of resources and the consequent control over the company's operations[17].

Initially issued mainly by supranational financial institutions (such as the European Investment Bank – EIB and the World Bank)[18], they have since become important financing instruments for individual companies, opening the market to corporate-type issues.

Until a few years ago, the regulatory context was characterized by the absence of a European standard of 'green' certification. Green bonds have, in fact, been issued in compliance, on a voluntary basis, with different standards and procedural guidelines developed by self-regulatory organisations operating internationally and based on voluntary adherence by issuers. Among these, the so-called Green Bonds

16 See OECD, Report on green, social and sustainability bonds issued by multilateral development banks and its use for infrastructure financing, 1 September 2023.

17 See Bassi *et al.* (2025), Greenwashing e tutela del consumatore per un'economia sostenibile.

18 The first green bond was issued in 2007 by the European Investment Bank. The following year, the World Bank, issued the World Bank Green Bond,

Principles (GBP) edited by ICMA and the CBI Climate Bonds Standards are the most widely accepted and recognized globally[19].

In particular, the ICMA GBP promotes integrity in the Green Bond market through guidelines that aim to encourage transparency, disclosure and reporting, strengthening market integrity. GBP consists of four fundamental components: 1. use of proceeds; 2. project evaluation and selection process; 3. management of proceeds; 4. reporting activities[20].

The critical issues relating to the degree of fragmentation and proliferation of the reference framework, together with the risk of greenwashing, have led the European legislator to intervene. On 30 November 2023, Regulation 2023/2631[21] on European green bonds (in implementation from 21 December 2024) was published, which introduces uniform requirements for the use of the 'European Green Bond' or 'EuGB' label by issuers (including non-EU ones) of bonds, providing for specific pre- and post-issuance disclosure obligations for them and the related supervision by the competent national authorities[22]. The regulation also establishes a centralized system at ESMA for registration and supervision of entities carrying out the external

19 CBI's standards complement the principles of ICMA and have been developed especially for investments that support the transition to a low-carbon and climate-resilient economy. Such standards are designed to be used as a certification mechanism that will help reduce the cost of capital for climate projects in developed and emerging markets. The CBI also provides its own taxonomy, the Climate Bond Taxonomy, to classify projects that can be financed through green bonds.

20 GBPs are a set of voluntary guidelines aimed at ensuring the transparency, disclosure, and integrity of green bonds. They do not set specific criteria for defining what constitutes a green project but focus on the process of issuance and disclosure. In fact, the ICMA principles require issuers: 1) to clearly communicate the projects to which the funds raised are intended; 2) to indicate the environmental benefits of the projects and the methods used to classify the projects in the categories of Green Projects identified by the guidelines; 3) to manage the sums collected for green projects separately from the others; (4) to prepare and make available updated information over time on the use of funds. ICMA provides a checklist covering the above areas, with reference to point 2., ICMA recommends: «*Issuers are also encouraged to identify alignment with market-wide green, social or development objectives, such as the Sustainable Development Goals (SDGs), to help investors that may use them as part of their investment decisions*».

Issuers are also recommended to appoint an external auditor to verify compliance with the GBP and monitor the management and allocation of proceeds. The latest version of the guidelines was published in 2021. However, in June 2022, GBP Appendix 1 was updated to distinguish between 'Standard Green Use of Proceeds Bonds' and 'Secured Green Bonds'.

The GBP principles were first drafted in early 2014 and continuously updated over the years, the latest version dates back to June 2021, to which an appendix was added in June 2022. See ICMA, Green Bond Principles, 2021, in https://www.icmagroup.org/assets/documents/Sustainable-finance/2022-updates/Green-Bond-Principles-June-2022-060623.pdf.

21 https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=celex%3A32023R2631.

22 Prior to issuing European green bonds, issuers will complete the EuGB factsheet set out in Annex I of the Regulation and ensure that the completed EuGB factsheet has undergone a pre-issuance review by an external auditor with a positive opinion. For each 12-month period until the date of full allocation of the proceeds of their European Green Bonds and, where applicable, until the completion of the CapEx Plan (the CapEx Plan, provided for in Article 7 of the Regulation, specifies a deadline, prior to the maturity of the European Green Bonds, by which all capital and operational expenditure financed by the European Green Bonds must be aligned with the Taxonomy), issuers of European green bonds will draw up a report on the allocation of European green bonds using the template set out in Annex II of the Regulation.

Issuers of European green bonds will be required to draw up, after the full allocation of the proceeds and at least once during the life of the bonds, an EuGB impact report on the environmental impact of the use of the proceeds of those bonds. In order to be able to use the European Green Bond or EuGB denomination, the issuer will have to publish a prospectus.

verification of information documentation relating to EuGBs[23], and provides for voluntary disclosure models for bonds marketed as 'environmentally sustainable' or as 'sustainability-linked bonds' without resorting to the EuGB label. These EU standards for green bonds are similar to the principles defined by ICMA but contain some more specific guidance; in particular, the funds raised with the bonds must be consistent with the EU taxonomy, green projects must comply with the requirement of 'do not significant harm ' to other environmental objectives, the certification must be provided, as mentioned, by companies included in a list managed by ESMA[24].

Furthermore, unlike the ICMA standard, the EuGBs adopts a much more rigorous approach by imparting perceptiveness to several aspects previously characterized by an exclusively programmatic nature. In fact, the previous regulatory framework, which was not sufficiently stringent and highly fragmented, together with the similarity between traditional bonds and 'green bonds', has facilitated the use of these instruments for purposes that have not always been effectively aligned with the pursuit of 'green' objectives.

The EuGB aims to effectively reduce the risk of greenwashing, especially in the pre-issuance phase, and to strengthen investor confidence in the market by imposing more stringent obligations on participating issuers than those provided for by current guidelines and private certification schemes. The aforementioned EU Regulation aims to overcome the critical issues of the *green bond* market and, in particular, the great fragmentation caused by the presence of several individual schemes which could make the characteristics and the structure of these instruments difficult to compare and understand, even though the adherence of issuers can only occur on a voluntary basis.

CONSOB[25], like the other NCAs, has supervisory and investigatory powers to ensure that issuers of European Green Bonds comply with the disclosure requirements

23 To improve the transparency of the external auditors' methodology, to ensure that external auditors have adequate qualifications, professional experience and independence, and to reduce the risk of potential conflicts of interest, and thus to ensure adequate investor protection, issuers of European green bonds will only use external auditors, including from third countries, that have been registered and are subject to continuous supervision by the ESMA. To ensure their independence and safeguard high standards of transparency and ethical conduct, external auditors will comply with organizational requirements and rules of conduct to mitigate and avoid situations of actual or potential conflict of interest or to appropriately manage such conflicts when they are unavoidable.

24 According to the Regulation, all proceeds from European green bonds must be invested in economic activities aligned with the EU taxonomy, provided that the sectors concerned are already covered by this taxonomy. For sectors not yet covered by the EU Taxonomy and for some specific activities, there is a 15% exemption. When the issuer allocates the proceeds of a European green bond, it must describe in the European green bond factsheet the activities concerned and the estimated percentage of the proceeds that will be allocated to finance those assets in total and on a per-asset basis.

It should also ensure that such activities do not cause significant harm to any of the environmental objectives and that they are carried out in compliance with minimum safeguards. Such evidence should be included in the European Green Bond sheet and should be validated by an external auditor through a positive opinion in the pre-issue review.

25 CONSOB is identified as the national competent authority pursuant to Article 44, paragraphs 1 and 2, of Regulation (EU) 2023/2631; to this end, CONSOB has the supervisory, investigative and precautionary powers provided for in Articles 18, paragraph 4, 45 and 48 of the aforementioned Regulation. In particular, Article 44 (*Supervision by competent authorities*) of Regulation provide that:

«*1. The competent authority of the home Member State designated pursuant to Article 31 of Regulation (EU) 2017/1129 shall supervise the following:*

set out in that Regulation: i) on the compliance with the reference legislation (Regulation (EU) 2023/2631) of the information relating to the issuance of green bonds[26]; ii) in general, on the verification, during the scrutiny of the prospectus, of the consistency of the information provided in the prospectus, with particular reference to ESG profiles; iii) on the information represented in the advertising material, in order to verify that it is not misleading and that it is consistent with the characteristics of the product and with what is reported in the prospectus.

Pending the first application of the Green Bonds Regulation and the amendments to the Prospectus Regulation resulting from the Listing Act and taking into account the importance of ESG issues for investors, ESMA, in its statement *'Sustainability disclosure in prospectuses'*, published in July 2023, invited issuers to consider, in the preparation of prospectuses, such issues when they are relevant for the decisions of investment. The statement also addresses the issue of advertising ESG characteristics of financial instruments not disclosed in the prospectus, inviting both issuers and competent authorities to assess the need to publish a supplement to the prospectus.

The market reacted rather favourably to the new European forecasts; in January 2025, A2A placed the first European green bond pursuant to Regulation (EU) 2023/2631 based on the offer documentation approved by CONSOB.

4.2 Green bonds evolution at the global level

Green bonds are fixed-income financial instruments designed to generate capital for projects with environmental benefits, including renewable energy, sustainable infrastructure, energy efficiency, and climate resilience initiatives. Introduced by the European Investment Bank in 2007, these bonds have gained widespread adoption among governments, corporations, and financial institutions. Their growth has been driven by increasing climate change awareness, regulatory

(a) issuers of European Green Bonds as regards compliance with their obligations under Title II, Chapter 2, and Articles 18 and 19;

(b) issuers that use the common templates provided for in Article 21 as regards compliance with those templates.

2. Competent authorities designated in accordance with Article 29(5) of Regulation (EU) 2017/2402 shall supervise the compliance of originators with their obligations under Title II, Chapter 2, and Articles 18 and 19 of this Regulation.

3. By way of derogation from paragraphs 1 and 2 of this Article, competent authorities shall not supervise issuers of European Green Bonds that are covered by Article 1(2), points (b) and (d), of Regulation (EU) 2017/1129».

26 In particular, the supervisory activity concerns:

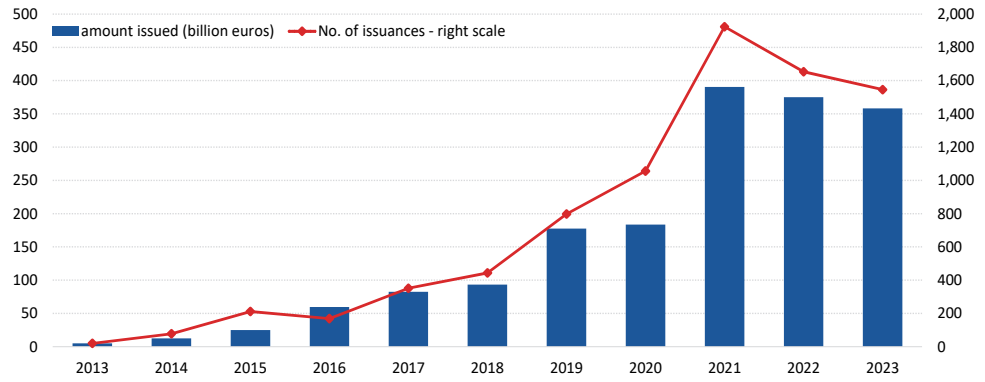
- the presence, within the prospectus, of the indication that «*the European green bond is issued in accordance with the EuGB Regulation in the section of the prospectus containing information on the use of proceeds*»; on the compliance of the offer documentation with the provisions of Article 14 of the EuGB Reg. and relating to the presence, within the entire prospectus, of the denomination of the bonds as 'European green bond' or 'EuGB';
- on the compliance by issuers of European green bonds with the obligations ascribed to them by Title II, Chapter 2, of the Regulation, with reference to the 'Transparency and external audit obligations', as well as Articles 18 and 19, in the case of a securitization obligation called the 'European Green Bond' or 'EuGB';
- on the fact that the issuer, prior to the issuance of European green bonds, has completed and published an information sheet (also known as a 'factsheet') according to the model set out in Annex I to the aforementioned Regulation; and that that information sheet has been pre-issued reviewed by an external auditor authorized by ESMA and that a favourable opinion has been issued.

incentives, and a rising demand for sustainable finance products. Unlike traditional bonds, green bonds are exclusively allocated to environmentally responsible projects, ensuring alignment with global sustainability objectives, such as the Paris Agreement and the United Nations Sustainable Development Goals.

In this section LSEG data on corporate green bond issuances from 2013 to 2023 at the world level are reported.

The issuance of corporate green bonds steadily increases until 2019, reflecting growing investor interest and corporate commitment to sustainability. After a temporary slowdown in 2020, the market surges in 2021, reaching a record high in total issuance volume. However, in 2022 and 2023, notwithstanding issuances remain historically high and above 2020 levels, a decline of total volume is registered from the 2021 peak. A similar pattern is observed in the number of issues, which rises consistently until 2020, doubles in 2021, and then slightly decreases over the next two years (see Figure 2).

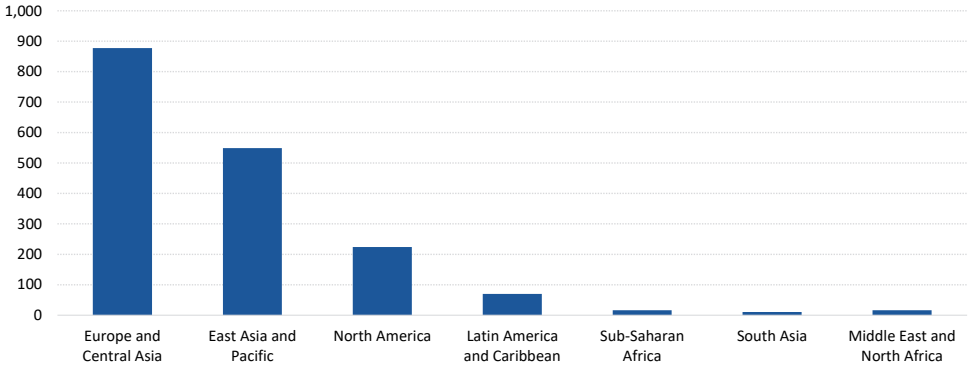
Figure 2 – Global green bond issuances



Source: LSEG.

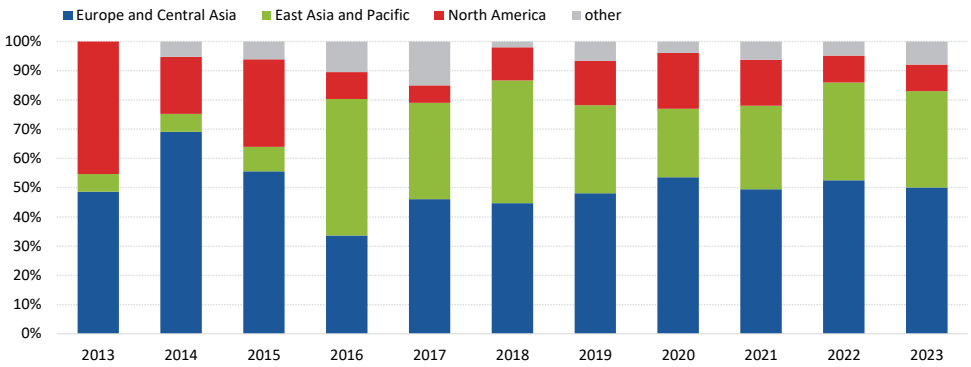
According to LSEG data, issuers in Europe and Central Asia account for half of the total green bond volume, reaching nearly 900 billion euros between 2013 and 2023, making Europe the leading region in this market. The East Asia and Pacific region follows with approximately 30% of total issuances (550 billion euros), while North America ranks third, contributing 13% (220 billion euros). At the country level, China leads global issuances with a 20% share, followed by the United States at 10%, while Germany and the Netherlands each account for 8%. These figures highlight regional disparities in green bond financing, with European and Asian markets at the forefront of sustainable debt issuance (Figures 3-4).

Figure 3 – Global green bonds by domicile
(total issuances from 2013 to 2023; billion euros)



Source: LSEG.

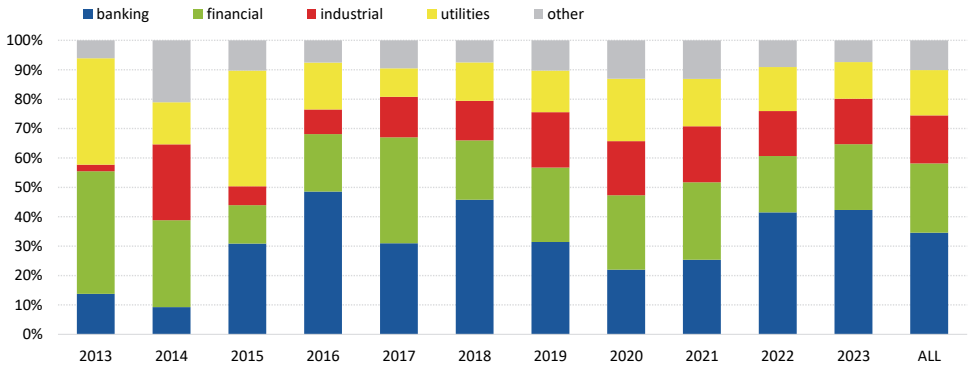
Figure 4 – Global green bonds by domicile and year
(percentage values)



Source: LSEG. Distributions refer to total annual amount of issuances.

Financial institutions – both banking and non-banking – dominate the market, representing over 50% of total issuance volume showing to have a crucial role in directing capital towards environmentally responsible projects through debt markets. Beyond finance, the industrial and utilities sectors each account for 15% of total issuance, reflecting the significant involvement of high-impact industries in green financing. These sectors require substantial investments to facilitate the transition to sustainable energy and infrastructure (Figure 5).

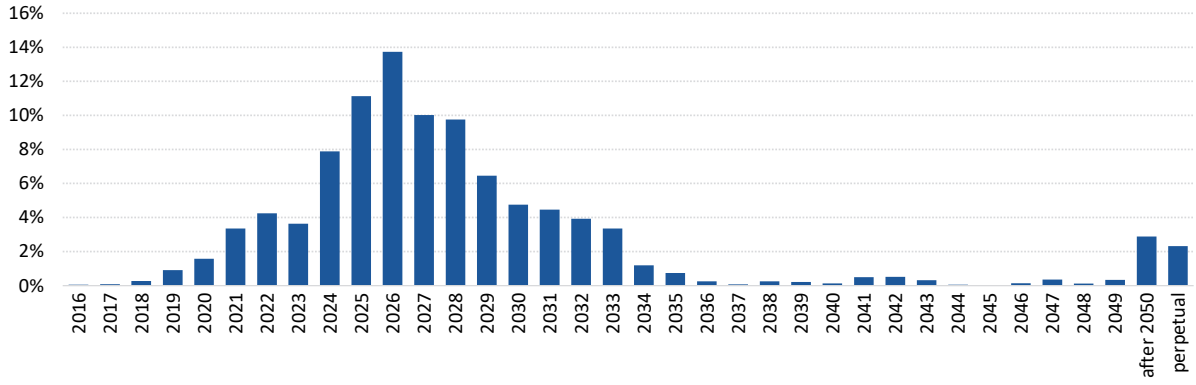
Figure 5 – Global green bonds by sector
(percentage values)



Source: LSEG. Distributions refer to total annual amount of issuances.

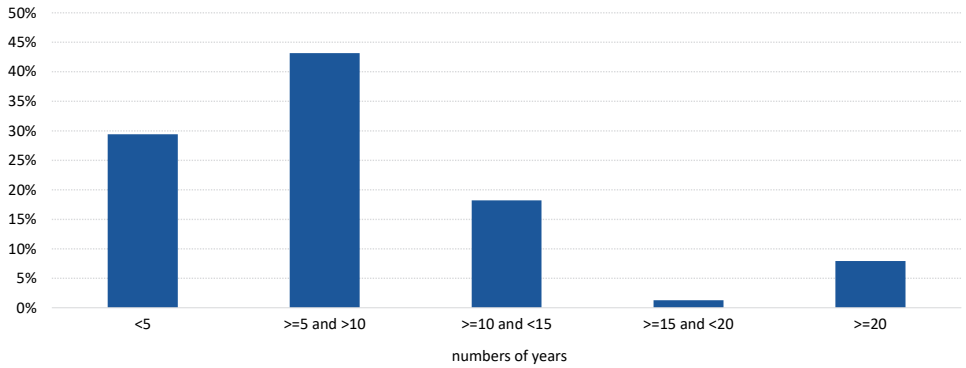
More than 50% of green bonds issued have maturities between 2024 and 2028, indicating a strong preference for medium-term financing. A smaller segment of the market consists of perpetual green bonds, which account for around 2% of total issuances, while those maturing beyond 2050 represent 3%, highlighting a limited but notable very long-term financing presence. Regarding tenor, green bonds are predominantly structured as short- to medium-term investments. Nearly 30% have a tenor of less than five years, while 43% fall within the five-to-ten-year range (Figures 6-7).

Figure 6 – Global green bonds by maturity
(total issuances from 2013 to 2023; percentage values)



Source: LSEG. Distribution refers to total amount of issuances from 2013 to 2023.

Figure 7 – Global green bonds by initial tenor
(total issuances from 2013 to 2023; percentage values)



Source: LSEG. Initial tenor is defined as the number of years between the date of issuance and the date of maturity. Distribution refers to total amount of issuances from 2013 to 2023.

4.3 Green bonds dataset

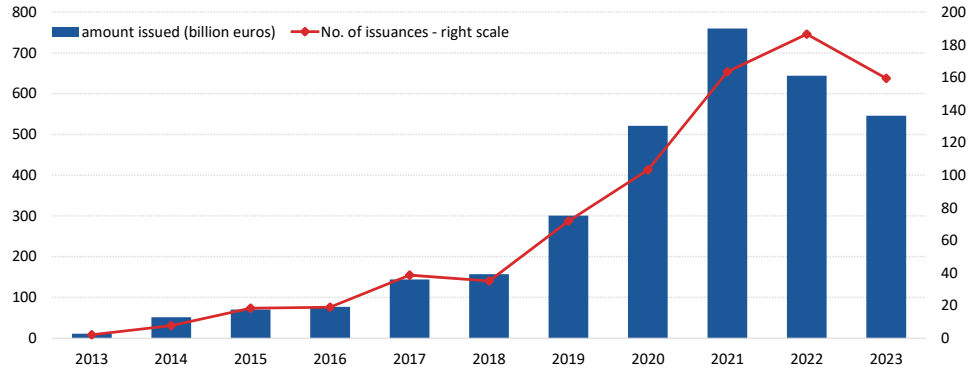
In this section, we report descriptive statistics on the green bond database built by considering issuers with domicile in Europe in the period 2013-2023. The database includes bonds identified as 'green' based on different standards and criteria by taking into consideration two data-providers. LSEG applies International Capital Market Association (ICMA) criteria to identify green bonds. FactSet provides data on bonds classified as green according to what is stated in the prospectus' section on the use of proceeds or in the final terms and conditions attached to the issue. The final sample includes corporate green bonds issued by firms domiciled in the European Union[27] from February 2013 to December 2023, for a total of 3,405 financial instruments that correspond to an issued amount of around 805,4 billion euros[28].

The volume and the amount in euros of the issuances show an upward trend until 2021 and 2022, respectively; afterwards, green bond issuances tend to remain on high levels even if decreasing, in line with what is reported in the previous section at the global level (Figure 8).

27 Therefore, issuer's domiciles could belong to the following list: Austria, Belgium, Bulgaria, Cyprus, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Hungary.

28 The issued amounts in euros were collected from the data provider FactSet, for the bonds for which data are available (96,4% of the cases). In the case of securities not issued in euros, the applied exchange rate refers to the issue date.

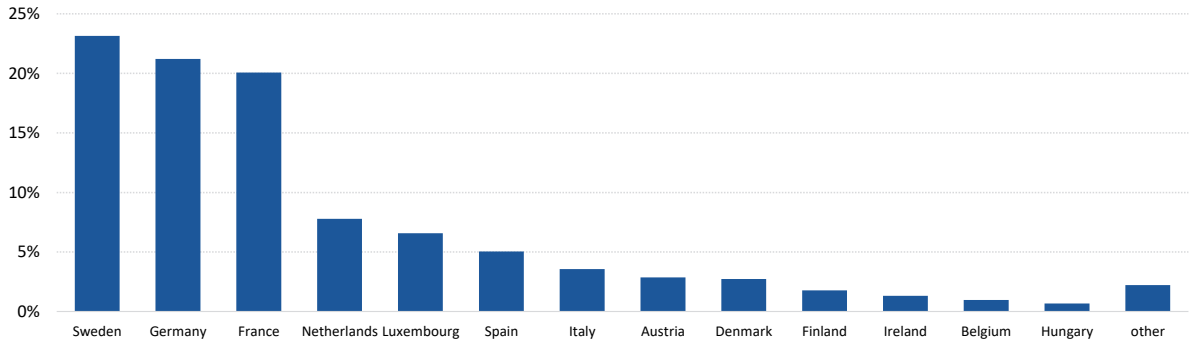
Figure 8 – Green bond issuances in the EU



Source: our elaborations on FactSet and LSEG data. The figure displays the evolution of green bond issuances in terms of number and amount issued (in billion euros). Issued bond amount is provided by FactSet.

It can be observed that green bonds are mainly issued by companies domiciled in Sweden (23%), Germany (21%) and France (20%; see Figure 9). The share of green bonds issued by Italian companies is approximately equal to 4%, that is less also than Netherlands (8%), Luxembourg (7%) and Spain (5%).

Figure 9 – Green bonds by domicile in the EU
(total issuances from 2013 to 2023; percentage values)

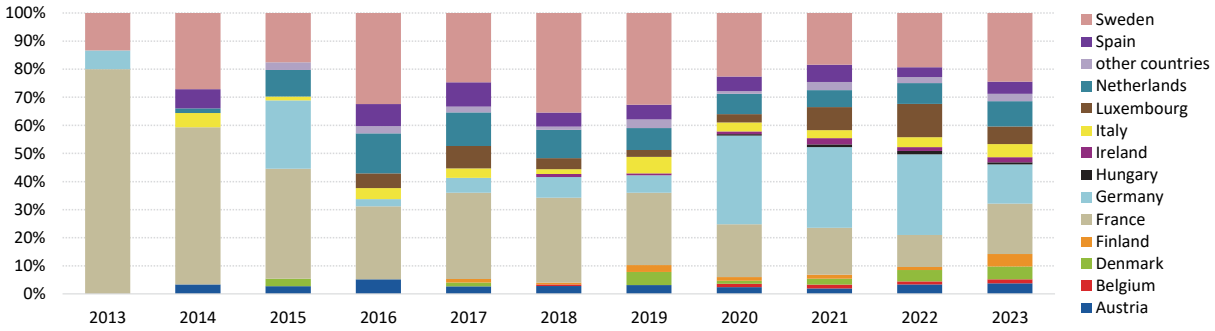


Source: our elaborations on FactSet and LSEG data. Distribution refers to total number of green bonds issued from 2013 to 2023. The classification of issuer's domicile is provided by LSEG.

Most of bonds issued in 2013 and 2014 refers to companies based in France (amounting to 80% and 56% respectively; Figure 10). The weight of bonds issued by companies domiciled in Sweden is almost stable over time with peaks in 2018 and 2019, whereas the relevance of German issuers tends to be high from 2020 to 2022. Bank bonds issues are the most frequent ones (40%), followed by other financial companies (25%), manufacturers (16%) and issuers belonging to the energy sector (9%; Figure 11)[29]. Banks tend to be the prevalent issuers in almost all periods of analysis; in particular, bank bonds represent 67% of the issues in 2013 (Figure 12).

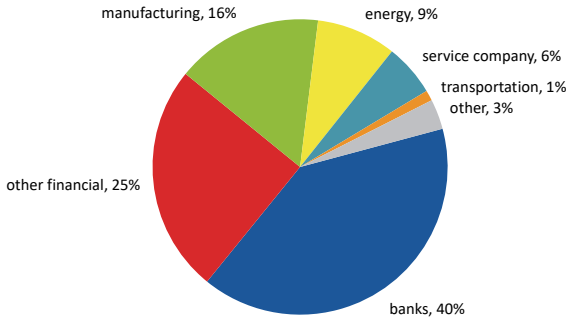
29 Referring to Italy and by considering all the period of time, 31% of the amount issued refers to banking sector, while the 36% to the energy sector.

Figure 10 – Green bonds by domicile and year in the EU
(percentage values)



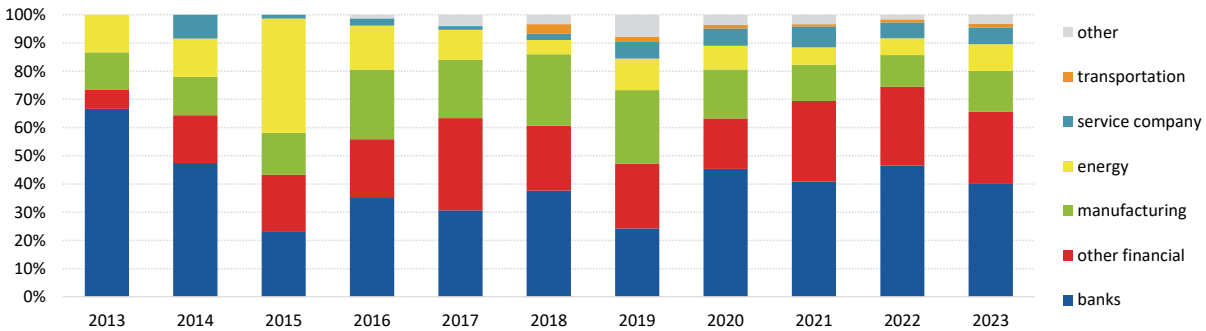
Source: our elaborations on FactSet and LSEG data. Distributions refer to the total annual number of green bonds. The classification of issuer's domicile is provided by LSEG.

Figure 11 – Green bonds by sector in the EU
(total issuances from 2013 to 2023; percentage values)



Source: our elaborations on LSEG and FactSet data. Distributions refer to the total number of green bonds issued from 2013 to 2023. The classification of issuers' sector is provided by LSEG. The category 'Energy' includes 'Electric Power', 'Energy Company' and 'Gas Distribution'. The category 'Other' includes 'Telephone', 'Agency', 'Consumer Goods'. Green bonds, which belong to the 'Agency' sector on the basis of LSEG, are classified as corporate bonds by FactSet and for this reason they are included in the sample.

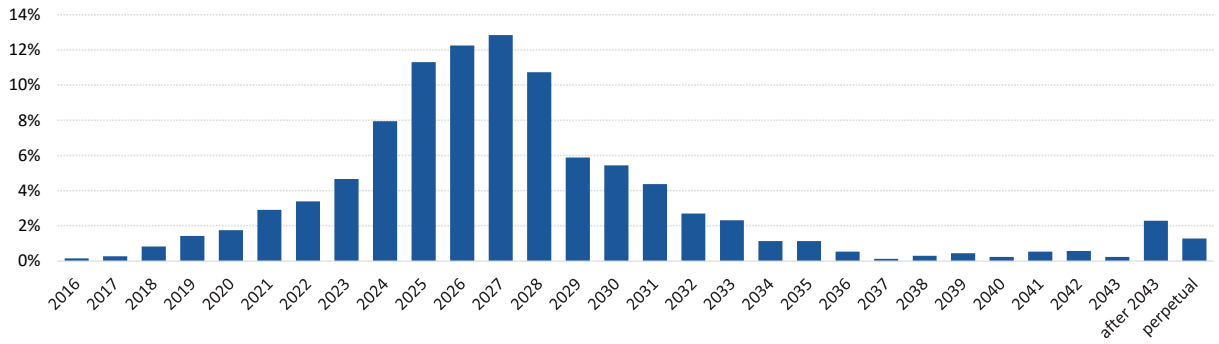
Figure 12 – Green bonds by sector and year in the EU
(percentage values)



Source: our elaborations on FactSet and LSEG data. Distributions refer to the total annual number of green bonds. The classification of the issuers' sector is provided by LSEG.

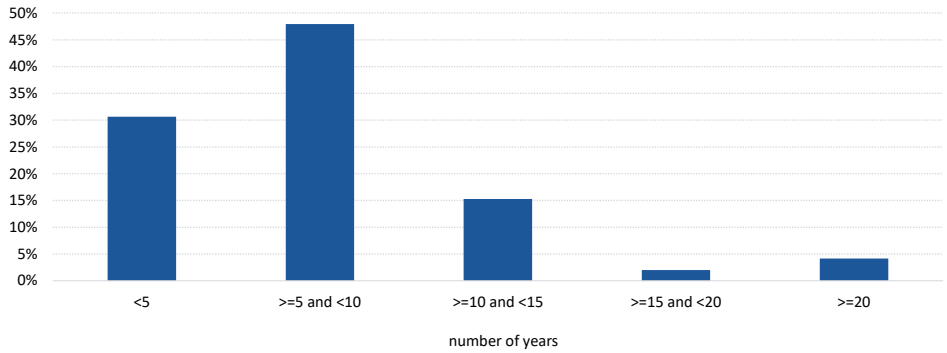
Regarding maturities[30], 55,8% of the green bonds included in the sample (corresponding to 1,852 securities) mature between 2024 and 2028; around 1% of green bonds are perpetual (Figure 13). Green bonds tend to represent short-medium investments; indeed, the most frequent classes of tenor[31] are 'less than five years' (31%) and 'five-ten years' (48%; Figure 14). Green bonds included in the sample are mainly fixed coupon bonds (62%); 31% have a variable coupon and only 6% are zero coupon (Figure 15).

Figure 13 – Green bonds by maturity in the EU
(total issuances from 2013 to 2023; percentage values)



Source: our elaborations on FactSet and LSEG data. Distributions refer to the total number of green bonds issued from 2013 to 2023. Maturities are provided by FactSet.

Figure 14 – Green bonds by initial tenor in the EU
(total issuances from 2013 to 2023; percentage values)

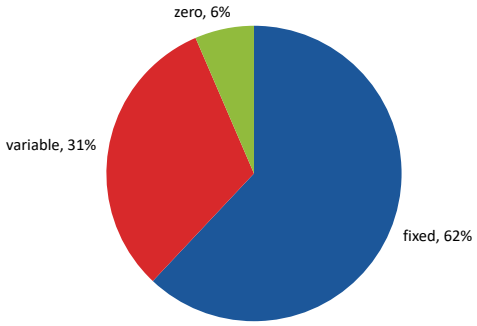


Source: our elaborations on FactSet and LSEG data. Distribution refers to the total number of green bonds issued from 2013 to 2023. Initial tenor is defined as the number of years between the date of issuance and the date of maturity. Tenor is provided by LSEG data.

30 Specifically, 42 bonds (representing 1%) were not included in the distribution, because maturity date was not available in these cases from FactSet.

31 The tenor is computed as the difference between the maturity date and the issue date using LSEG data.

Figure 15 – Green bonds by coupon type in the EU
(total issuances from 2013 to 2023; percentage values)



Source: our elaborations on FactSet and LSEG data. Percentage values refer to the total number of green bonds. The classification of coupon types is provided by FactSet. Coupon type data are not available in 42 cases.

Lastly, we analyse the news-implied sustainable profile of the issuers included in the sample by using ESG scores provided by FactSet[32], which applies AI techniques to gather information available on the web or published by the media after verifying their sources by a team of experts. Moreover, it collects analysts' views, industry-specific publications, studies conducted by government authorities, blogs, Twitter articles, reports published by NGOs (outside-in perspective)[33]. The volume score measures the information flow (*i.e.*, number of articles/news) and it can be also computed at pillar level (*i.e.*, environmental, social and governance). The pulse score is a synthetic indicator of the issuers' sustainable profile as it is implied in the news. It measures the near-term performance of the issuer by analysing recent events and it is, therefore, dependent also on the set of available information. The insight score is the long-term component of the pulse score and offers an historical perspective on the company's sustainability practices. Lastly, the momentum score tracks the trend of a company's ESG behaviour over time, indicating whether its performance is improving or declining. These scores range from zero to 100 with higher scores indicating better sustainability performance; when the indicators are less than 50, the company's ESG performance is negative; when they are above 50, issuer's sustainability performance can be considered positive.

On average, the news implied sustainability profile of issuers tends to keep high through all the analysed period based on both pulse and the insight score. The analysis of ESG score distribution, however, highlights some heterogeneity among scores above all in the lower and in the upper tails (Figure 16)[34]; the same results hold true if sector adjusted scores are taken into consideration (Figure 17). In addition, most of the news regards environmental issues as it can be detected by decomposing the volume score by pillar; consequently, news implied environmental profile tends to be

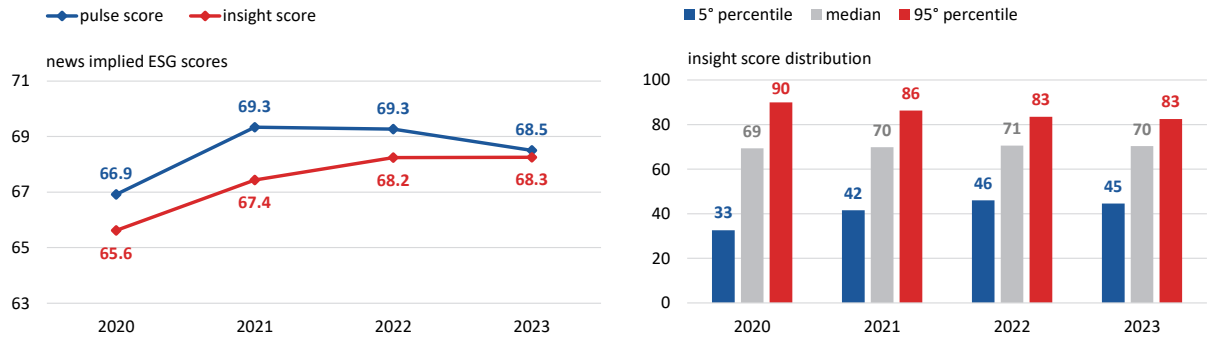
32 For reference see FactSet (2022): 'Truevalue Labs. Methodology Core Product' https://www.factset.com/marketplace/catalog/product/factset-truvalue-scores-and-spotlights.

33 Some examples of information sources are Automotive News, CleanTechnica, PharmaLive, Solar Industry, Hydrocarbon Processing, Fierce Telecom

34 Similar results have been obtained by considering momentum /pulse score distribution.

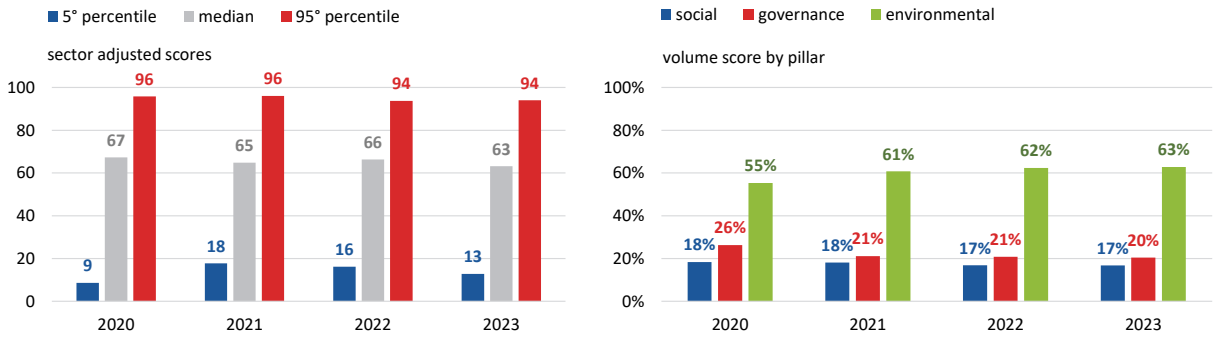
higher than the social and the governance ones (Figure 18). ESG scores do not show a high level of heterogeneity among domiciles and sectors, with the only exception of the group of banks whose sustainability performance is on average below other clusters of issuers (Figure 19).

Figure 16 – News implied sustainable profile of the issuers



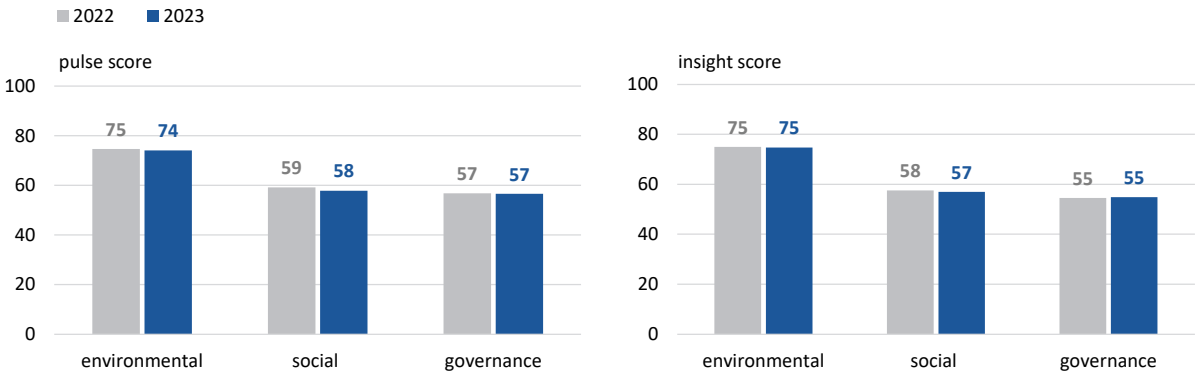
Source: our elaborations on FactSet data. Statistics refer to active bonds. On the left graph, year-on-year average values are reported. Issuers, included in the sample, with an ESG score are 241 in 2023, 238 in 2022, 209 in 2021 and 146 in 2020.

Figure 17 – Sector adjusted sustainable profile of the issuers and volume scores



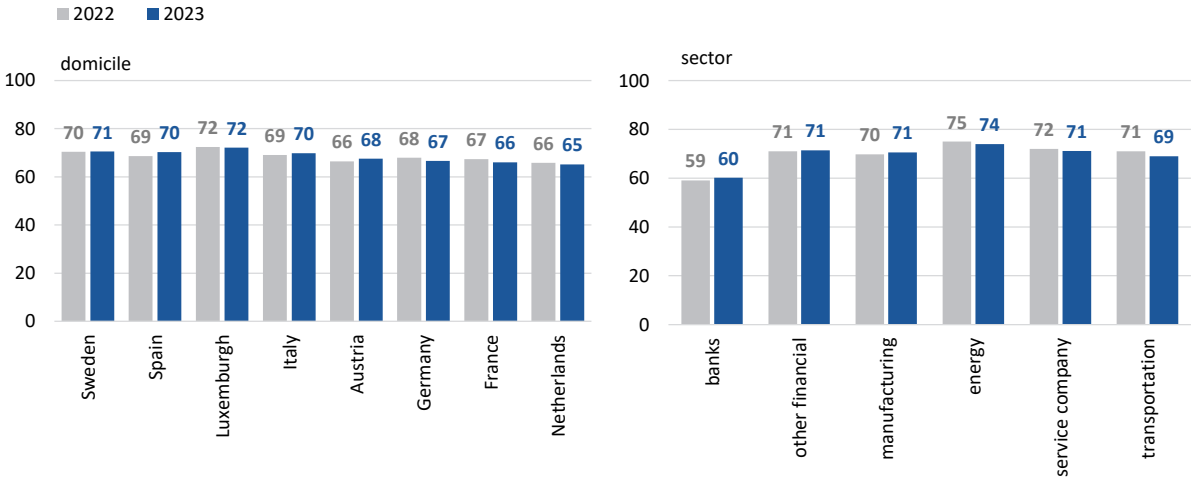
Source: our elaborations on FactSet data. On the right graph, the percentage of volume score by pillar is reported.

Figure 18 – ESG scores by pillars



Source: our elaborations on FactSet data. On the graphs year-on-year average values are reported.

Figure 19 – ESG scores by domicile and sector



Source: our elaborations on FactSet data. On the left-graph, the classification of issuer's domicile is provided by LSEG. On the right-graph, the classification of the issuer's sector is provided by LSEG. 'Energy' category includes 'Electric Power', 'Energy Company' and 'Gas Distribution'. 'Other' category includes 'Telephone', 'Agency', 'Consumer Goods'. Green bonds, which belong to the 'Agency' sector on the basis of LSEG, are classified as corporate bonds by FactSet and for this reason they are included in the sample.

5 Greenwashing alert prototype

5.1 Greenwashing alert prototype for green bonds issued in Europe

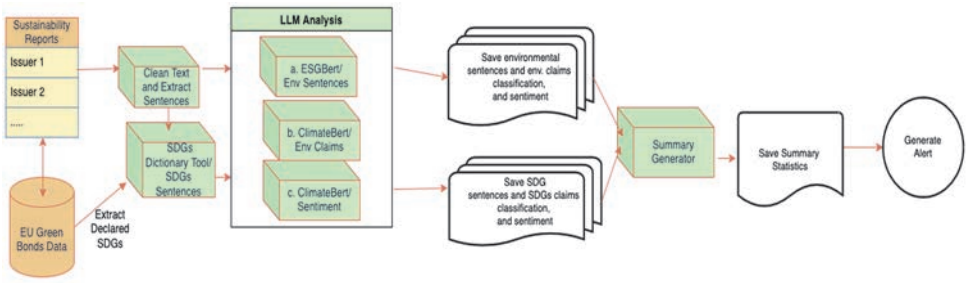
Developing a prototype to support regulators in giving alerts for potential greenwashing for green bonds is important, as the complexity and volume of environmental information and claims have grown significantly in recent years. NLP could play a valuable role in this effort by processing vast amounts of unstructured text data from a variety of sources, such as corporate reports, advertisements, press releases, and social media. By identifying key environmental phrases, claims, and sentiments, NLP tools could help regulators more efficiently pinpoint potential discrepancies or inconsistencies in the language used, which might indicate misleading environmental assertions and information omissions.

While NLP can enhance the speed and scale of these analyses, it is important to acknowledge its limitations. Language can be nuanced, and environmental sentences and claims often involve complex and context-specific terminology. NLP may struggle with understanding the full context in which these claims are made or distinguishing between genuine and misleading information in subtle cases. Therefore, the role of NLP in issuing greenwashing alerts should be seen as a complementary tool to human oversight rather than a complete replacement. A prototype that integrates NLP with expert review could provide regulators with a more efficient approach to tackling greenwashing, ensuring that environmental information and claims are thoroughly validated and aligned with sustainability regulations.

A key technology in NLP is BERT, an advanced language model developed by Google. BERT represents a state-of-the-art NLP framework with contextual understanding, that is BERT analyses the context of words by interpreting their relationships bidirectionally, *i.e.*, both left-to-right and right-to-left, allowing it to understand nuanced meanings in text. BERT has been trained in massive text corpora to understand general language patterns. Furthermore, relevant for the development of the prototype, several versions of BERT have been developed for specialized applications, including ESGBERT (Schimanski *et al.*, 2024) and ClimateBERT (Stammbach *et al.*, 2023; Bingler *et al.*, 2022, 2024) which are specifically tailored for analysing sustainability-related and climate-focused phrases and claims and their sentiment. Besides pre-trained models, relying on BERT, the first prototype developed also includes a dictionary-based tool, which by mapping the Green Bond Principles to Sustainable Development Goals allows to assess if the so-called a priori *declared* commitments to SDGs can also be *found* in the corporate sustainability documents.

The prototype, which can be considered a first attempt to support regulator's work in issuing alert for greenwashing for European green bonds, implements a structured process to analyse the sustainability reports for each issuer for each available year. Figure 20 below provides a schematic overview of the first CONSOB-UNITN prototype.

Figure 20 – The CONSOB-UNITN first prototype – a schematic overview



The prototype follows a procedure consisting of the following steps. First, the system begins by loading the sustainability report of an issuer for a given year and converting it into a machine-readable format. Once the text extraction is complete, it undergoes a cleanup process to remove noise and improve the quality of the sentences to be further analysed in the next steps.

In the first step, the prototype extract sentences from the full report and undergoes analysis using LLMs (*i.e.*, LLM-Based Full Report Analysis). This process involves applying three specialized models: (a) ESGBERT classifies sentences as either environmental or non-environmental[35]; (b) ClimateBERT, focused on environmental claims, detects specific claims about environmental issues, tagging sentences as either 'environmental claim' or not; (c) a specialized ClimateBERT model, dedicated to

35 Constraints are imposed to the algorithm and only social/governance sentences are detected.

sentiment analysis, categorizes sentences by tone, labelling them as 'Risk', 'Opportunity', or 'Neutral'.

In the second phase, the prototype extracts SDG-related sentences from sustainability reports using a proprietary dictionary-based approach. To ensure accurate attribution, the system constructs a dictionary that defines a set of keywords linked to each SDG identified by mapping the Green Bond Principles into SDGs[36] and integrating it with the dictionary used by LSEG for classifying the use of proceeds of GBs[37] Leveraging this enhanced dictionary, the tool identifies SDG-related sentences and classifies them using the LLM models applied in the first step. Specifically, ESGBERT categorizes sentences as environmental or not, ClimateBERT detects environmental claims and ClimateBERT Sentiment assesses the tone of the SDG-related sentences (sentiment analysis). This second round of LLM-based classification is performed exclusively on the SDG-related subset of sentences.

The whole procedure is repeated for all issuers for a given year, or it could be performed for a given issuer in multiple years. Lastly, the prototype consolidates and summarizes the findings from the previous steps, generating a structured output that presents summary statistics for all analysed issuer reports. Additionally, it performs an SDG attribution process to assess the degree of alignment between SDGs *declared* at issuer level, based on the information provided by LSEG regarding the use of proceeds from green bonds, and the SDG-related sentences identified directly in the sustainability report (SDGs found) using the dictionary tool, which enables SDGs labelling based on keywords search.

Based on the summary results, the prototype is designed to issue alerts when some predefined metrics indicate potential inconsistencies, that is when there is a significant mismatch between *declared* and *found* SDGs or when SDG information is entirely omitted. Additionally, sentiment indicators derived from the text analysis, such as an unusually high prevalence of positive or opportunistic language in contrast to objective environmental disclosures, could serve as further warning signals. These preliminary alerts have been established after analysing the prototype output for two greenwashing cases, as discussed in the following section. Further research is needed to refine and validate the specific metrics used to trigger alerts, ensuring their effectiveness in helping the analyst to further draw attention on some potential greenwashing cases to be then prioritized for further analysis.

The prototype represents a first step toward developing supervisory technology (SupTech) tools aimed at assisting analysts in assessing sustainability reports more efficiently and systematically. By identifying key areas such as environmental sentences and claims, SDG-related content, and discrepancies between

36 See https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/June- 2020/Mapping-SDGs-to-Green-Social-and-Sustainability-Bonds-2020-June-2020-090620.pdf

37 In the second phase, the prototype extracts SDG-related sentences from sustainability reports using a proprietary dictionary-based approach. To ensure attribution, the system constructs a dictionary that defines a set of keywords linked to each SDG identified by mapping the Green Bond Principles into SDGs. Such dictionary is then integrated with the dictionary used by LSEG for classifying the Use of Proceeds of GBs for the corresponding SDGs, as LSEG is using similar, but not identical, wording for each GBP.

declared and found SDG goals, as well as analysing the overall tone of the discourse, the system provides structured insights that can support regulatory and supervisory efforts.

By automating these processes, the prototype can significantly reduce the time[38] analysts need to manually review sustainability reports while also mitigating potential biases that can arise from subjective interpretation. Instead of relying solely on human judgment, which can be inconsistent or influenced by prior expectations, analysts receive structured, data-driven insights that enhance their ability to further prioritize and then analyse potential greenwashing cases. This systematic approach could not only improve efficiency but also strengthen the reliability and transparency of the analysis. As a first prototype, it serves as a foundation for future enhancements and refinements, paving the way for more advanced SupTech tools that can further support oversight and regulatory decision-making.

5.2 Testing the prototype

Besides the two greenwashing cases described in the following Subsection, the prototype was also tested on the green bond sample, offering further insights into its performance. Reports from 195 European issuers were collected for 2019-2023, when available. Non-English documents were excluded, as the models are fine-tuned for English sustainability issues. To address inconsistencies in report availability, a hierarchical selection was applied, prioritizing: (1) Sustainability Reports, (2) Annual and Sustainability Reports, and (3) other Non-Financial Reports. Henceforth, we will refer to all these documents as sustainability reports.

In 2022, sustainability reports were available for 192 issuers, and in 2023, for 180 issuers. These issuers account for approximately 70% (quote respect to total numbers) of all green bonds issued in Europe included in the database.

Table 2 shows that, on average for both years, about 35% of sentences are classified as environmental by ESGBERT, while only 6% are identified as environmental claims by ClimateBERT. Dictionary analysis reveals that sentences containing SDG-related content make up just over 1% of the total, with only 0.5% classified as claims, of which 1% are environmental claims. This highlights that by focusing on environmental sentences, claims, or SDG-related content, analysts can significantly narrow their review to a much smaller portion of the document.

38 For example, while an analyst might need about 4 hours to read a sustainability report containing 2,465 sentences (https://reading-time-calculator.com/), the prototype takes only about 10 minutes on a standard desktop. The prototype also saves the sentences along with their classification details, including environmental phrases, environmental claims, SDG-related phrases, their sentiment, and scores. For a report with 2,465 sentences, the analyst could then focus her attention on selected environmental sentences and claims with the following times: 1.5 hours (892 environmental sentences), 12 minutes (127 environmental claims), and 2 minutes (21 SDG-related sentences).

Table 2 – Descriptive statistics: classifications of sentence and claims

	2022		2023	
	mean	standard deviation	mean	standard deviation
quote of environmental sentences	34.7%	13.2%	35.1%	13.0%
quote of environmental claims	6.3%	4.2%	6.3 %	4.2%
quote of environmental claims of environmental sentences	17.7%	7.7 %	17.3%	7.9%
quote of SDG sentences	1.2%	1.6%	1.3%	1.3%
quote of no. SDG claims	0.5%	0.6%	0.4%	0.4%

Source: mean and standard deviation of relative frequency for environmental content, claims and SDGs on the total number of sentences.

Furthermore, ClimateBERT enables sentiment classification of extracted sentences as opportunity, risk, or neutral. On average while neutral sentiment dominates environmental content (about 62%), followed by opportunity (about 27%) and then risk (about 11%), the pattern shifts for SDG-related sentences, with nearly 55% classified as opportunity, followed by neutral (about 41%) and risk (4%; Table 3). Mean values are stable throughout the years. This suggests that SDG statements tend to be more opportunistic, potentially indicating a higher level of confidence when making SDG related statements.

Table 3 – Descriptive statistics: Sentiment Analysis

	2022		2023	
	mean	standard deviation	mean	standard deviation
quote of sentiment neutral on environmental sentences	61.9%	10.8%	62.8%	10.7%
quote of sentiment opportunity on environmental sentences	27.3%	12.5%	26.2%	12.4%
quote of sentiment risk on environmental sentences	10.8%	5.5%	11.0%	5.4%
quote of sentiment neutral on SDG sentences	41.4%	23.5%	41.1%	23.5%
quote of sentiment opportunity on SDG sentences	55.0%	23.9%	54.3%	24.6%
quote of sentiment risk on SDG sentences	3.6%	6.0%	4.7%	10.0%

Source: mean and standard deviation of relative frequency for Sentiment classification.

In 2022, we have no declared SDGs for 24 issuers, and this number increased to 29 in 2023. This suggests that for a subset of issuers there is inconsistency between SDG declared and found. Such discrepancies could warrant further investigation to assess whether they stem from a lack of commitment to sustainability or potential efforts to obscure environmental impact or other reasons.

Additionally, for 16 issuers in 2022 and 9 in 2023, no SDGs were identified through the dictionary-based analysis, even though these issuers had declared some SDGs. This discrepancy is particularly noteworthy, as it mirrors a pattern observed in a known greenwashing cases (*i.e.*, Issuer A for years 2022-2023 and Issuer B for the entire period). In that instance, the declared SDGs were not substantiated within the actual content of sustainability reports, raising concerns about the credibility of the disclosures. As a result, similar cases should be prioritized and subject to further scrutiny.

Figure 21 presents a bar plot comparing the frequency of SDGs declared and SDGs found in 2023 across different SDG goals. As expected, not all SDGs that issuers declare can be identified through dictionary-based analysis of sustainability reports. This discrepancy underscores the importance of investigating the SDG Mismatch, defined as the difference between the number of SDGs declared and those found through textual analysis. The extent of this mismatch is further visualized in Figure 22.

The distribution of SDG Mismatch is asymmetric. While 80 issuers exhibit no mismatch – meaning all their declared SDGs were identified in their reports – others display varying degrees of inconsistency. Specifically, 46 issuers have a mismatch of 2, while 27 issuers show a mismatch of 3. These figures suggest that SDG declarations are not always fully reflected in the textual content of sustainability disclosures, raising concerns about the information provided.

When considering the case of Issuer A in Section 5.3.2 as a potential instance of greenwashing, we noticed it exhibited at least three missing SDGs in the years 2021-2022. Given these findings, a ranking could be established to trigger an alert when the SDG Mismatch exceeds it.

Still, it must be acknowledged that the inability to detect SDG-related sentences may also stem from limitations in the keyword definitions used by the dictionary tool, as well as from the use of alternative means – such as figures – in sustainability reports to convey information on the SDGs.

Figure 21 – Sustainable development goals distribution Università (2023)

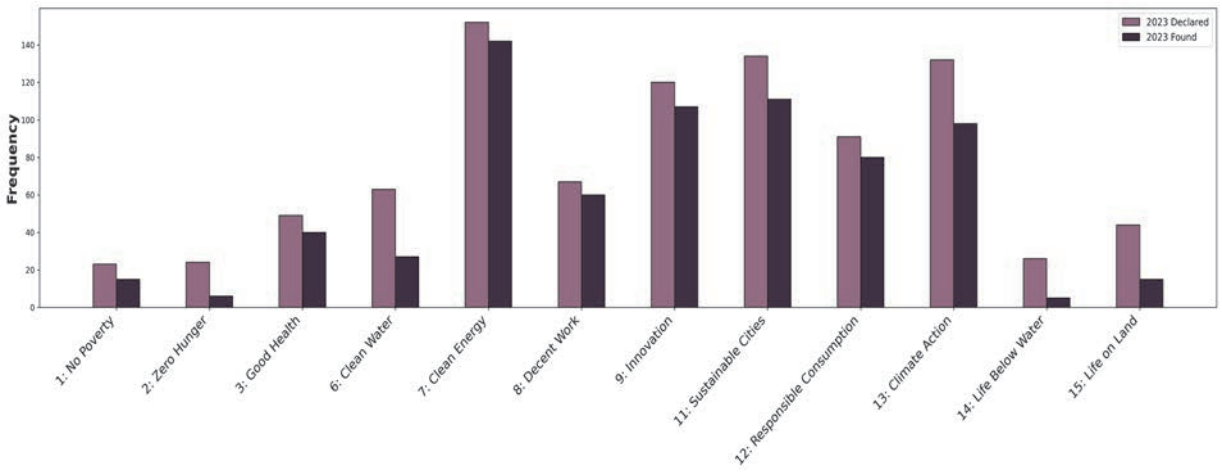
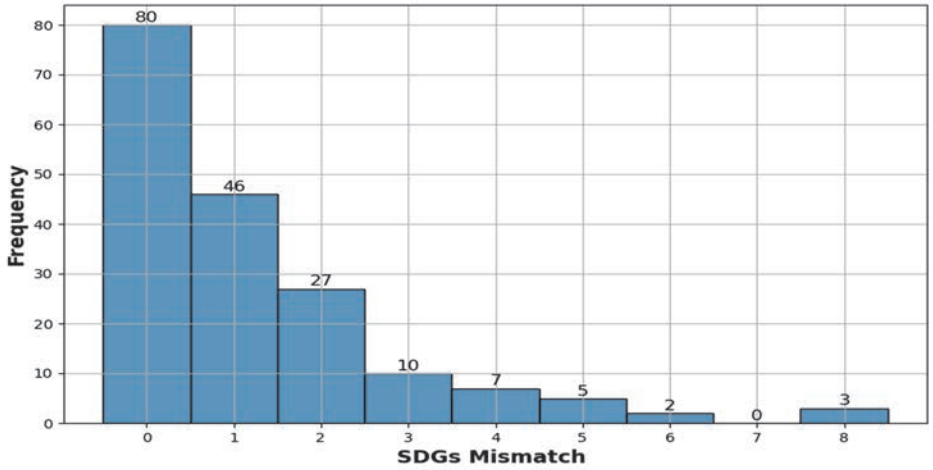


Figure 22 – SDG Mismatch
(2023)



5.3 Greenwashing use cases

5.3.1 Mapping of greenwashing cases

Detecting greenwashing cases reliably is particularly challenging due to the limited and only recently mandated environmental and social reporting standards for firm disclosures. Calamai *et al.* (2025), reviewing 61 research works, report the absence of publicly available greenwashing cases as one of the main limitations for corporate greenwashing detection in text.

According to ESMA[39], identifying greenwashing phenomena is hindered by several challenges, including the lack of detailed methodologies or guidance, insufficient resources and expertise, and the absence of explicit legislation at both national and EU levels. Moreover, in the realm of prospectuses, the pre-approval process has helped mitigate the risk and occurrence of greenwashing.

As reported before, the European Supervisory Authorities (ESAs) define greenwashing as the practice where sustainability-related statements, declarations, actions, or communications do not clearly and fairly reflect the underlying sustainability profile of an entity, financial product, or financial service. This practice can mislead consumers, investors, or other market participants. Misleading communications can occur due to the omission of relevant information (including partial, selective, unclear, unintelligible, vague, oversimplistic, ambiguous, untimely information, and unsubstantiated statements) or the provision of false information that deceives or is likely to deceive stakeholders.

39 See ESMA Final Report on Greenwashing, https://www.esma.europa.eu/sites/default/files/2024-06/ESMA36-287652198-2699_Final_Report_on_Greenwashing.pdf

Therefore, based on the above definition, we have developed a multi-layered approach. First, we map alleged or actual greenwashing practices reported by external sources. Second, we assess these allegations through quality checks based on publicly available information. However, caution should be exercised when interpreting the analysis due to the alleged nature of the claims. This approach aims to mitigate the risks associated with relying solely on abstract methodologies, while acknowledging the intrinsic limitations of this method[40].

In-depth research was conducted to identify cases of greenwashing that occurred between 2012 and 2023, focusing on companies that make up the EU Stock Index – Stoxx 600[41] because of its broad representation as it includes 600 of the largest publicly traded companies across 17 European countries.

We explored information included in the FactSet database by carrying on a text-based content search regarding the word 'greenwashing' in all news related to companies belonging to EU Stoxx 600 index. Another source of information taken into consideration is Sustainalytics through its ESG Risk Rating Portfolio Report also in this case with reference to EU Stoxx 600 index.

The research conducted using FactSet and Sustainalytics has identified 10 cases of alleged or confirmed greenwashing among the companies.

Therefore, we expanded the research sample through manually collected greenwashing cases from research on websites of EU markets and securities authorities and national competent authorities.

Using the above manual search tool, we identified additional 30 cases of greenwashing related to listed or non-listed entities.

A total of 40 cases of alleged or confirmed greenwashing related the company in general (therefore not distinguishing at this stage between green bonds or other financial products) were identified, mainly concerning: use of unclear, misleading language and/or the omission of relevant information in advertisements; inconsistency between the information provided in marketing materials and regulated information; forward-looking information regarding future ESG performance (*i.e.*, net zero emissions targets and information on contributions to the United Nations SDGs; Table 4).

40 Even if firms comply with regulatory requirements, accusations of greenwashing can arise when the accusing party has a different perspective on what constitutes 'green'. Firm-level greenwashing could arise, for example, when a firm might claim to be on the path to net-zero carbon emissions in its production process, while its strategy primarily involves purchasing carbon offsets from questionable issuers rather than materially reducing emissions.

41 The STOXX Europe 600 is a broad measure of the European equity market. With a fixed number of 600 components, the index provides extensive and diversified coverage across 17 countries and 11 industries within Europe's developed economies, representing nearly 90% of the underlying investable market.

Table 4 – Summary of greenwashing cases

sector	no. of cases	main findings
finance	16	a. forward-looking information: adoption of net-zero emission strategies, wh investments (loans and securities portfolios) are directed towards highly pollutinç changes to the ESG rating calculation methodology without transparent com potentially spreading incorrect information about companies' sustainability profiles; c information in marketing materials about the nature of investments (funds are rep compliant with Article 9 SFDR, even if a significant percentage of investments are direc polluting sectors); d. issuance of green bonds whose projects seem indeed to destroy of various animals.
energy	10	a. misleading advertisements where companies make deceptive statements about investments, while omitting the actual percentage of investments in oil and gas; b. sustainability-linked credit lines seem to partially finance fossil fuel investments, aimed at net-zero targets, while companies appear to continue investing in fossil fuel
consumer staples	5	a. misleading advertising regarding the actual environmental characteristics of the pro packaging (*i.e.*, eco-friendly detergents, biodegradable diapers, eco-friendly plastic bo of raw materials); b. net-zero emission targets, yet the actions taken by compan contradict these goal
industrials	4	a. net-zero emission targets, yet the implemented strategy does not seem orien achieving the goals; b. production process emissions exceeding regional law limits bu with national limits.
consumer discretionary	3	a. sustainability targets modified before the maturity; b. misleading advertising sustainability of materials used in the production of the finished product
others	2	missing information

Out of 40 cases identified, 27 concern listed companies and only 2 of these firms results as issuers of green bonds during the period under investigation[42].

5.3.2 Testing and evaluating the prototype with the greenwashing cases

The prototype was then applied to two cases involving the alleged greenwashing identified before. The following sections provide: a detailed description of the two cases, and the primary evidence supporting the application of the greenwashing alert system to these cases. Below, we provide two uses cases referring to issuers of green bonds, which have been detected with the procedure described in the previous section.

Issuer A, which is a financial institution that offers advisory service and financial support to the economic transition primarily through three key areas of action, aligning its financial activities with long-term sustainability goals.

This firm issued green bonds in the years 2019, 2020, 2021, 2022 and 2023.

The news regarding greenwashing was published in 2023. In particular, the whistleblower accused Issuer A of having increased the volume of loans to specific high climate risk sector (coal, oil and gas), during the first half of 2022, despite the financial institution having declared its commitment to pursuing net zero targets.

42 We excluded a company fully owned by UK consolidating parent and a greenwashing case occurred before the period under investigation.

Issuer B is an energy company that produces and markets energies: oil and biofuels, natural gas and green gases, renewables and electricity. The energy company supports the objectives of the Paris Agreement, which calls for reducing greenhouse gas (GHG) emissions in the context of sustainable development and eradicating poverty, and which aims to hold the increase in the planet's average temperature to well below 2°C above pre-industrial levels.

The green bonds of Issuer B were issued in 2021, while the news of the alleged greenwashing was published in 2022, based on an investigation conducted in 2021. The case involved a lawsuit filed in 2021 by a group of non-profit organisations about the issuer's advertising campaign. According to the plaintiffs, the advertisement may have been in tension with European consumer protection laws, particularly considering Issuer B's planned investments in fossil fuel projects, which they argue could undermine the credibility of the carbon neutrality target.

The three functions of the prototype (identification of environmental phrases and claims, sentiment analysis and identification of SDG phrases and SDG mismatch) were applied to the alleged greenwashing cases of firms A and B to assess whether, prior to the greenwashing event, the application of the prototype would have been able to identify a greenwashing alert. For this reason, the three functions of the model were applied over the period 2015-2023, using the sustainability reports of the two issuers published during the period under investigation.

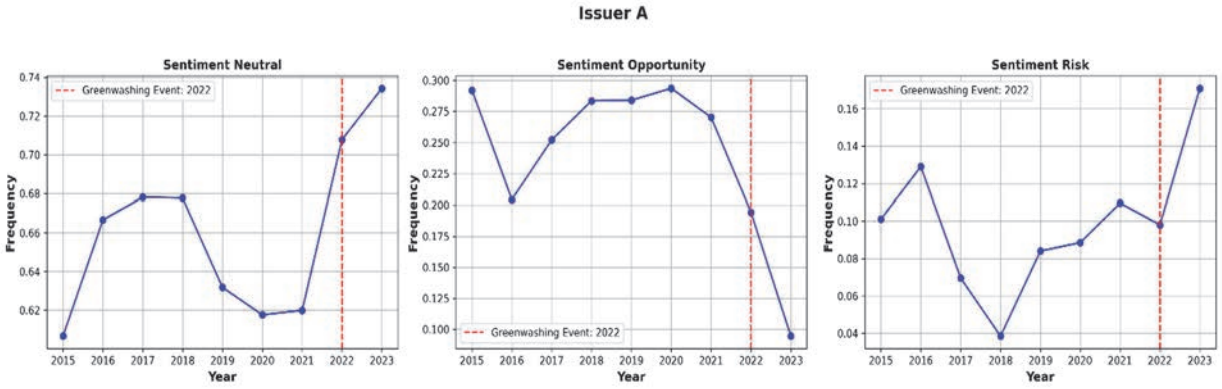
Several NLP-derived key metrics increased before the greenwashing event (GWE), and following that event there was a notable decline for both Issuer A and Issuer B. Specifically, the proportion of environmental phrases relative to environmental content for Issuer A followed an upward trend, reaching a peak in 2021 and beginning to decline from 2022, while for Company B, the trend continued to rise until 2022. While, after the GWE this metric for both issuers experienced a particularly sharp decrease, highlighting a significant drop in the frequency of environmental claims within the remaining environmental content.

Furthermore, for Issuer A, the proportion of SDG claims relative to the total environmental phrases exhibited an upward trend starting from 2020, reaching a peak in 2022; following the GWE, this indicator experienced a significant decline. As for Issuer B, no consideration can be made, since, as stated below, the prospectus of Issuer B does not include any SDGs. These trends reveal that both issuers before the GWE registered an increasing trend in the proportion of environmental phrases relative to environmental content in their sustainability reports. Moreover, findings observed a substantial shift in the companies' communication strategies post-greenwashing event, potentially as a response to increased scrutiny and the need to rebuild credibility.

The application of the sentiment analysis using Climate BERT on the sentences of the sustainability reports published by Issuer A and B, allowed us to explore the intensity of climate-related disclosures, categorized into Risks, Opportunities, and Neutral Tone, within the total environmental content. The results indicate the following trends. For Issuer A, the sentiment analysis reveals that the opportunity sentiment for Issuer A begins to decline after 2020 in the years just before the identified

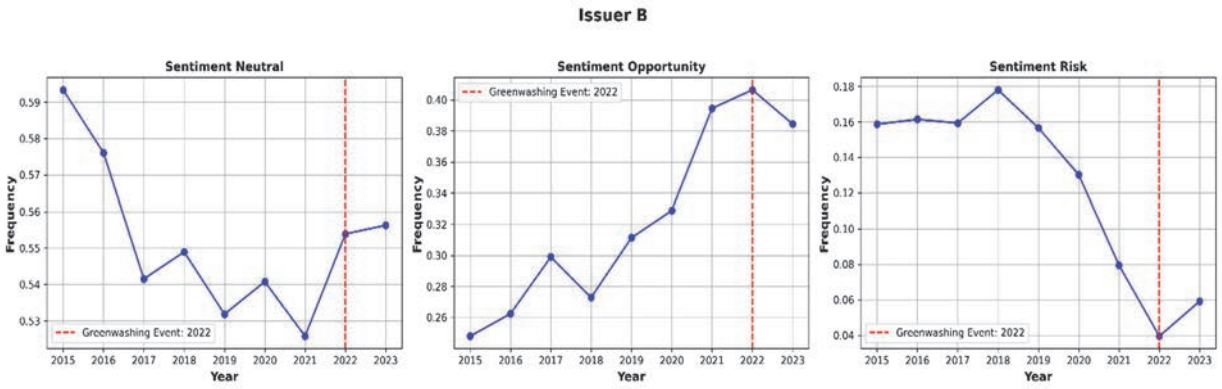
greenwashing event. This decline is accompanied by an increase in the risk sentiment, suggesting a shift in the company's communication strategy towards emphasizing potential risks more prominently than opportunities. This change may reflect a growing awareness of environmental challenges or a strategic response to external pressures linked to the alleged greenwashing event (Figures 23 and 24).

Figure 23 – Issuer A's climate-related disclosures by tone: Risks, Opportunities and Neutral



For Issuer B, the opportunity sentiment shows a significant decrease following the greenwashing event. This decline occurs after a prolonged period of increasing opportunity sentiment, indicating a notable shift in the company's narrative. The greenwashing event appears to have prompted Issuer B to adjust its communication, possibly to use more risky or neutral sentences.

Figure 24 – Issuer B's climate-related disclosures by tone: Risks, Opportunities and Neutral

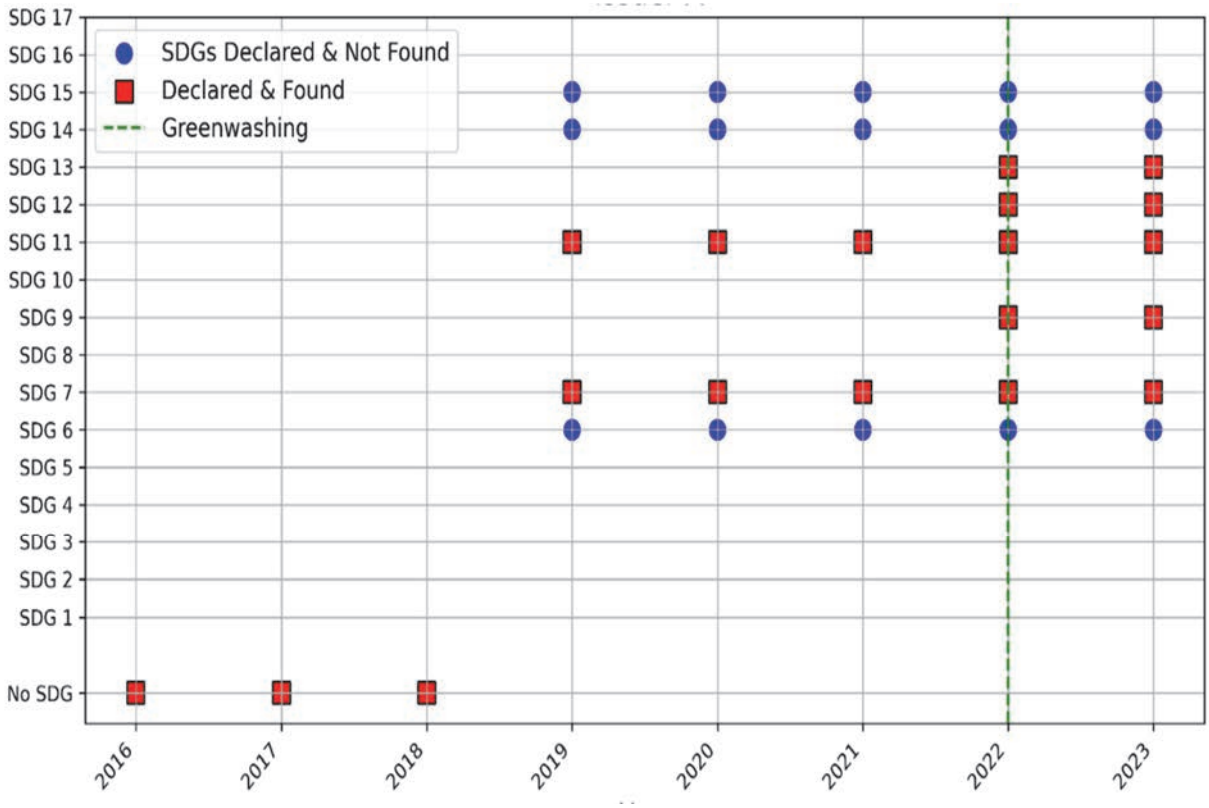


These findings indicate that both companies exhibited similar path configurations of the sustainability report content before the GWE, characterized by numerous opportunistic statements. Following the GWE, they made significant changes to their sustainability reports, likely in response to increased external scrutiny and the necessity to present a more balanced perspective on risks and opportunities.

Lastly, the analysis of SDGs declarations and the corresponding mismatches between the SDGs declared in the prospectus and those found in the sustainability report (referred to as SDGs mismatch) provides significant insights into the transparency and consistency of corporate sustainability claims. The SDGs mismatch function was employed to evaluate the alignment between declared and actual SDGs.

Starting from 2019, Issuer A declared five SDGs. This number increased to eight SDGs from 2022. However, the CONSOB-UNITN prototype, revealed that three of these SDGs were not mentioned in the sustainability reports. This discrepancy between the declared and found SDGs for Issuer A could raise concerns about potential greenwashing practices. Moreover, throughout the entire assessment period, the prospectus for Issuer B, as evaluated by LSEG, did not include any SDGs. The absence of SDG declarations by Issuer B could indicate a lack of transparency regarding the use of proceeds from green bonds (Figure 25).

Figure 25 – Issuer A's SDG Mismatch



6 The CONSOB-UNITN prototype as support in the supervisory activity

In this section we are going to highlight possible use of the prototype as support in the supervision activity.

Firstly, during the approval phase of prospectuses, both SDG mismatch detection function and sentiment analysis function can be leveraged to find whether the prospectus meet the standards of completeness, comprehensibility and consistency necessary to an investor for making an informed assessment. Particularly, as reported in ESMA's public statement of July 2023, 'Sustainability Disclosure in Prospectuses[43]', in relation to 'use of proceeds' bonds, ESMA expects disclosure about the use and the management of the proceeds and information enabling investors to assess the sustainability ambition underpinning the process for project evaluation and selection. Moreover, in relation to risk factors, ESMA expect that issuers of 'use of proceeds' bonds should disclose risks that are material and specific to the security. Risks regarding the allocation and management of proceeds should be disclosed as well as risks concerning the viability and achievement of the sustainable project. In this regard, the prototype could help in scrutinising the information provided by the issuer in line with ESMA expectations.

Specifically, first the Prototype could help officers in identify a risk profile of the issuer. In particular, the sentiment analysis of environmental and claim related phrases in the sustainability report helps evaluate the issuer's disclosure approach in relation to sustainability information. The prototype supports the understanding of whether the sustainability disclosure is excessively skewed toward opportunistic focused language rather than incorporating environmental statements with risk or neutral sentiment. In detail, ESMA advises issuers to ensure transparency in sustainability-related disclosures within prospectuses. ESMA expects that issuers clearly state the basis for any sustainability claims, such as adherence to specific market standards or labels, referencing relevant data, assumptions, or third-party research. This could ensure more objectivity, by presenting both positive and negative aspects to provide a balanced perspective.

Secondly, the SDG mismatch function[44] could identify the absence or lack of SDG-related disclosures, such as in the case of Issuer B (see Section 5.3.2). This may indicate a lack of transparency and omission of information regarding the allocation of green bond proceeds. In such cases, in line with ESMA expectations, disclosures should include details on the use and management of proceeds, and information to help investors assess the sustainability goals of project evaluation and selection. Therefore, during the prospectus scrutiny phase, the prototype could help in checking the material information about the proceeds and how they are allocated for sustainable purposes.

43 ESMA public statement, https://www.esma.europa.eu/sites/default/files/2023-07/ESMA32-1399193447441_Statement_on_sustainability_disclosure_in_prospectuses.pdf

44 For example, the declared SDGs can be manually input by the responsible official.

Moreover, in line with the above-mentioned ESMA Statement, if issuers of 'use of proceeds bonds' provides post-issuance information, the SDG mismatch function could help assess whether the issuer's declarations in the prospectus (*i.e.*, in case of a supplement) align with the information found in the annual allocation report. In its Final Report on Greenwashing, ESMA recommends that NCAs conduct risk-based supervision of sustainability reports. The prototype's 'sentiment analysis using ClimateBERT' and 'SDG mismatch' functions can help identify riskier sustainability documents such as sustainability reports or marketing materials. Specifically, if the sentiment analysis of an issuer's sustainability report reveals an excessive number of opportunistic statements exceeding a predefined threshold, a risk alert could be triggered. This could indicate the need for further scrutiny to ensure that sustainability-related risks are properly disclosed.

The above mentioned ESMA report on greenwashing also highlights that information regarding contributions to the UN SDGs, both past and forward-looking, appears particularly vulnerable to greenwashing risks. Therefore, if the analysis of SDG declarations identifies significant discrepancies between the SDGs stated in the prospectus and those referenced in the sustainability report (referred to as SDG mismatch), as observed for Issuer A, further analysis could be needed, and the issuer may be required to provide clarifications to enhance the transparency of the sustainability report.

Another possible application of the prototype is the compliance with EU Green Bond Regulation (Regulation (EU) 2023/2631 - EuGB) of the information about the use of proceeds raised by an issuer and the verification of marketing materials of EU Green Bonds.

As mentioned above, the EU Green Bond Regulation was published in the *Official Journal of the EU* on 30 November 2023. Following its entry into force on December 20, 2023, its provisions became applicable on December 21, 2024. According to Article 45[45], national competent authorities (NCAs), in accordance with national

45 In order to fulfil their duties under this Regulation, competent authorities shall have, in accordance with national law, at least the following supervisory and investigatory powers:

(a) to require issuers to publish the European Green Bond factsheets referred to in Article 10 or to include in those factsheets the information referred to in Annex I;

(b) to require issuers to publish reviews and assessments;

(c) to require issuers to publish annual allocation reports or include in annual allocation reports the information referred to in Annex II;

(d) to require issuers to publish an impact report or include in the impact report the information referred to in Annex III;

(e) to require issuers to notify the competent authority of the publication in accordance with Article 15(4);

(f) where issuers use the common templates provided for in Article 21, to require those issuers to include the elements referred to therein in their periodic post-issuance disclosures;

(g) to require auditors and the senior management of the issuer to provide relevant information and documents;

(h) to suspend an offer or admission to trading on a regulated market of European Green Bonds for a maximum of 10 consecutive working days on any single occasion where there are reasonable grounds for suspecting that the issuer has failed to comply with an obligation pursuant to Title II, Chapter 2, or Article 18 or 19; OJ L, 30.11.2023EN ELI: http://data.europa.eu/eli/reg/2023/2631/oj 37/68

law, have supervisory and investigatory powers over EU Green Bond issuers. These powers include, among other things: requiring the provision of relevant information and documents, such as annual allocation reports and suspending or prohibiting advertisements for up to 10 days. The SDG mismatch function allows to verify whether the information provided in the prospectus aligns with sustainability report, in accordance with Article 38, letter d)[46], of the Commission Delegated Regulation (EU) 2019/980. If an SDGs mismatch is detected, as in the case of Issuer A, it triggers a greenwashing risk alert. Consequently, in the prospectus section related to the use of proceeds, the issuer should clearly outline the goals and characteristics of the relevant sustainable project, along with how the stated sustainability objectives are expected to be achieved. Indeed, to verify the use of proceeds raised by an issuer through the issuance of EU Green Bonds, the prototype could be enhanced by integrating a dictionary-based tool leveraging tailored taxonomy-based information. This would help assess whether the issuer's declarations in the prospectus align with the information found in the annual allocation report. Additionally, given the supervisory powers of NCAs over marketing materials, the prototype, using the taxonomy-based dictionary, could be utilized to verify whether the issuer's statements in the prospectus regarding the use of proceeds are consistent with the information presented in related marketing materials.

(i) to prohibit an offer or admission to trading on a regulated market of European Green Bonds where there are reasonable grounds for suspecting that the issuer continues to fail to comply with an obligation pursuant to Title II, Chapter 2, or Article 18 or 19;

(j) to suspend advertisements for a maximum of 10 consecutive working days, or require issuers of European Green Bonds or financial intermediaries concerned to suspend advertisements for a maximum of 10 consecutive working days on any single occasion where there are reasonable grounds for suspecting that the issuer has failed to comply with an obligation pursuant to Title II, Chapter 2, or Article 18 or 19;

(k) to prohibit advertisements, or require issuers of European Green Bonds or financial intermediaries concerned to cease advertisements where there are reasonable grounds for suspecting that the issuer continues to fail to comply with an obligation pursuant to Title II, Chapter 2, or Article 18 or 19;

(l) to make public the fact that an issuer of European Green Bonds fails to comply with this Regulation, and to require that issuer to publish that information on its website;

(m) to prohibit an issuer from issuing European Green Bonds for a period not exceeding one year if an issuer has repeatedly and severely infringed Title II, Chapter 2, or Article 18 or 19;

(n) following a three-month period after the requirement referred to in point (l) of this subparagraph, to make public the fact that the issuer of European Green Bonds no longer complies with Article 3 as regards the use of the designation 'European Green Bond' or 'EuGB', and to require that issuer to publish that information on its website;

(o) to carry out on-site inspections or investigations at sites other than the private residences of natural persons, and for that purpose to enter premises in order to access documents and other data in any form, where a reasonable suspicion exists that documents and other data related to the subject matter of the inspection or investigation may be relevant to prove an infringement of this Regulation.

46 Article 38: «*For the purposes of scrutinising the consistency of the information in a draft prospectus, the competent authority shall consider all of the following: (a) whether the draft prospectus is free of material discrepancies between the different pieces of information provided therein, including any information incorporated by reference; (b) whether any material and specific risks disclosed elsewhere in the draft prospectus are included in the risk factors section; (c) whether the information in the summary is in line with information elsewhere in the draft prospectus; (d) whether any figures on the use of proceeds correspond to the amount of proceeds being raised and whether the disclosed use of proceeds is in line with the disclosed strategy of the issuer; (e) whether the description of the issuer in the operating and financial review, the historical financial information, the description of the issuer's activity and the description of the risk factors are consistent; (f) whether the working capital statement is in line with the risk factors, the auditor's report, the use of proceeds and the disclosed strategy of the issuer and how that strategy will be funded.*»

7 Conclusions

Green bonds, a subset of GSS (green, social, and sustainability) bonds, are financial instruments used to fund environmentally sustainable projects.

The benefits of green bonds include financing the green transition, attracting ESG investments, reducing capital costs, providing regulatory incentives, and enhancing corporate reputation. However, as demand for sustainable investment products rises, the risk of greenwashing also increases, which can undermine investor confidence, harm market integrity, and slow down the transition to a sustainable economy.

According to ESMA, identifying greenwashing is challenging due to the lack of detailed methodologies, insufficient resources and expertise, and the absence of clear legislation at both national and EU levels. However, the pre-approval process in prospectuses has helped reduce the risk of greenwashing.

We developed a prototype for greenwashing alert system leveraging on large language models such as ClimateBERT and ESGBERT, along with a proprietary dictionary that defines set of keywords linked to each SDG identified by mapping the GBPs into SDGs.

In depth, the prototype encompasses three key functions, supporting CONSOB's supervisory activities in three areas. First, the prototype can identify environmental phrases and environmental claims in selected documents such as the sustainability report, tagging them accordingly as 'environmental' or 'environmental claim'. Second, the prototype can provide the sentiment of each sentence of sustainability reports using ClimateBERT and classify sentences into three categories: risk, opportunity, or neutral, depending on the tone of the content. Third, the prototype performs a dictionary-based search to extract SDG-related phrases from the sustainability report and identify to which SDGs such sentences refer to (labelled as 'Found SDGs'). It then compares them with the Declared SDGs (SDGs stemming from LSEG's use of proceeds information[47] collected from prospectus or other information) of the active Green Bonds in the reference year (SDG mismatch function).

The prototype represents a first step toward developing supervisory technology (SupTech) tools aimed at assisting analysts in assessing sustainability reports more efficiently and systematically. By identifying key areas such as environmental sentences and claims, SDG-related content, and discrepancies between declared and detected SDG goals, as well as analysing the overall tone of the discourse, the system provides structured insights that can support regulatory and supervisory efforts.

By automating these processes, the prototype can significantly reduce the time[48] analysts need to manually review sustainability reports, while also mitigating

47 See LSEG, (2022) ESG Bonds, An overview of Refinitiv data on the fast-growing sustainable bond market.

48 For example, while an analyst might need about 4 hours to read a sustainability report containing 2,465 sentences (Source: https://reading-time-calculator.com), the prototype takes only about 10 minutes on a standard desktop. The prototype also saves the sentences along with their classification details, including environmental phrases,

potential biases that can arise from subjective interpretation. Instead of relying solely on human judgment, which can be inconsistent or influenced by prior expectations, analysts receive structured, data-driven insights that enhance their ability to further analyse potential greenwashing cases. This systematic approach could not only improve efficiency but also strengthen the reliability and transparency of the analysis.

As a first prototype, it serves as a foundation for future enhancements and refinements, paving the way for more advanced SupTech tools that can further support oversight and regulatory decision-making by taking into consideration also the evolution of the regulatory framework regarding sustainable finance.

The application of the prototype to the alleged greenwashing cases demonstrates the tool's potential in issuing greenwashing alert signals to the analyst to determine which cases to prioritize for further analysis.

This study underscores the importance of rigorous analysis of corporate sustainability claims to ensure transparency. The prototype's ability to identify discrepancies between declared and actual SDGs highlights its value as a tool for enforcement activities aiming to assess the risk related to corporate sustainability disclosure. Future research could further explore the prototype's capability and reliability in issuing greenwashing alerts also referring to new EU green bond regulation.

* * *

As highlighted in the 'greenwashing use case' section, the prototype has not been yet completely validated and tested due to the limited number of greenwashing cases. Consequently, the prototype would need an in-depth validation to be enhanced.

However, even now, the prototype triggers greenwashing alerts in a very short time, giving insights useful for carrying on further investigations and examining prospectuses. Even if at a first stage, it results to be flexible for future enhancements and refinements, paving the way for more advanced SupTech tools.

The prototype developed by CONSOB in collaboration with the University of Trento is a significant example of regulatory innovation enabled by a multidisciplinary integration of skills. Its development required the convergence of data science, advanced semantic and linguistic analysis, applied research in artificial intelligence and deep expertise in supervisory practices. Crucially, it also demanded a robust understanding of the extensive regulatory landscape governing ESG instruments, particularly green bonds.

Such combination of competences has been essential not only to shape a tool tailored to the actual needs of financial supervision, but also to ensure its alignment with key principles of accountability, transparency, and legal compliance as articulated

environmental claims, SDG-related phrases, their sentiment, and scores. For a report with 2,465 sentences, the analyst could then focus her attention on selected environmental sentences and claims with the following times: 1.5 hours (892 environmental sentences), 12 minutes (127 environmental claims), and 2 minutes (21 SDG-related sentences).

in the European Union's AI Act. Moreover, this multidisciplinary foundation will remain critical in the model's fine-tuning phase and in its potential scalability across other supervision domains where similar risks of mismatch or misrepresentation exist.

From a legal standpoint, the prototype can be qualified as a decision-support system rather than an autonomous decision-maker. This distinction is essential to determine its classification under the AI Act. According to Article 6(1), only systems that independently produce legal or similarly significant effects are considered 'high-risk'. In its current form, the prototype does not autonomously issue binding decisions, but instead assists human analysts, thus mitigating this risk classification.

However, Article 6(2) clarifies that even decision-support systems may fall under the high-risk category when deployed by public authorities in regulated sectors - such as financial supervision (according to Annex III, point 5, lett b) «*AI systems intended to be used to evaluate the creditworthiness of natural persons or establish their credit score, with the exception of AI systems used for the purpose of detecting financial fraud*»); consequently, the system should still undergo a formal risk assessment in line with Article 9, evaluating its level of automation, potential for indirect bias, and impact on fundamental rights.

At the same time, it could be observed that Article 6(3) offers a pathway to exclude certain systems from the 'high-risk' classification, provided that a documented assessment is submitted demonstrating the absence of significant risks. In the case of the 'greenwashing alert' prototype, if such an assessment can be provided, the system may not fall under the 'high-risk' category, despite its inclusion in Annex III.

Anyway, at the current stage, several characteristics of the prototype already support its alignment with the AI Act's core obligations. In terms of traceability and auditability (Articles 12–13), the system's use of structured dictionaries and pre-defined thresholds for flagging mismatches (*i.e.*, in SDG claims) facilitates transparency and post-hoc inspection. Considering the meaningful human oversight (Article 14), we underline that analysts remain fully responsible for interpreting alerts and making final decisions, ensuring effective human-in-the-loop governance. With reference to transparency and explainability (Article 13), although built upon complex models like ESGBERT and ClimateBERT, the system integrates rule-based features that make outputs interpretable and easier to justify. If we look at accuracy and robustness (Article 15), initial case studies suggest qualitative coherence between prototype alerts and potential greenwashing indicators; yet full-scale validation on broader datasets remains a necessary next step.

From a governance perspective, in case of further development of the prototype, further requirements will be needed, such as a systematic logging of system operations and outputs, and formal protocols for analyst interaction with AI-generated findings.

Literature on public-sector AI adoption underscores the need for legal proportionality and democratic accountability. The governance of artificial intelligence requires more than technical standards or legal compliance: it must integrate ethical principles, institutional accountability, and democratic oversight. As Ebers *et al.* (2021)

observe, aligning AI with fundamental rights necessitates moving beyond voluntary ethical frameworks to establish binding legal and institutional safeguards: this perspective underscores the importance of embedding such tools within governance structures that ensure transparency, explainability, and human oversight. Furthermore, Veale *et al.* (2023) emphasize that effective AI governance requires a critical examination of the power dynamics and institutional contexts in which these systems operate, ensuring that they serve the public interest in a democratically legitimate and socially equitable manner. Complementing these views, Azzutti et al.(2024), looking at banking supervision, highlight the significance of good administration in AI-enhanced supervision, advocating for a risk-based approach that balances innovation with accountability. Collectively, these insights reinforce the imperative of integrating AI tools like the 'greenwashing alert' prototype within robust regulatory frameworks that uphold fundamental rights and promote trust in AI-driven supervisory processes.

The proposed prototype aligns with this approach, aiming to enhance - not replace - human supervisory capacity and to strengthen preventive oversight through structured, data-driven analysis. While the prototype might be subject to high-risk classification depending on its deployment context, at the current stage it demonstrates substantial alignment with the AI Act's key requirements - provided it is accompanied by risk monitoring, continuous evaluation, and strong institutional governance.

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Appendix

The prototype follows a procedure consisting of the following four steps.

Step 1: Preprocessing the Sustainability Report

The system begins by loading the sustainability report of an issuer for a given year and converting the PDF into a machine-readable format. Once the text extraction is complete, it undergoes a cleanup process to remove noise and improve the quality of the sentences to be further analysed in the next steps.

Step 2: Full Report Analysis with LLM Models

The prototype applies LLM models to classify the extracted sentences from the full report using three specialized pretrained models:

ESGBert / Environmental Sentences for labeling sentences as 'environmental'. Using pre-trained *ESGBert/EnvironmentalBERT-environmental*, sentences from sustainability reports are classified under the label 'environmental' to identify text related to environmental topics or 'none' and a score from 0 to 1 is assigned. The closer the score is to 1, the higher the confidence in the classification of the sentence.

ClimateBert/ Environmental Claims: *ClimateBert/environmental-claims* is employed to detect specific claims about the environment, tagged under the label 'environmental claim' with 'yes' or 'no' and also associated a score from 0 to 1 to quantify the confidence in the classification.

ClimateBert/Sentiment: the sentiment analysis of the sentences from the sustainability report is then performed using *ClimateBert/distilroberta-base-climate-sentiment*, categorizing sentences based on the tone. In particular, the model can assign sentiment label 'Risk', 'Opportunity' or 'Neutral' with a confidence score from 0 to 1. The closer the score is to 1, the higher the confidence in the sentiment classification of the sentence.

Step 3: Targeted Analysis on SDGs-sentences with LLM Models

The prototype employs a proprietary tool based on a dictionary-search approach to systematically identify and analyse SDG-related content in sustainability

reports. To ensure accurate attribution, the system constructs a dictionary that defines a set of keywords linked to each SDG identified by mapping the GBPs into SDGs and merging it with the dictionary used by LSEG to classify the use of proceeds. We consider only the SDGs mapped from the Global Green Bond Principles[49], that is we consider SDGs: one, two, three, six ,seven, eight, nine, 11, 12, 13, 14 and 15. For each SDG, a set of keywords is defined, such as for example in SDG1, we have 'SDG1', 'No Poverty2', 'Climate Change' and others. Using this enhanced dictionary, the tool extracts SDG-related sentences from reports and classifies them with LLM models, as outlined in Step 2: ESGBert for environmental categorisation, ClimateBert Environmental Claims to detect environmental claims, and ClimateBert Sentiment to assess the tone of these SDG sentences. Summing up, a second round of LLM-based classification is then applied specifically to the subset of sentences related to SDGs.

Step 4: Summarizing Results for Issuers

Finally, the prototype consolidates and summarizes the findings from Steps 1 and 2, producing a structured output that highlights summary statistics for all issuer reports analysed for a given year. Additionally, it conducts a Sustainable Development Goals (SDG) attribution process to assess the alignment between the *Declared* and *Found* SDGs. By *Declared SDGs,* we refer to the information provided by LSEG regarding the use of proceeds from green bonds. By *Found* SDGs, we refer to the identification of SDG-related sentences using the dictionary tool, which enables SDGs labeling based on keywords search. We define *SDG Mismatch* = *Declared SDGs- Found* SDGs and such metric is used to issue an alert. In fact, the larger the SDG Mismatch, the larger the potential omission of information is, which can be considered a signal for potential greenwashing.

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