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- Green Patents as an Opportunity to Commercialize Innovations Supporting Sustainable Development

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- Technical Analysis as a Tool for Determining Cryptocurrency Trends in Times of Chaos

- A Decadal Systematic Review of Factors Underlying Tax Compliance in the Informal Sector

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Bartłomiej Wiśniewski*

Technical Analysis as a Tool for Determining Cryptocurrency Trends in Times of Chaos

Summary

Technical analysis is a widely applied method for forecasting market trends and making investment decisions. This article assesses the effectiveness of basic technical analysis indicators, such as MACD, EMA, and trendlines, in the volatile cryptocurrency market during significant events like the COVID-19 pandemic and Russia's aggression against Ukraine. The study utilizes weekly data from 2018 to 2023, focusing on Bitcoin and Ethereum due to their high market capitalization. The results confirm that these tools can provide valuable investment signals, particularly during periods of high market volatility, identifying trend changes and key entry or exit points. However, limitations of technical analysis, such as conflicting signals among indicators, highlight the need for caution and a multilayered analytical approach. Notable findings include the effectiveness of using multiple indicators simultaneously to enhance decision-making and the potential risks of relying solely on individual indicators.

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The research also acknowledges the challenges posed by external, unpredictable events, such as the collapse of major projects or regulatory changes, which can disrupt market dynamics. Despite these challenges, the findings underscore the relevance of technical analysis in modern financial contexts, providing investors with practical insights for navigating volatile markets.

This study contributes to the understanding of cryptocurrency markets by demonstrating the utility of traditional technical tools in identifying trends, while stressing the importance of their thoughtful application in conjunction with other analytical methods.

Key words: technical analysis, cryptocurrencies, cryptocurrency exchange
JEL codes: D40

Analiza techniczna jako narzędzie do predykcji trendów kryptowalut w Czasach Chaosu

Abstrakt

Analiza techniczna jest szeroko stosowaną metodą prognozowania trendów rynkowych i podejmowania decyzji inwestycyjnych. Niniejszy artykuł ocenia skuteczność podstawowych wskaźników analizy technicznej, takich jak MACD, EMA i linie trendu, w zmiennym rynku kryptowalut podczas znaczących wydarzeń, takich jak pandemia COVID-19 i agresja Rosji przeciwko Ukrainie. Badanie wykorzystuje dane tygodniowe z lat 2018–2023, koncentrując się na Bitcoinie i Ethereum ze względu na ich wysoką kapitalizację rynkową. Wyniki potwierdzają, że narzędzia te mogą dostarczać wartościowych sygnałów inwestycyjnych, szczególnie w okresach wysokiej zmienności rynkowej, identyfikując zmiany trendów oraz kluczowe momenty wejścia i wyjścia z rynku.

Jednakże ograniczenia analizy technicznej, takie jak konflikty sygnałów między wskaźnikami, podkreślają potrzebę ostrożności oraz wielowarstwowego podejścia analitycznego. Kluczowe wnioski obejmują skuteczność jednoczesnego stosowania wielu wskaźników w celu poprawy procesu decyzyjnego oraz potencjalne ryzyko polegania wyłącznie na pojedynczych wskaźnikach.

W badaniu uwzględniono także wyzwania związane z nieprzewidywalnymi wydarzeniami zewnętrznymi, takimi jak upadek dużych projektów czy zmiany regulacyjne, które mogą zakłócać dynamikę rynkową. Pomimo tych trudności, wyniki podkreślają znaczenie analizy technicznej we współczesnym kontekście finansowym, dostarczając inwestorom praktycznych wskazówek dotyczących nawigowania po zmiennych rynkach.

Artykuł wnosi wkład w zrozumienie rynków kryptowalut, ukazując użyteczność tradycyjnych narzędzi analizy technicznej w identyfikowaniu trendów, przy jednoczesnym podkreśleniu znaczenia ich przemyślanego stosowania w połączeniu z innymi metodami analizy.

Słowa kluczowe: analiza techniczna, kryptowaluty, giełda kryptowalut

1. Introduction

The cryptocurrency market, characterized by high volatility and decentralization, is attracting private and institutional investors. Since Bitcoin's inception in 2009, this segment has grown in importance, offering a growth potential and diversification of portfolios. However, due to unique features such as uninterrupted 24/7 availability and the lack of central regulation, cryptocurrency markets present special analytical challenges, and thus a natural demand for analytical tools is awakening.

Research problem: How effectively can technical analysis indicators such as MACD, EMA or trendline predict turning points in the cryptocurrency market under high volatility?

The purpose of the study is to evaluate the effectiveness of MACD, EMA and trendline indicators in identifying turning points in the cryptocurrency market and their ability to generate accurate signals under conditions of high market volatility.

The article is based on the research hypothesis that technical analysis indicators, such as MACD and EMA, provide valuable investment signals comparable to those used in traditional financial markets, are effective in identifying trends and turning points in the cryptocurrency market, and provide investment signals comparable to traditional financial markets. The article examines this hypothesis by analyzing the price changes of Bitcoin and Ethereum in the period 2018–2023. The choice of cryptocurrencies is justified by their high capitalization among cryptocurrencies, which allows us to assess the effectiveness of technical analysis under conditions of high market volatility on well-known cryptocurrencies.

To better understand the peculiarities of the cryptocurrency market and the need to apply technical analysis, the following section includes basic information on the structure and history of this market. In today's world, the cryptocurrency market has become one of the most dynamic and intriguing segments of the global

economy. Since the inception of Bitcoin and its derivatives, the market has attracted many private investors and institutions. The ability of cryptocurrencies to fluctuate widely makes them a fascinating field of study for economists. The purpose of this text is to introduce the essence of the most important cryptocurrencies and the possibilities of using technical analysis in this market. Cryptocurrency is a new financial instrument, characterized primarily by being a fully digital currency based on the Blockchain organization system. Unlike fiat currencies, cryptocurrencies do not have a physical form and are not controlled or issued by central banks. They are designed to be independent of political or governmental power, functioning in a peer-to-peer network. Satoshi Nakamoto is the first creator of cryptocurrency, who wrote his manifesto under this pseudonym in 2008 (Nakamoto, 2008). It is unclear whether Satoshi Nakamoto is an individual or a group. In his manifesto, he explains the idea of money based on a *peer-to-peer* (P2P) network, allowing money to flow online directly between two entities without the need for a third party – a financial institution. He proposed a system that would be public and anonymous, like the information available on the stock exchange, where only the timing and size of individual transactions are made public without disclosing the parties involved. Satoshi's model emphasizes creating new keys with each transaction to prevent linking transactions to common owners, ensuring privacy. Each coin is assigned an individual code that gives a sense of ownership, and to prevent double spending, a peer-to-peer network records public transaction. If most of the computing power controls the code, attacking the network becomes unattractive. Despite its simplicity, the network operates simultaneously without external coordination, allowing users to leave and return, accepting changes that occurred during their absence. The year of the manifesto's publication is significant, as October 2008 marked the height of the financial crisis in the USA, with the collapse of Lehman Brothers and the NASDAQ crash causing global panic (Amadeo, 2022). Satoshi acknowledged that the electronic payment system worked well but had trust-related drawbacks, which his proposed system aimed to overcome by being self-regulating and more private. The study aims to prove that even the basic tools of technical analysis can accurately assess moments of entry or exit of trades and indicate changes in trends. By analyzing cryptocurrency markets using technical analysis indicators, the study seeks to determine whether these tools provided signals about the outbreak of the COVID-19 pandemic and Russia's aggression against Ukraine, confirming the assumption that "the market discounts everything". The study focuses on Bitcoin and Ethereum against the US dollar, chosen due to their largest capitalization, popularity, and market impact.

Technical analysis is recommended for use by analysts, brokers, and investment advisors to understand stock market sentiment and predict trends. It is utilized in weekly market reports and forecasts prepared by institutions such as the Brokerage House of Bank Ochrony Środowiska (BOŚ, 2024) and the XTB Brokerage House (XTB, 2024).

This article aims to contribute to the study of cryptocurrency markets through the application of technical analysis, despite its subjective and interpretive nature. By explaining the essence of technical analysis, its applications in cryptocurrency markets, and discussing related controversies and challenges, the article seeks to enhance understanding of the mechanisms influencing cryptocurrency prices and informed investor decisions This study contributes to the ongoing discussion in the literature regarding the effectiveness of cryptocurrency markets and provides practical implications for investors, especially those using algorithmic strategies based on technical analysis.

2. Literature review

Cryptocurrencies are often characterized by their high volatility, continuous market operation, and the dual nature of their appeal, attracting both risk-seeking investors and those cautious about significant risk exposure. This inherent volatility and the fact that the cryptocurrency market operates 24/7 mean that investing in these assets involves substantial risk. Effective investing requires a deep understanding of how cryptocurrencies function and the ability to analyze them to navigate the significant risks involved. The literature review will cover key studies and theories that shed light on these aspects, as well as how various analytical approaches contribute to a better understanding of cryptocurrency investments.

In 2009, the Bitcoin (BTC) network was created, Satoshi Nakamoto "mines" his first Bitcoin, and its rate is determined by its mining cost. When talking about Bitcoin mining, it is about lending the computing power of graphics processing units (GPUs). Cryptocurrency mining is a sector of blockchain technology. The previously mentioned blockchain is a share-based technology that allows a group of users to share data. The data is not stored in one place but is scattered to other locations – network participants. Even though the data is shared between the participants of the network, it cannot be manipulated or modified, because other participants of the network will be informed about it, and the network itself will not allow modifications, because the data will be different from that of its other participants. It has also begun to build a belief among some people that Bitcoin is an invention as revolutionary as the automobile or the Internet (Mezrich, 2019). Bitcoin's early years come with a poorly developed infrastructure. This is related to the initial nature of Bitcoin, which was of interest to hobbyists and was a rather marginal phenomenon, enjoying low interest. As mentioned in Chapter II of Bitcoin's history of creation, the price was set on October 5, 2009 based on the cost of its mining (Mezrich, 2019). At that time, one dollar could buy 1309 BTC.

To acquire Bitcoin, one had to mine it or purchase it from third parties, which was a complex and time-consuming process due to the lack of market knowledge

and the absence of services available today. In 2010, the Mt. Gox exchange was established, where the first Bitcoin exchange rate during the session was priced at $0.05. The Mt. Gox exchange was the most popular exchange at the time, offering instant exchange for Bitcoin or fiat currency. Bitcoin was referred to as a speculative bubble, comparing it to *tulipmania*, i.e., a speculative bubble prevailing in the Netherlands in the 17th century concerning tulips, which Oczko from the Jagiellonian University wrote about in his work (Oczko, 2016). Quite often, in the public opinion, one could and still can hear opinions negatively expressing themselves about investing in Bitcoin, comparing them to historical investment bubbles, including the Mississippi or South Seas company stock bubbles (Bitcan, 2021). An important year is 2011, when altcoins began to appear as an alternative to Bitcoin, offering various solutions, including *Litecoin*. It is worth mentioning that today there are currently more than 1000 cryptocurrencies and the new ones are constantly appearing. There is also the first crisis caused by waves of hacker attacks aimed at stealing cryptocurrencies from exchanges or crypto wallets (Ashmore & Pradhan, 2023). The stock market in 2014 was valued at $450 million (Berdnard, 2021). Technical analysis is one of the most popular methods of market analysis, along with fundamental analysis, which focuses on interpreting charts. As Borowski writes, behavioral finance contributed the most to the popularity of technical analysis, as it contributed to the promotion of the thesis that investors are also torn by emotions, and their analysis also contributes to increasing the rate of return on investment. He also mentions that we can quite often come across technical analysis during the exams for an investment advisor organized by the Polish Financial Supervision Authority, or the analyses prepared on Wall Street not only include a fundamental analysis, but also a short technical analysis of the examined asset is posted (Borowski, 2015). As Staszak points out in "Fundamentals of technical analysis", the most important task of technical analysis is to find the moment of a trend, and this moment is the most important element of the strategy, and recognizing the pattern before it is formed is extremely difficult, as it resembles a typical upward movement (Staszak, 1995)

Some attribute the popularity of cryptocurrencies to a certain natural factor, along with a digitalization trend in our social life. The rise in popularity is often linked in research (An Nguyen & Ching Chan, 2024) to the growing popularity of fintech services, virtual reality, and metaverse during the same period, suggesting a natural progression of events. Bitcoin is considered one of the most recognizable cryptocurrencies, given its largest market capitalization and being the first cryptocurrency, as concluded by Magnusson and Stenberg (Magnusson & Stenberg, 2022) in their publication, which also suggests that Bitcoin plays the most crucial role in the cryptocurrency market and has the greatest influence on other cryptocurrencies. Thus, Bitcoin sets the main trend for other alternatives. Moreover, some publications argue that Bitcoin can be considered as a hedge

asset like gold, as demonstrated in their study (Gambrielli, et al., 2023), which proves that gold can act as a safe haven during bear markets but not always It is emphasized that the need to explore alternatives, and cryptocurrencies, despite the high risk, can offer the opportunity to diversify one's investment portfolio.

Technical analysis receives mixed opinions; some believe it is justified and can indeed lead to profit and predict future movements, while others believe it does not work at all and consider its use irrational. This often makes technical analysis the subject of various debates and discussions, which may arise from research findings as well as personal beliefs. Technical analysis has been used in the studies by Hudson and Urquhart (Hudson & Uquhart, 2019), among others, who used moving averages in their research, precisely indicating that it is one of the most popular methods. Their results suggest that technical analysis tools can bring significant benefits to investors. These studies motivate efforts to increase access to technical analysis tools so that investors can use them more effectively. There are also studies (Dingyu & Tahir Ismail, 2022) demonstrating the effectiveness of technical analysis, indicating that econometric models using technical analysis had lower errors than those that did not, suggesting that combining technical analysis with advanced deep learning models could be an effective investment strategy. This indicates that despite the complexity and volatility of the cryptocurrency market, even basic technical analysis methods can be effective in making investment decisions. Another study on machine learning to predict future Bitcoin prices utilized indicators from technical analysis, including EMA (*Exponential Moving Average*), indicating that it had a significant impact on prediction results. Therefore, it can be concluded that technical analysis, combined with neural networks, can yield potential profits, as mentioned in an article that uses simple technical analysis indicators, RSI (*The Relative Strength Index),* and MACD (*Moving Average Convergence Divergence)* (Zatwarnicki, et al., 2023) in the study. These mentioned studies highlight the value of technical analysis and its ability to predict future price movements.

3. Methodology and data

The study analyzes the cryptocurrency market in the period from 2018 to 2023, which was characterized by high volatility, caused, among other things, by the COVID-19 pandemic and Russia's aggression against Ukraine. The selected events had a significant impact on financial markets and allow us to see how the cryptocurrency market reacted amidst volatility.

Two popular technical analysis indicators were used to identify trends and turning points in the cryptocurrency market: Exponential Moving Average (**EMA**) with a 30-day period and Moving Average Convergence Divergence (**MACD**).

These indicators were chosen because of their widespread use in a trend analysis in financial markets, as well as their usefulness in high volatility conditions. In addition, trend lines were used to better identify the main directions of price changes.

The analysis was carried out using weekly price data of Bitcoin (BTC) and Ethereum (ETH) against the US Dollar. The choice of these cryptocurrencies was justified by their high capitalization and influence on the cryptocurrency market, which allows to evaluate the indicators in the context of well-recognized assets with high liquidity. Weekly interval data minimizes the impact of short-term fluctuations and allows the identification of long-term trends. The following tools will be used for technical analysis:

- Exponential Moving Average (EMA) – 30-period;
- Moving Average Convergence Divergence (MACD) indicator – with basic settings of 12,6,9;
- Trend line determination.

Exponential Moving Average (EMA) – 30-period – a technical analysis tool used to track the average price of an asset for the last 30 trading periods. It is a type of moving average that gives more weight to the most recent data, making it react faster to current price changes compared to simple moving averages. It is often used to identify trend direction and support resistance levels.

Moving Average Convergence Divergence (MACD) Indicator – a technical analysis indicator that uses the difference between two moving averages (usually EMAs) to detect changes in trends. It consists of two lines: the MACD line (calculated as the difference between the shorter-term EMA and the longer-term EMA) and the signal line (the EMA of the MACD line). The MACD is used to identify moments to enter or exit a position in the market depending on the crossover of these lines.

Trend Lines – straight lines that connect two or more points on a chart, allowing one to visually determine the direction and slope of a trend. They are used to identify market trends and forecast future price movements.

These tools will be applied using the xStation5 program, created by the Polish broker XTB as an alternative to the MetaTrader program.

Despite their simplicity, these tools are still used in market analysis for several reasons:

- *Ease of Understanding:* EMA 30, MACD, and trend lines are easy to understand and relatively simple to use, making them accessible to both beginners and experienced traders;
- *Versatility:* They can be applied to a variety of markets and financial assets, from stocks to currencies and commodities;
- *Efficiency:* Despite their simplicity, these tools are often effective in identifying market trends and entry or exit points for potential profits;

- *Quick Response:* EMA 30 and MACD react relatively quickly to price changes, allowing traders to quickly adjust to changing market conditions;
- *Consideration of Historical Data:* Both EMA 30 and MACD consider previous prices, allowing analysis of price behavior over a longer period.

4. Empirical results

4.1. Bitcoin Exchange Rate Analysis

The chart below shows a study of the Bitcoin cryptocurrency exchange rate, where the quote currency is the US dollar in the period 2018–2022 using trend lines and the EMA and MACD indicators.

Figure 1. Bitcoin exchange rate in the period 2018–2023

Source: In-house analysis using xStation5.

Bitcoin's price in 2018 starts with a downward trend. The dashed red line indicates a strong downtrend, which starts with the first price breakout in the first quarter, and finds two consecutive peaks during this period, which are a strengthening of this trend. At the turn of the third and fourth quarters, there is a slight break of the downward trend, which could indicate a possible reversal of the downward trend (orange area). To check, the trend guideline (black dashed line) was used, considering a slight breakout to see if it would find support. The

line does not find a third vertex that could confirm the downtrend, so this is a signal that the trend may change in some time. The EMA indicator has been generating signals to sell for almost the whole year, when there have been slight breakouts, which are support lines for the trend, it signaled to buy. Therefore, it can be assumed that the EMA indicator mainly gave signals to sell. The MACD indicator, where the MACD line is marked in yellow and the signal line in purple, gave a bright signal to sell at the beginning of the year, but a slight departure of both lines indicates a weak downtrend. Since the second half of the year, both lines have been running very closely, which indicates a significant weakening of the downward trend and the possibility of its change.

The year 2019 and its beginning continues the trend from the end of 2018, but both trend-setting lines are broken in the middle of the first quarter. By the first half of 2019, the price has been broken out. An attempt to draw a trend line from the first vertex clearly indicates a downtrend, which is strongly confirmed by the next four vertices. To confirm this trend, a secondary line from the second vertex is drawn, however, it does not find as strong a confirmation as the first line. It is confirmed at the very beginning, however, it is crossed by the third vertex, which was the resistance line for the red trend line. This signals that the trend, as in 2018, may change. The EMA indicator started generating signals to buy now of the crossover of the 2018 auxiliary trendline and it lasted until September, when the main red trendline was confirmed by the third peak. Throughout 2019, the MACD indicator signaled a weak upward and downward trend. It gave a weak signal to buy, now of the breakout of the Bitcoin price, as well as signaled weak selling in the second half of the year.

The year 2020 opens with a slight breakout and an attempt to reverse the trend, but it is a short-lived phenomenon that is interrupted by a slight low, which, interestingly, is a support line by the auxiliary trend. From this low, an attempt is made to establish a new trend line. The trend maintains a horizontal but upward trend. The main red trend line indicates a slight increase, which is confirmed by as many as three lows. An important moment occurs in the second half of the year, which is marked with a purple area. This is the moment of confirmation of the previously mentioned trend line, with three upward lows, which may already signal a change in trend. An auxiliary red dashed line is drawn to the assistance, which also confirms the uptrend. However, this is the moment when it is difficult to predict whether this trend will continue, change pace or change. However, from the angle of the slope of the line, one could conclude another breakout. At the end of 2020, there is a clear break above the trend previously indicated by the market. The key moment is marked by the blue area, which is the biggest breakout of 2020, and may be a continuation of the trend, where the auxiliary red line will continue the horizontal trend as a support line. The EMA indicator, after the low of the first half of the year, started to generate signals to buy. At the very beginning they are

quite weak, but with each month it starts to generate a stronger signal, especially around the area highlighted in blue, it gives strong indications to buy. The MACD indicator has shown weak signals to buy and sell throughout the year, and both MACD and signal lines have given signals of a weak trend. The key moment is the three lows, which indicated an uptrend, then the MACD gave strong signals to buy. Thus, both indicators signaled that there would be an increase in price.

The year 2021 is a year of massive fluctuation for Bitcoin. The moment of drawing the trend line is the moment marked in the red area. The red trend line indicates that this is a strong price increase, but the weak trend is due to the lack of confirmation in even the third low. The weak trend is confirmed already in the first quarter, where there is a decline and a slight breakout to fall sharply downwards. At this point, an attempt is made to draw a trend line from the blue area, it is confirmed by three upward lows, where the trend line is then a support line for the price. This may signal the continuation of the uptrend, but it is not possible to set a trend guide, which may already signal that the uptrend will not be confirmed by the trend lines themselves. The EMA indicator continues the signals from the end of 2020, giving strong signals to buy all the time, which are not weakening. The first breakdown occurs at the last high, which forms a low, giving a signal to sell. At the first stronger breakout, it gives a buy signal again, but it is not as strong as in the first half of the year. With the end of 2021, it gives signals to sell. The MACD indicator, on the other hand, also generates strong signals to buy, which started at the end of 2020. However, the lines of this indicator suggest a weak uptrend. The MACD also generates similar sell signals as the Exponential Moving Average. The year 2021 closes with a downward spiral for Bitcoin, which has not found any support line.

The year 2022 opens with a slight breakout, where the dashed line from the red area is already a support line rather than a resistance line for the price. This may still be heralded by an uptrend, but the trend line will be a resistance line here. However, the assumptions are not confirmed. The price of Bitcoin begins to gradually fall in the second quarter, and the exchange rate is so chaotic that it is difficult to draw a new trend line during this period. Thus, the attempt to draw a new trend line starts from the highest point of the last quarter of 2021, which is the orange dashed line. Because it finds only the third support just in the fourth quarter, it indicated a certain slowdown of the downward trend (red area). It is worth mentioning the purple trend line that has been drawn since 2018, which was constantly signaling the main uptrend, and after the great price fluctuations of 2021 and the sharp declines of 2022, constituted some resistance (red area) that was not broken, which already gave indications that this line will now be providing some support and signaling upward tendencies. The EMA indicator strongly specifies sales throughout the year, only occasionally did it indicate a purchase at the end of the first quarter. Similar signals are also generated by the MACD, which already

started generating strong sell signals at the end of 2021. In the second half of the year, both MACD lines were close to each other, which proved a weak trend, but they were already generating subtle buy signals.

The year 2023 starts with strong gains, which was signaled by the main trendline (purple) after a sharp rebound in the last quarter of 2022. The price of Bitcoin gained slightly compared to last year, and what is also worth mentioning is that the trend line from 2020, which signaled a potential increase, found support twice, one from 2022 and the third from 2023, which could potentially be a resistance to growth, but in the last quarter it is broken. The EMA indicator signals to buy almost all year, only once it signaled to sell around the third quarter, however, it was quite a weak signal. Similar signals are given to us by the MACD, which has been signaling successively from the second half of 2022 to the first half of 2023, where, however, it has been sending signals to sell, and recently signaling quite a strong buy.

4.2. Ethereum Exchange Rate Analysis

The chart below shows a study of the Ethereum cryptocurrency exchange rate, where the quote currency is the US dollar, in the period 2018–2023 using trend lines and the EMA and MACD indicators.

Figure 2. Ethereum exchange rate in the period 2018–2023

Source: In-house analysis using xStation5.

The year 2018, as in the case of Bitcoin, opens with a downtrend, which, despite being confirmed at two peaks in the first half, is weakly confirmed at the third peak in 2019, which ends this downward trend, as it is about to be broken. A black dashed trend guideline is drawn to confirm the downtrend. The second peak is only found at the beginning of 2020, which indicates a horizontal and long-term downtrend. The blue area in 2019 marks a moment that could confirm the strength of this trend, but the auxiliary line does not become a resistance line. Thus, the year 2018 from the second half opens a slow downward trend that continues until the first half of 2020. The EMA indicator, for the second half of the year, generates a signal to buy, which ends in a similar period as the red trend line. Then, for the rest of the period, it generated weak buy and sell signals. The MACD indicator behaved similarly, which also indicated a weak trend.

In 2019, the exchange rate was quite stable and only a slight breakout in the second quarter can be noticed, but as it has just been mentioned, this is a continuation of the trend that has been taking shape since the second half of 2018. Also, the EMA or MACD indicators did not indicate different signals. Thus, 2019 was a quiet period with a stable exchange rate.

The first half of 2020 was also a continuation of the trend from the second half of 2018. A slight decline could be observed, where there is a slight rise in the price until the end of the first half of 2020. At this point, the first breakout of the auxiliary trend line occurs, which signaled a long-term slight downtrend. This is an important moment (the area marked in orange) as it foreshadows the rebound that will take place at the beginning of 2021. However, by the end of the year, there has been a slight decline and increase from this rebound. In the first half of the year, the EMA indicator informed us about buying, only for a moment with this slight decline it informed about selling, then successively until the end of the year it informed us about buying. The MACD indicator, on the other hand, did not give clear signs to buy, in the first quarter it generated a very weak buy signal, but it can be assumed that the MACD did not announce clear signals to buy, and the lines running close to each other rather informed about a weak trend. Only the last quarter of 2020 gave clearer signals to buy.

The year 2021 brought sharp increases and, like Bitcoin, the price fluctuated quite a lot throughout the year. To draw a trend line, the moment of the first increase from 2020 was used, but the main red trend line was not supported by three vertices that would confirm a certain strength of the trend. A subsidiary line was also drawn, which, like the main one, did not find three vertices that would confirm the strength of the trend, but only one. Therefore, both lines give a strong signal that the trend is quite weak despite the spectacular growth and may change. The EMA indicator has been generating buy signals since the beginning of the year, only at the turn of the half of the year, it generated a short-term sell signal, only to generate a strong buy signal again by the end of the year. The MACD

showed a similar trend to the EMA, however, the MACD at the end of the year, began to generate a strong sell signal, just after the first decline.

In 2022, Ethereum's exchange rate, like Bitcoin's, behaved quite erratically, and setting a trend line in the 2022 period alone was pointless. An interesting phenomenon is that from the moment marked in orange in 2020, where the red uptrend line for 2021 was drawn, when trying to create a trend line with the fan principle, we have slight signals, when the purple line is a bounce point and in the middle of the year. The third line was resistance once and tried to be a resistance line a second time at the end of 2022. This may indicate that the exchange rate did not want to return to its pre-2020 state. The EMA indicator has been generating a sell signal throughout the year, only for a short period of time, a weak buy signal can be noticed. In contrast, the MACD from the beginning of the year to the first half of 2022, showed a strong selling trend, just as the EMA showed a buy signal over the same period. It is interesting to note that, unlike the EMA, the MACD indicator showed weak buy signals in the second half of the year.

Overall, 2023 is on a rather slow upward trend. A red line is drawn from the first low of 2022, which is confirmed at the end of 2022 and in the last quarter of 2023. This line confirmed an uptrend that had rather little upward strength, the last quarter confirmed the uptrend with the last low and then rebounded to close 2023 with the biggest high. The EMA line, as in the case of Bitcoin, sent quite similar signals, but they were not as clear, and the MACD indicator, which signaled a purchase, also behaves similarly.

5. Conclusion

The main research hypothesis was that technical analysis, particularly MACD, EMA and simple trendline indicators, can be effective in identifying trends and key turning points in the cryptocurrency market. The study confirms that these analytical tools provided valuable signals in many cases, especially during periods of high volatility, such as the COVID-19 pandemic and the conflict in Ukraine, where they reacted dynamically to price changes. The simple trendline proved to be a useful tool for tracking market direction and overall structure, supporting long-term trend analysis, while MACD and EMA offered more timely information on possible price changes.

However, it is worth noting that in many cases these indicators generated conflicting signals, which posed the risk of making wrong investment decisions. For example, when analyzing the 2020 trend, the MACD indicated the possibility of further increases, while the EMA began to generate sell signals, suggesting a potential weakness. Such discrepancies underscore that neither indicator should be used in isolation – their simultaneous use provides a more complete picture

of the market situation. In situations where the trendline confirmed the signals generated by the MACD and EMA, traders were able to make more informed decisions, but more caution is recommended when there are inconsistencies between the indicators.

In addition, the volatility of the cryptocurrency market makes technical analysis vulnerable to sudden, unpredictable events, such as the collapse of the *Terra Luna* project. These types of events are difficult to predict using technical analysis alone and point to the need to integrate technical indicators with other risk assessment methods, in this case fundamental analysis, which could provide a broader macroeconomic context. Cryptocurrency markets, which are still a new and growing segment, but mainly through their speculative nature, react to global events and regulatory changes in a less predictable manner than traditional financial markets, further increasing the importance of using a more nuanced analytical approach.

In conclusion, the results of the study suggest that technical analysis based on MACD, EMA and straight trendline can be a valuable tool in the cryptocurrency market, but its effectiveness is highest when investors use these indicators thoughtfully, considering their limitations and the possibility of conflicting signals. Using additional indicators can help reduce the risk of false signals, providing a more comprehensive picture of the market and increasing the certainty of investment decisions. This approach is particularly useful in the volatile cryptocurrency market, where rapid price changes and high volatility require diversified analysis to better manage risk.

Key findings:

Technical analysis in the cryptocurrency market:

- Technical analysis and its indicators can be used in cryptocurrency markets.
- Simple trend lines can indicate a change in trend.

Multi-layered approach:

- It is important to use multiple indicators at the same time to get a comprehensive picture.
- Relying on a single indicator can often result in wrong signals and is not always effective.

Volatile cryptocurrency markets:

- The cryptocurrency market is characterized by high volatility, leading to rapid price changes.
- The COVID-19 pandemic and war had a noticeable impact on cryptocurrency values.
- Bitcoin and Ethereum showed similar price movements, indicating little correlation.

Limitations of technical analysis:

- Technical analysis cannot predict unpredictable events such as the collapse of a cryptocurrency exchange.
- Events such as pandemic and war were evident in the cryptocurrency markets and did not come as a surprise to the market – the market discounted this news.

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Green Patents as an Opportunity to Commercialize Innovations Supporting Sustainable Development

Summary

Climate change and sustainable development are the most current topics when companies try to plan their strategies. New technologies are the tools that can help to solve various problems. To commercialize new technologies one of the most important topics is intellectual property protection. In case of green technologies, the good form of protection are green patents. The author argues that green patents are an opportunity to commercialize innovations supporting sustainable development.

The aim of this article is to identify current trends in the creation of environmental technologies ("green technologies") and to identify areas where the newest technologies supporting sustainable development are created. This goal will be achieved by analyzing "green patents".

Research methods included descriptive, comparative, and expository analysis. These methods were used to better understand the areas where "green innovations" are being created. To identify the current trends, a desk research

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method was used. As part of the research, literature, documents, and statistical data were analyzed as well as a case study of the "WIPO Green" technology platform supporting the transfer of green technologies to implement sustainable development was presented.

The research shows that in many areas related to the implementation of sustainable development goals, a number of patents protecting green technologies is increasing. However, protecting new solutions in the form of patents does not solve the problem. The solution is their commercialization, which opens up opportunities for achieving sustainable development goals.

Keywords: green technologies, green patents, sustainable development, commercialization

Zielone patenty jako szansa na komercjalizację innowacji wspierających zrównoważony rozwój

Streszczenie

Zmiany klimatyczne i zrównoważony rozwój to obecnie jeden z kluczowych tematów zarówno dla decydentów jak i przedsiębiorstw. Narzędziami, które mogą pomóc w rozwiązaniu wielu problemów współczesnego świata są nowe technologie. Jednym z najważniejszych obszarów w procesie komercjalizacji nowych technologii jest ochrona własności intelektualnej. W przypadku zielonych technologii dobrą formą ochrony są zielone patenty. Autorka stawia tezę, że zielone patenty stanowią szansę na komercjalizację innowacji wspierających zrównoważony rozwój. Celem artykułu jest identyfikacja aktualnych trendów w tworzeniu technologii środowiskowych („zielonych technologii") oraz identyfikacja obszarów, w których powstaje najwięcej nowych technologii wspierających zrównoważony rozwój.

Zastosowano zintegrowane podejście badawcze, łączące metody analizy deskryptywnej, komparatywnej i opisowej. Metody takie zastosowano, aby zidentyfikować obszary, w których powstają „zielone innowacje". Dodatkowo, aby uzyskać kompleksowy obraz aktualnych trendów, wykorzystano metodę *desk*

research. W ramach badań dokonano analizy literatury, dokumentów i danych statystycznych oraz zaprezentowano studium przypadku platformy technologicznej „WIPO Green" wspierającej transfer zielonych technologii na rzecz wdrażania zrównoważonego rozwoju.

Z przeprowadzonych badań wynika, że w wielu obszarach związanych z realizacją celów zrównoważonego rozwoju liczba patentów chroniących zielone technologie wzrasta. Ochrona nowych rozwiązań w postaci patentów nie rozwiązuje jednak problemu. Rozwiązaniem jest ich komercjalizacja, która otwiera możliwości dla realizacji celów zrównoważonego rozwoju.

Słowa kluczowe: zielone technologie, zielone patenty, zrównoważony rozwój, komercjalizacja

Introduction

Today's world has enormous amounts of technology that enrich our lives. Unfortunately, in many cases, technological progress disturbs the balance of our planet. In recent years, unfavorable climatic phenomena have increased. People face air and water pollution, floods, droughts and fires, tornadoes, and others. They are the result of industrialization and are the result of human activity.

However, more people feel the need to take care of the environment. Fearing the loss of our planet, several initiatives of a systemic nature are being undertaken to prevent environmental degradation and ensure sustainable development (Heshmati, Tsionas, 2023; Hansa et al., 2023). The actions are undertaken both locally and regionally. New technologies and innovations repeatedly bring solutions to environmental problems.

To be created, new technologies require long-term research and development (R&D) work as well as financing. The purpose of their creation is to solve a problem or meet a need. To serve people, the final effect of the innovation process should be their commercialization. However, before they appear on the market, they should be protected to avoid copying them by others mainly interested in the profits derived from them.

In the case of technological solutions suitable for industrial use, patents are a good form of intellectual property protection. They can secure a new technical solution for up to 20 years and facilitate the commercialization of a new technology.

In recent years, with growing problems related to environmental protection and the pursuit of sustainable development by economies, there has been a tendency to increase a number of patents in this area. Such patents are called "green patents" and since 2013 they have been subject to a detailed analysis by the World Intellectual Property Organization (WIPO).

The author argues that green patents are an opportunity to commercialize innovations supporting sustainable development. The aim of this article is to identify the current trends in the creation of environmental technologies ("green technologies") and to identify areas where the newest technologies supporting sustainable development are created. This goal will be achieved by analyzing "green patents".

Research methods included descriptive, comparative, and expository analysis. These methods were used to better understand the areas where "green innovations" are being created. To identify the current trends, a desk research method was used. As part of the research, literature, documents, statistical data were analyzed, and a case study of the "WIPO Green" technology platform supporting the transfer of green technologies to implement sustainable development was presented.

The article contributes to the discussion on the role of green patents in achieving the sustainable development goals, encouraging reflection on the directions of development of new technologies. It emphasizes the need to protect "green technologies", which may be crucial in the process of their commercialization.

Green technologies as a source of innovations

Global environmental issues have become a global challenge. Over recent years we can observe a tremendous amount of research, innovation and new technologies deployed to address the challenge of the climate change. The companies worldwide are obliged by environmental policies force, growing competitive pressure and technological capabilities to focus on improvements in their environmental performance (Semenova et al., 2023). The fact is that the world now has access to 80 percent of the technologies needed to halve global greenhouse emissions by 2030. The estimates show that in the nearest future we will see many more game-changing solutions (WIPO, 2023).

The problem of the need to prevent the negative effects of economic growth and development, the main cause of which were previously recognized criteria for running a business (increased production, its rapid renewability, increase in profits), leads to the conclusion that the balance in the ecosphere can be restored by innovations. For this to happen, the approach to creating innovations must change radically. Modernizing innovative activities should consist in subordinating them to the criteria of sustainable development. Therefore, the criterion of harmlessness to the natural environment should be introduced into the definition of innovation. It can be stated that no new product, process, management system or marketing tool should be considered an innovation if, during their implementation, natural resources of the natural environment are reduced, or the quality of their components is reduced (Białoń, 2012: 197). The desire to create new knowledge

and innovative solutions create new development opportunities for the companies. Modern enterprises strive for sustainable development. This situation means that entities in their activities must consider both aspects of innovation and ecology (Marczewska, 2016: 19).

Currently, there is an increasing connection between sustainable development issues and economics and the environment (Nitta, 2005; Jovanovic et. al., 2022). They are of interest not only to business, but also to political circles and society as well as universities and research institutes (Salvamani et al., 2020). There is also a significant increase in consumer awareness of environmental pollution and its consequences. Moreover, new technologies are more efficient and contribute to reducing global poverty.

Due to the global nature of the challenges related to climate change and poverty, there is a need to ensure the widest possible dissemination of appropriate technologies in countries with various levels of development. This applies to both developed and developing countries, which could reduce the negative effects of environmental pollution, or cause less environmental pollution compared to alternative solutions (COM, 2002: 2). Such technologies are called green technologies or environmental technologies and are referred to in the literature as technological solutions that perform many crucial functions (Marczewska, 2016: 21; Chakrabarti, 2014: 3–4; Waszak, 2015):

- support the protection of the natural environment;
- in practice, they cause less environmental pollution;
- use all available resources in a more sustainable way;
- they recycle their waste and unnecessary products;
- process residual waste in a more ecological way than alternative substitutes.

According to the OECD, green technologies are environmentally sound technologies that "*protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products, and handle residual waste in a more acceptable manner than the technologies for which they were substitutes*" (United Nations, 1992). Green, environmental, and eco-technologies or innovations are used as synonymous terms according to some authors (Fayot et al., 2023).

Well-designed environmental technologies can be described by the following characteristics: they are created and operate in accordance with the principle of sustainable development, they meet the needs of society without compromising the ability of future generations to meet their own needs, and they do not contribute to the depletion of natural resources (Chakrabarti, 2014: 3). In the case of products that result from the use of this type of technology, they should be designed in such a way that they can be fully regenerated or reused. Green technologies reduce waste and pollution by changing production and consumption patterns. They are an alternative to technologies that negatively impact health and the natural world.

They contribute to creating a center of economic activity around technologies and products that bring benefits to the environment, accelerate their implementation and diffusion, and influence the creation of new jobs (Chakrabarti, 2014: 4).

The following elements influence the development of green technologies: knowledge, experience, products, services, equipment, procedures, as well as organizational and management systems. It may prove that technologies which are environmentally friendly in a specific time and geographical conditions will be replaced in the future by other, more ecological solutions.

Environmental technologies are remarkably diverse. They differ not only in the process of creation, but also in their maturity (some have already been commercialized, others are in the development phase), as well as the scope of application. Some authors identify common features, distinguishing them from other types of technologies and comparing these two groups according to the following criteria (Marczewska, 2016: 28–26; Desheng, Jiakui, Ning, 2021; Juma, 1994):

- the main factors of creation – in the case of environmental technologies, these are: regulations, multilateral agreements on environmental issues; while for other technologies it may be market forces (e.g., demand, competition, production bottleneck, etc.);
- sources of financing – in the case of environmental technologies, public financing is significant, other technologies are largely financed from private funds, including reinvestment of profits, the use of risk capital and the sale of shares;
- location of R&D activities – environmental technologies are mainly developed at universities, public institutions, and research laboratories, while other technologies may also be created in enterprises;
- technology transfer mechanisms – in the case of environmental technologies, we are dealing with a transfer to the private sector, the importance of partnerships is growing public-private (science-business cooperation); while in the case of other technologies, there are forms of transfer between enterprises and partnerships between enterprises and research institutes;
- commercialization – in the case of environmental technologies, small and medium-sized enterprises are increasingly involved in their commercialization, sometimes external incentives and support are needed; for other technologies, commercialization takes place mainly within the enterprise;
- applications – only some environmental technologies can be used on a large scale, so the location of their application is mainly determined; other technological solutions are increasingly expanding their scale even to the global scope;
- methods of transfer to developing countries and countries undergoing economic transformation – in the case of environmental technologies,

such transfer takes place through enterprises, sometimes with financial support from various sources; in other technologies, the transfer takes place through the companies' own channels.

Green technologies include diverse solutions and can be used in many sectors, e.g.: pollution control, waste management, recycling, waste minimization, clean technologies, measurement and control, clean products. The analysis of green technologies allows us to distinguish three functional categories (Juma, 1994: 141). The first one includes processes and materials developed to reduce or eliminate the negative effects on nature of the activities undertaken so far, excluding a need to introduce fundamental changes to the existing process. The second category of green technologies refers to the modification of the production process, including the use of new monitoring and control techniques or changes to the raw materials and materials used. They can be incorporated into already existing technologies to eliminate or reduce their negative impact on the environment. The third category is related to the development of new technologies that have a smaller negative impact on the environment than previously used alternative solutions.

The issue of green technologies and their management is becoming an increasingly important topic discussed on an international scale. Among many related issues, much attention is paid to the analysis of enterprise strategies aimed at developing nature-friendly innovations. Green technologies provide the basis for creating this type of innovation, which is commonly referred to as eco-innovation, green innovation, or environmental innovation.

Green patents

"A green patent is a patent on products or designs that provide environmental benefit. The term green patent represents one use of the term green, which refers to items or phenomena that accommodate decreased energy consumption or otherwise benefit the environment" (Techopedia, 2024). Green patents can be broadly defined as technologies or applications that mitigate or adapt to the climate change. They are identified through the specific code Y02 assigned by the European Patent Office – EPO (Lavopa, Menendez, 2023). The eco-innovation intensity of companies may be measured by green patents as a parameter. Some authors underline their positive impact on the financial performance of the companies (Jovanović, Krstić, Berezjev, 2022).

Looking at the green patent filings globally, one can say that they have a positive impact on economic activity, especially in the medium term, which is not statistically distinguishable from that of nongreen patent filings. Green patents have an impact on higher investments but they do not enhance aggregate TFP over the horizon considered. For the companies green patents may boost revenue – but

not as much as nongreen patents. It depends on production systems' continued reliance mostly on nongreen technologies. The green transition seems to be at least as promising as the ICT revolution (Hasna et al., 2023).

Evidence shows that green patents are important for green innovation development. Green patents may be the source of technology diffusion. They constitute a significant percentage of the world's green innovations. However, the countries that rank high as important markets for new technologies do not necessarily rank high in terms of the development of such technologies. For example, 15.4 % of the world's environmentally related innovations were patented in Europe and 28% of world's environmentally related innovations were developed in Europe. 25.1% of the world's environmentally related innovations were patented in the United States and 21.1 % of world's environmentally related innovations were developed in the United States. Opposite 37.7% of the world's environmentally related innovations were patented in China and 3% of world's environmentally related innovations were developed in China (OECD, 2024).

According to the UNIDO new technologies have been steadily growing since 2000 to accelerate the transition to net zero. The main source of green innovation is a manufacturing sector. Industrial firms submit six out of every ten global patent applications for technologies that can be used to help the climate change. What is interesting, 85% of green patents are held by industrial firms from just five countries: Japan, China, the USA, Germany, and the Republic of Korea. Green technologies have the potential to revolutionize and affect most aspects of our lives – especially those associated with renewable energies (Lavopa, Menendez, 2023: 3).

The biggest problem because of its high contribution to global greenhouse gas emissions is the industry. It has always been perceived as one of the major sources of the problem. Now, according to some authors, it is increasingly becoming part of the solution (Lavopa, Menendez, 2023: 6). Patent system plays an important role in connecting economic growth and environmental degradation. That is why it should play a significant role in ensuring that future development is sustainable (Nitta, 2005).

Different organizations recognize green patents as an important source of information about sustainable green innovations development. Measurement of green innovation includes three main indicators: R&D expenditure (input), number of green patents (output), green total factor productivity (performance). Such indicators reflect the technology innovation achievement performed by the companies in comparison to the other indicators (Desheng et al., 2021).

Some authors also suggest that filing patents has big importance for green energy development. Protection of patents can play an important business role and what is crucial, they may drive a company's growth, no matter it is a small or big size one. Patent applications and granted patents are assets. They can enable more effective collaboration and unlock preferential tax breaks, they can be valued in the accounts but also influence investors (Brown, Belcher, 2023).

International organizations such as the World Intellectual Property Organization (WIPO), Organization for Economic Co-operation and Development (OECD) and the European Patent Office (EPO) have focused many of their studies on the role of patents in the development and dissemination of sustainable technologies, using patent databases. To identify green patents scientists can use three types of methodologies. They are based on the code classification: ENV-Tech (developed by OECD), IPC Green Inventory (WIPO) and Y02/Y04S Tagging Scheme (EPO) (Fayot et.al, 2023).

Enterprises that are interested in introducing green innovations to the market often look for green patents. According to the International Monetary Fund we can divide green patent filings into eight categories: 1. adaptation to climate change; 2. buildings; 3. carbon capture and storage of greenhouse gases; 4. ICT aimed at the reduction of energy use; 5. production, distribution, and transport of energy; 6. industry and agriculture; 7. transportation; and 8. waste management and wastewater (Hasna et al., 2023).

Green patents may be divided into six categories: energy, transportation, water adoption, buildings, environmental management and capture, storage, and sequestration of GHG emissions (Ghodsi, Mousavi, 2024). According to the results of the research by of Ghodsi and Mousavi energy generation and transportation, out of six defined categories, lead with 36% and 34% of global green patents. Countries in advanced economies are viewed as drivers of innovation. In the eyes of many they are leaving developing nations far behind. This gap worsens climate risks and inequalities.

A good and easy to access source of information about green patents and their classification is IPC Green Inventory created by WIPO (Bretas et al., 2019). It facilitates searches for patent information relating to the Environmentally Sound Technologies (ESTs), ESTs are currently scattered widely across the IPC in numerous technical fields (Table 1). The Inventory attempts to collect them in one place (WIPO, 2024).

Table 1. IPC Green Inventory topics

General topic	Detailed topics
1	2
Alternative energy production	Biofuels, fuel cells, hydro energy, wind energy, geothermal energy, harnessing energy from human-caused waste, solar energy, other production, or use of heat, not derived from combustion, e.g., natural heat, using waste.
Transportation	Vehicles in general, rail vehicles, vehicles other than rail vehicles, marine vessel propulsion, cosmonautic vehicles using solar energy.
Energy conservation	Storage of electrical energy, power supply circuity, thermal building installation in general, low energy lighting, recovering mechanical energy.

Table 1 (cont.)

1	2
Waste management	Treatment of waste, reuse of waste materials, pollution control.
Agriculture / forestry	Forestry techniques, alternative irrigation techniques, pesticide alternatives, soil improvement
Administrative, regulatory or design aspects	Commuting, e.g., telework, etc., carbon/emissions trading, e.g., pollution credits, static structure design.
Nuclear power generation	Nuclear engineering, gas turbine plants using heat source of nuclear origin

Source: based on IP Green Inventory database analysis, https://www.wipo.int/classifications/ipc/green-inventory/home (accessed: 20.01.2024).

Analyzing data from an investor point of view, Global Data identified and mapped relevant patents to the environmental themes (Table 2). Identified patents can help in decreasing emissions, decreasing energy consumption, and providing other environmental benefits. In 2022 patent data showed: 57,367 assignees, 199,542 inventions, 2,078,117 patent filings, 1,262,790 grants. The data shows that we can observe an increase in a number of patents in some vital environmental themes like climate change, carbon emissions, renewable energy, sustainable transportation, solar, food and agri-tech, biodiversity, sustainable farming, electric vehicles, circular economy are discussed (Global Data, 2024). Climate Change is one of the environment-related themes with 3,366,795 patents, highest among all themes.

Table 2. Environmental themes and number of patents in 2018–2022

Environmental theme	Number of patents
Climate change	3,366,795
Carbon emission	1,855,352
Renewable energy	796,288
Sustainable transportation	477,661
Solar	404,523
Food and Agri Tech	331,161
Biodiversity	283,114
Sustainable Farming	278,105
Electric vehicles	187,358
Circular economy	86,153

Source: based on Global Data, https://www.globaldata.com/esg/environment/patents/signals/ (accessed: 10.01.2024).

We can also observe an increase in a number of green patents by sector (Table 3). Some sectors are more active in creating green technologies than others. For example, an automotive sector is the key innovator in the green patent landscape in years 2020–2022 with the 179,992 of patents. The next are technology, media, and telecom; chemicals; industrial goods & machinery; agriculture & forestry. However, one can see that a number of patents in some sectors decreased in 2022. It may be a result of the pandemic and lockdown in previous years. Generally, the increase in green patent filings is visible.

Table 3. Green patents by sectors (2020–2022)

Sector	Number of patents 2020	Number of patents 2021	Number of patents 2022
Automotive	61, 686	71, 035	43, 839
Technology, Media, Telecom	18, 073	27, 068	29, 206
Chemicals	8, 582	9, 215	5, 814
Industrial Goods & Machinery	7, 021	8, 819	6, 865
Agriculture & Forestry	7, 511	7, 292	2, 909

Source: based on Global Data, https://www.globaldata.com/esg/environment/patents/signals/ (accessed: 10.01.2024).

Importance of technology transfer in green patents

To commercialize green technologies sometimes companies need to transfer them from research institutes, universities, or other companies. Finding the partner and networking is not an easy task. An example of practical activities in the implementation of sustainable development goals and activities for the transfer of green technologies is the technological platform developed and implemented by WIPO called "WIPO Green" (WIPO GREE, 2024).

WIPO GREEN is a type of public-private partnership established in 2013 by the World Intellectual Property Organization (Lisowska-Bilińska, 2020). It is an online platform that supports all activities aimed at accelerating progress in the field of green innovations and the development of new environmentally friendly technologies and their dissemination in societies on a global scale (WIPO Green platform, 2024). Through its databases, cooperation networks and numerous networking events brings together inventors of "green" innovations and those who are looking for such "green" solutions to a specific problem. For example, it may be a sustainable access to water or environmentally friendly management of the sanitary system.

WIPO leverages its intellectual property expertise to focus on three global issues: climate change, public health, and food security. Access to the platform is free for

anyone who registers in the system as a WIPO GREEN user. It is financed from the regular budget of WIPO, although financial support for specific projects is provided by both national governments and associations related to intellectual property. WIPO member states can also support this initiative at both national and regional levels and finance individual projects developed within it by entrusting their deposit funds.

The platform is a unique idea because it collects technologies at all levels of development in one place, from prototypes to fully attractive market products. These technologies are available as licenses, collaborations, joint ventures, or for sale. The WIPO GREEN database already contains over 3,000 technologies and reported demands from entities looking for "green" solutions (Lisowska-Bilińska, 2020). It is divided into seven categories: buildings and structures, products, materials and processes, energy, agriculture and forestry, pollution and waste, transport, and water. Registered users only need to describe the benefits their technology can bring to the environment. In 2022 the platform was used by almost 2,500 users from all over the world; there were 128 000+ listed technologies, needs and experts; 150 partners; 1000+ connections were made via their databases, events, and projects. These include small and medium-sized enterprises, universities, research institutes and international companies. All technologies available on the WIPO GREEN platform remain the property of the entitled person, and interested parties negotiate the terms of cooperation themselves.

Climate change and food security are one of WIPO GREEN's three strategic goals as well as climate-smart agriculture, which aims to improve the resilience of crops and reduce their vulnerability to climate change, increase productivity and reduce greenhouse gas emissions. For example, in 2019, WIPO GREEN in South America launched a project to explore the feasibility of using innovative climate change-adapted solutions for wine production in Chile, as well as for land cultivation and management in Argentina and Brazil. Innovations at the regional level since 2015, WIPO GREEN has been organizing numerous projects at the regional level to accelerate the development of innovations and the dissemination of "green" technologies within individual sectors. Already underway are wastewater treatment projects in Indonesia, the Philippines and Vietnam, a project improving agriculture and water management in Ethiopia, Kenya and Tanzania, water resources management in Switzerland, and a project on energy resources, clean air, water and agriculture in Cambodia, Indonesia, and the Philippines.

Mutually beneficial partnerships have also been established because of international projects. For example, in 2018, thanks to the project launched in Southeast Asia as part of WIPO GREEN, the "Green School" in Bali, Indonesia, established cooperation with the American company Zero Mass Water. As a result of this cooperation, the entire school campus in Bali gained an opportunity to use source hydro panels provided by an American company for a constant supply of

drinking water. The school in Bali already operates entirely based on the principles of sustainable development, also using other "green" technologies, e.g., those based on renewable energy, which cover up to 85 percent of the school's energy needs, an ecological water filtration system, a composting station, aquaponics, or buses powered by biofuel. As the director of the "Green School" Innovation Center in Bali emphasizes, finding the right partner for cooperation is not always an easy task. When making decisions regarding the implementation of a new technology, many factors must be considered, such as the area in which we work, or the geographical and climatic factors of our workplace. Such a cooperation between technology providers and potential customers can take place not only through the above-mentioned innovation development projects, but also through the WIPO GREEN databases, through which registered users from the most distant countries can contact each other directly and initiate a partnership that will enable them to find solutions to specific challenges related to climate change. The WIPO GREEN initiative is constantly improving its tools and database functionalities to better serve its users in searching for both the most effective, environmentally friendly technologies that are worth implementing for the benefit of the environment and humans.

The rise in a number of green patents doesn't mean there will be more green innovations. Only commercialization of protected technologies may bring new solutions to the market and help to meet sustainable development goals. Commercialization is a complex process that is not always easy, especially for small and medium companies. It requires specific knowledge and resources. Technology transfer is very important for those who lack it. Even if the company faces the market opportunity by owning a green patent it may not succeed but a green patent can open new possibilities. That is why it can create the opportunity for sustainable development.

Conclusions

The commercialization of green technologies is important in achieving the sustainable development goals. In recent years, there has been a clear upward trend in submitting applications for green patents to patent offices. However, it is still the domain of highly developed countries. For the poorest and most needy countries to benefit from the commercialization of green technologies, it is important to undertake initiatives enabling technology transfer. This is not an easy task. Enterprises operate for profit, and green patents are intended to provide them with financial benefits. The poorest countries do not have money to buy expensive advanced technologies. Therefore, the discussion and development of methods for the transfer of green technologies to achieve the sustainable development goals are extremely important and should constitute an inspiration to undertake new directions of scientific research.

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A Decadal Systematic Review of Factors Underlying Tax Compliance in the Informal Sector

Summary

Urban informality has been a subject of economic discussion for over five decades. Since the late 2000s, renewed interest has been focused on the sector's rapid growth and frequent operation outside formal economic systems, raising pressing concerns about tax evasion and regulatory compliance. Previous attempts to tax the informal sector often fell short due to a failure to account for its heterogeneity, which distinguishes it from the formal sector. Effective tax collection in the informal sector hinges on operators' compliance with the tax regime; however, discussions on the determinants of compliance in this context remain limited. This study addresses the need for an effective taxation framework for the informal sector by examining the role of tax compliance in this initiative. This study uses a systematic literature review of papers published between 2015 and 2024 and indexed in Scopus and Web of Science, to investigate the determinants of tax compliance within the informal economy. The findings

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indicate that compliance determinants can be categorized into governance quality, operational characteristics, tax morale, and the effectiveness of past and existing taxation strategies, with interconnected pathways linking these factors. This study advances the discourse on informal sector taxation in three key ways. First, it outlines tax compliance determinants within a structured framework, providing a basis for statistical analysis. Second, it offers practical insights for flexible, sector-specific taxation approaches. Third, it lays the groundwork for legislative discussions, potentially shaping standalone statutory instruments for formal and informal sectors. Considering the study's limitations in scope and sampling bias, future research could explore variations within the informal sector through a taxation perspective, examine digital taxation strategies, and investigate the root causes of informality to gain a deeper understanding of their impact on contemporary tax compliance challenges.

Keywords: informal sector, taxation; tax compliance, operational characteristics, governance quality, tax morale, taxation strategy

Systematyczny przegląd czynników wpływających na przestrzeganie przepisów podatkowych w sektorze nieformalnym w latach 2015–2024

Streszczenie

Nieformalna działalność gospodarcza w miastach pozostaje przedmiotem zainteresowania ekonomistów od ponad pięćdziesięciu lat. Od końca pierwszej dekady XXI wieku rośnie zainteresowanie dynamicznym rozwojem tego sektora. Jego funkcjonowanie poza formalnymi strukturami gospodarczymi budzi obawy związane z unikaniem opodatkowania i nieprzestrzegania przepisów. Dotychczasowe próby opodatkowania sektora nieformalnego często kończyły się niepowodzeniem, głównie z powodu nieuwzględniania jego zróżnicowanej natury. Skuteczność poboru podatków w tym obszarze zależy od poziomu zgodności podatkowej jego uczestników, jednak kwestia ta pozostaje słabo zbadana.

Niniejsze badanie podejmuje próbę wypełnienia tej luki poprzez analizę czynników wpływających na przestrzeganie przepisów podatkowych w sektorze nieformalnym. W tym celu przeprowadzono systematyczny przegląd literatury z lat 2015–2024, obejmujący publikacje indeksowane w bazach Scopus i Web of Science. Wyniki wskazują, że determinanty zgodności podatkowej można podzielić na cztery główne kategorie: jakość rządzenia, cechy operacyjne, moralność podatkową oraz skuteczność dotychczasowych i obecnych strategii fiskalnych. Elementy te są wzajemnie powiązane i tworzą złożoną sieć zależności.

Badanie wnosi wkład w rozwój dyskusji na temat opodatkowania sektora nieformalnego na trzech poziomach: 1) proponuje uporządkowane ramy analizy zgodności podatkowej, 2) dostarcza praktycznych wskazówek dla elastycznego i dopasowanego podejścia do opodatkowania, 3) stanowi punkt wyjścia dla prac legislacyjnych nad odrębnymi regulacjami dla sektorów formalnego i nieformalnego. Mając na uwadze ograniczenia badania – w tym zakres tematyczny i możliwość błędu doboru próby – przyszłe analizy mogą skupić się na zróżnicowaniu wewnątrz sektora nieformalnego, strategiach opodatkowania cyfrowego oraz przyczynach powstawania nieformalności, by lepiej zrozumieć ich wpływ na wyzwania podatkowe współczesnych gospodarek.

Słowa kluczowe: sektor nieformalny, opodatkowanie, przestrzeganie przepisów podatkowych, charakterystyka działalności, jakość zarządzania, moralność podatkowa, strategia podatkowa.

Introduction

The concept of informality emerged in economic discussions during the 1970s when Hart (1973) examined informal employment and income in Ghana. At that time, scholars who advanced the idea of informality were influenced by a dualist perspective, which held that informality was a temporary phenomenon. This view assumed that informality would decline over time and with economic growth, as it was seen as merely a symptom of an underperforming economy (Despres, 1988; Ntlhola, 2010; Onoshchenko, 2012). Informality was perceived as a short-term solution to labor absorption, driven by rapid urbanization and economic crises, and thus little effort was directed toward its management.

A decade after its initial emergence, structuralist perspectives started challenging the assumption that informality would vanish over time. For instance, Granstrom (2009) and Bairagya (2010) used case data from Senegal and India, respectively, to demonstrate that the formal and informal sectors are interconnected, serving both complementary and competing roles (Narula, 2020). This indicates the existence of interconnections that contribute to the sector's resilience

and continuity, despite shifts in regulations and policy approaches. In the face of this recognition, attempts during this period to formalize and harness value from the informal sector often fell short, as authorities tended to apply the same management strategies to both formal and informal sectors. Additionally, research on urban informality has consistently highlighted that informal operators frequently free-ride, evade taxes, flout zoning regulations, and function with limited accountability due to their unique operational characteristics (Kanbur, 2010; Keen & Kanbur, 2015; Verberne & Arendsen, 2019).

The expansion of informal activities and the shortcomings of management strategies rooted in dualist and structuralist perspectives have reignited academic interest since the late 2000s and early 2010s (Varley, 2008). Contemporary studies (e.g., Yiftachel, 2009; Miraftab, 2009; Musara, 2015; Villamizar-Duarte, 2015), informed by post-colonial approaches to urban management, urban finance, and entrepreneurship, now recognize the resilience and inevitability of informality. These scholars highlight the sector's heterogeneity, advocating for management and taxation strategies tailored to its distinct operational characteristics. This emerging body of work also draws on the Cost of Service Theory (CST), which argues that citizens should not expect free services and local public goods from the government, despite the state's responsibility to finance and provide these goods. Instead of relying on formal direct taxation or intergovernmental grants, CST suggests that local revenue can be mobilized through informal taxation. Supporting this view, Olken & Singhal (2011) contended that informal taxation enables communities to address the free rider problem, thereby ensuring the provision of local public goods that might otherwise be underfunded. Specifically, Olken & Singhal (2011, p. 2) outlined that *"informal taxation is a mechanism used to finance local public goods…a system coordinated by public officials but enforced socially rather than through the formal legal system"*.

Olken & Singhal (2011) underscored the importance of designing taxation strategies tailored to the unique characteristics of the informal sector. This is particularly critical as many developing economies, particularly in Africa and Latin America, are increasingly dominated by informal activities, with significant financial resources circulating outside formal systems (Verberne & Arendsen, 2019; Dube & Casale, 2019; Maiti & Bhattacharyya, 2020; Chan, Dang, & Li, 2020; Isak & Mohamud, 2022; Bussy, 2023). While informality is a global phenomenon, its scale is notably larger in developing nations compared to their developed counterparts (Olga et al., 2015; Karlsson et al., 2020; Saifurrahman & Kassim, 2024). Over a decade ago, Schneider et al. (2010) reported that the informal sector constituted 38.4% of the economy in Africa, 36.5% in Europe and Central Asia (primarily transition countries), and 13.5% in high-income Organization for Economic Cooperation and Development (OECD) countries. Schneider et al. (2010) identified weak institutional

and regulatory frameworks as the primary reason for higher informality in developing countries compared to developed ones. Under these conditions, informal enterprises flourish as entrepreneurs opt to operate outside the formal economy to bypass regulatory burdens.

Advocates of informal sector taxation argue that leveraging sector-specific tax frameworks could enhance revenue generation and sector management (Piccolino, 2015; Eriksson Baaz et al., 2018; Sebele-Mpofu, 2020; Anyidoho et al., 2023; Hammond et al., 2023; Akor et al., 2024). However, scholars such as Benhassine et al. (2018), Narula (2020), and Moore (2023) have highlighted concerns, noting that many informal operators engage in subsistence-level activities, face financial strain, and operate unsystematically. Additionally, Benhassine et al. (2018) argued that the cost of collecting taxes from this sector often outweighs potential revenues due to its typically small-scale operations. Despite these challenges, there is consensus on the need for informal sector participants to contribute to public services. Efforts are ongoing to develop efficient, equitable, and socially just taxation methods that minimize the burden on this sector while optimizing revenue generation. To successfully operationalize this initiative, Joshi et al. (2014, p. 1326) have suggested the *"need for research into the conditions under which potential benefits are most likely to be realized".* One key condition identified is the need to understand the factors influencing tax compliance, given the inherently evasive nature of the informal sector (Keen & Kanbur, 2015). Bussy (2023, p. 1) refers to this phenomenon as the *"trade evasion channel"*.

Taxing the informal sector has proven challenging due to low compliance rates among operators (Hammond et al., 2023). Tax compliance, defined as the willingness of operators to adhere to government tax requirements, is essential for a successful tax regime. However, compliance levels differ across regions and sectors, with the informal economy often deemed *"hard-to-tax"* due to its diverse and fluid nature (Verberne & Arendsen, 2019, p. 6; Aruoba, 2021). For example, the presumptive tax system has been criticized for its poor fit with the sector's structure (Dube & Casale, 2019). Although there is growing advocacy for taxing the informal economy, understanding compliance is critical for designing effective taxation strategies. Few studies have thoroughly explored this issue, and the literature remains fragmented, evolving in multiple directions. This is reflected in the fact that only 28 papers published over the past decade were included in the review (see the methodology). Kanbur (2009, p.1) aptly described it as being *"in a mess"*, needing comprehensive and systematic packaging to inform policy and practice. Similarly, Sebele-Mpofu (2020) emphasized the need to foster voluntary compliance, particularly by systematically addressing financial issues within the informal sector.

This review addresses the question: what are the key drivers and barriers to tax compliance in the informal sector? This question is answered through a systematic review of studies published in the past decade (2015–2024) following the

renewed interest in urban management and finance in the late 2000s and early 2010s. This study adopts the view that the informal economy, sector, or enterprise refers to economic activities that operate outside formal regulations but follow social norms within legally recognized informal domains (Bennihi et al., 2021; Routh, 2021). Economists often use 'economy' and 'sector' for broader commercial groupings, while business analysts use 'enterprise' to describe small business startups. The papers included in the review used these three terms, all referring to the same concept. Therefore, this paper employs all three terms interchangeably. The methodology, findings, and conclusions are discussed in subsequent sections.

Methodology and data

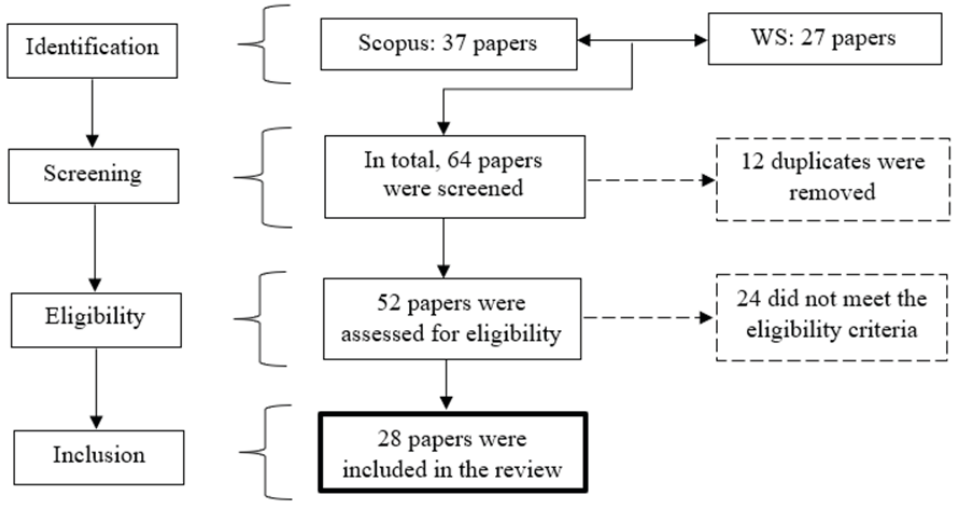
I conducted a systematic literature review to investigate the drivers and barriers to tax compliance among actors in the informal sector. Although there is no universally agreed-upon method for conducting such reviews, there is consensus that they must include well-defined research question(s), a replicable search strategy, clear inclusion and exclusion criteria, and a transparent process for transforming collected data into insights (Waddington et al., 2012; Krnic Martinic et al., 2019). The research protocol I adopted was shaped by the research question outlined earlier, the databases used for sourcing literature, language and timeframe restrictions, study type, and thematic focus. First, I purposively and conveniently selected Scopus and Web of Science (WS) as the primary search platforms. This choice was purposive to minimize bias by relying on more than one database and convenient because I had ready access to these resources during the study.

Second, my search was guided by two primary keywords, 'informal sector' AND 'taxation'. Using these keywords, the search parameters were refined to include:

1. Papers published in English between 2015 and 2024 inclusive, hence decadal review;
2. Open-access publications; and
3. Papers categorized under three subject areas: social studies, economics (econometrics and finance), and business (management and accounting).

Third, the eligibility criteria were based on the relevance of a study's objectives and contributions. The review included only papers that directly addressed tax compliance in the informal sector or indirectly explored the factors influencing and limiting compliance. Using this research protocol, I followed the four steps proposed by Waddington et al. (2012): identifying literature, screening identified papers, checking for eligibility of selected studies, and including studies in the final review. Figure 1 offers a visual overview of the results obtained after completing this four-step process.

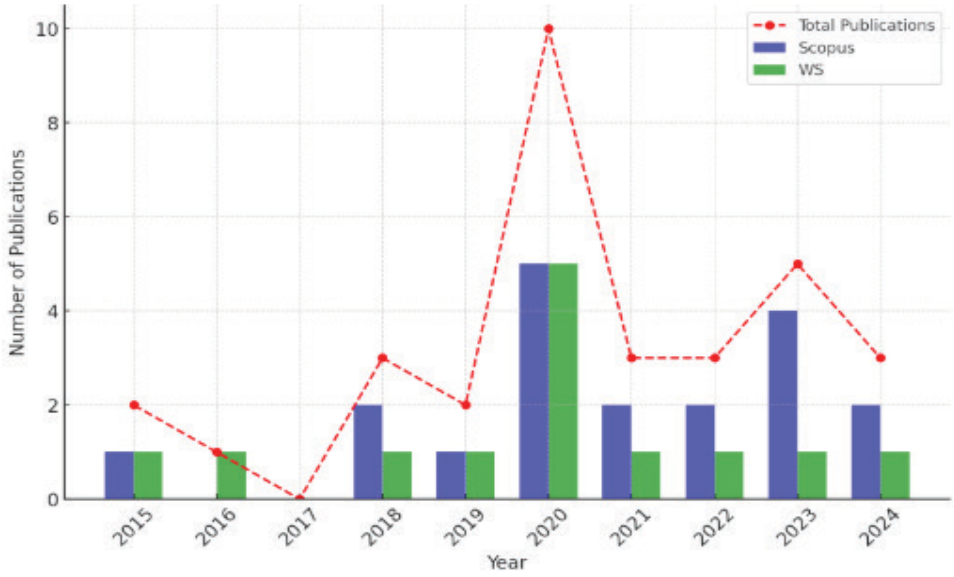
Figure 1. Schematic view of the research protocol



Source: Own study (2024).

During identification, 64 papers were found: 27 from WS and 37 from Scopus. Then, 12 papers were dropped during screening because they were duplicates; that is, they appeared in both databases. So, 52 papers passed the screening stage, and I examined their abstracts for eligibility. 24 papers by Williams (2015), Araujo & Rodrigues (2016), Di Porto et al. (2017), Kuralbayeva (2018), Christiaensen & Martin (2018), Kuralbayeva (2019), Romanova et al. (2019), Lopez-Martin (2019), Nakabayashi (2019), Novikova et al. (2019), Bloeck et al. (2019), Narita (2020), Esaku (2021), Roy & Khan (2021), Williams & Krasniqi (2021), Langot et al. (2022), Mpofu & Mhlanga (2022), Doligalski & Rojas (2023), Arbex et al. (2023), Sahoo, Rout, & Jakovljevic (2023), Kalaitan et al. (2023), Keating (2024), Ho & Tirachini (2024), and McKay et al. (2024) did not meet the eligibility criteria. For example, their abstracts were not relevant to the research question, that is, they did not mention anything to do with tax compliance. Where taxation issues were raised, they were meant to clarify and specify certain issues, most of them not related to the core of this paper. So, a total of 28 papers were finally included in the decade-long review, constituting 54% of the papers with the keywords adopted for selection. Figure 2 provides a detailed summary of the included papers' distribution across databases and years of publication.

Figure 2. Composition of reviewed papers (2015–2014)



Source: Own study (2024).

The year 2020 recorded the highest number of publications addressing the determinants of tax compliance in the informal sector, while 2017 did not contribute a single paper to the review. Regarding contributions from each database, Scopus yielded slightly more papers meeting the eligibility criteria compared to WS. During the screening process, 12 duplicate papers were identified, of which four met the eligibility criteria while the remaining eight did not. Figure 2 shows that Scopus did not have any publications meeting the eligibility criteria in 2016, evidenced by the absence of a bar for that year. Similarly, neither Scopus nor WS had eligible publications in 2017. In 2015 and 2019, both Scopus and WS contributed one publication each. Then, the line graph shows the total number of publications included in the review each year, irrespective of duplicates. Consequently, the analysis and discussion of findings in the subsequent sections are largely shaped by the composition of papers summarized and depicted in Figure 2.

Additionally, the review's output is influenced by the types of included papers and the data and approaches they used. Of the 28 included papers, 26 are empirical papers, and two are conference proceedings, representing 93% and 7%, respectively. Regarding the data and approaches used, I classified the papers along two dimensions: primary versus secondary (or a combination of the two); and qualitative versus quantitative (or a mixture of the two). Table 1 presents the distribution of the reviewed papers based on these dimensions.

Table 1. Data and methods of included papers

		Absolute	Percentage
First Dimension [Primary versus Secondary]	**Primary**	14	50
	Secondary	8	28.6
	Combined	6	21.4
Total		**28**	**100**
Second Dimension [Qualitative versus Quantitative]	**Qualitative**	11	39.3
	Quantitative	12	42.9
	Mixed-Methods	5	17.9
Total		**28**	**100**

Source: Own study (2024).

Table 1 reveals that, for the first dimension, 50% of the eligible papers relied on primary data to explore the informality-taxation relationship, followed by 28.6% that used secondary data and 21.4% that employed a combination of both. The heavy reliance on primary data likely reflects the fact that this topic gained prominence in the late 2000s and early 2010s, limiting the availability of substantial secondary data tailored to this emerging area of study. This partially accounts for the limited number of accessible studies on the subject, particularly before 2018 (as highlighted in Figure 2). Arguably, this study represents one of the initial comprehensive reviews of the existing knowledge on this topic since its resurgence of interest over the past decade. Regarding the second dimension, there is a slight preference for quantitative approaches over qualitative ones, with only a marginal difference in their prevalence. Additionally, about 18% of the studies employed a mixed-methods approach, combining diverse perspectives to examine the factors driving tax compliance in the informal sector. Consistent with this paper's objective of explaining the determinants of tax compliance in the informal sector, I used a manual textual analysis to review the 28 included papers. To ensure nuanced insights, I meticulously analyzed the texts, identifying underlying assumptions, contradictions, and recurring themes, with the findings presented in the next section.

Empirical results

In this section, results are thematically presented according to similarities and contradictions of ideas found in papers included in the review. Identified themes have been grouped into governance quality, operational characteristics, tax morale, and effectiveness of current strategies, with numerous pathways linking them. It must be noted that the identified themes are partly skewed and explained by the composition of reviewed papers.

Governance quality

Even though there are numerous stakeholders in a tax system, there are two key sides; the tax collector and the taxpayers' sides. In this case, the taxpayers' side is composed of informal operators and the tax collector is the government, mostly represented by appointed agencies or administrators. Considering these players, the performance of a tax system is largely dependent on the quality of the relationship between the taxpayer and the tax collector. Using the concept of fiscal sociology, Piccolino (2015) argued that effective taxation is based on a quasi-consensual relationship between the state and the taxpayers. It is this quasi-consensus that fuels tax compliance among economic players. This means, as Hammond et al. (2023) keenly observed, tax compliance is a function of the link between political trust and the quality of governments. It has been observed that administrators can easily win the trust of players in the informal sector if they uphold the principles of performance, professionalism, and impartiality (Piccolino, 2015; Hilson, 2020). Performance, as Anyidoho et al. (2023) noted, can be assessed according to the ability of the tax administrators to deliver their mandate as implied by the law, without deviating from what has been agreed upon or simply put, citizens' attitude towards public services. Expanding on the issue of citizens' attitudes, Verberne & Arendsen (2019) clarified that tax compliance attitudes are influenced by issues relating to taxpayers' confidence and knowledge of the tax regime. But, where do taxpayers get some of this knowledge? Ansong (2024) gave some proxies to this question by noting that administrators best execute their duties, including educating taxpayers when they serve and act professionally. In any given country, tax systems are run on set institutional rules and administrative procedures, and adherence to these rules of engagement brings about confidence in the government. So, if administrators exhibit higher levels of performance and professionalism, the greater the trust citizens have in them, and the greater the chance of preventing financial cheating and tax evasion. Professionalism, according to Sebele-Mpofu (2020), can be viewed through the lens of the impartiality of tax administrators. It has been asserted that enforcement must be combined with tax reforms that improve transparency and accountability in the use of tax revenues to boost tax morale and heighten tax compliance in developing countries (Akpan, 2022; Saifurrahman & Kassim, 2024).

Scholars such as Dube & Casale (2019) and Bertinelli et al. (2020) used case data from Zimbabwe and Mali, respectively, to show how impartiality is compromised on the count of politics. For example, Dube & Casale (2019) characterized deregulation as a selective, and sometimes politically motivated, application of law. This brings about an uneven playing field because some taxpayers are exempted from certain sections of the law whilst some are caught on the wrong side of the law using the same sections. Bertinelli et al. (2020) clarified that the

selective application of law undermines both vertical and horizontal equity. On one hand, horizontal equity refers to the uniform application of law to economic players in the same tax bracket regardless of who they are affiliated with. On the other hand, vertical equity defines fairness that applies to economic players in different tax brackets. For example, taxpayers in a lower tax bracket are charged a percentage that is lower than players in a higher tax bracket. The idea is to ensure that those who earn more, pay more, and those who earn less, pay less. According to Bertinelli et al. (2020), horizontal and vertical inequity, as an act of corruption, takes the form of misuse of resources or power for private gain. Similarly, Ansong (2024) has argued that taking bribes by administrators significantly reduces tax compliance.

Moore (2023) outlined the political dimension of taxation that diverts people's attention by showing how the continual drive to register more taxpayers provides an impression of the tax administrators' efforts to collect more revenue. In such a narrative, the general populace is made to believe that under taxation of small enterprises, mostly in the informal sector, is the main explanatory factor for revenue scarcity. Moore (2023) underlined that this helps divert attention from corrupt tendencies involving tax administrators and larger enterprises. To this effect, Maiti & Bhattacharyya (2020) have described weak enforcement in the informal sector as deliberate. For example, the state can heavily tax the formal sector to subsidize informal income and finance public infrastructure. It has, therefore, been reasoned that deregulation and weak enforcement are sites of considerable state power where politicians (through their administrators) retain electoral loyalty from people exercising informality. So, tax systems are, arguably, designed to paint a certain narrative that serves the interests of vote-seeking politicians, thereby compromising the quality of governance. But how does the quality of governance shape, or is shaped by the operational characteristics of the informal sector?

Operational characteristics

Several sources have shown that the quality of governance has some causal linkages with the way the informal sector operates (Bertinelli et al., 2020; Maiti & Bhattacharyya, 2020; Isak & Mohamud, 2022; Bussy, 2023; Moore, 2023). Major explanatory variables to informal sector operations are deeply rooted in urban management, politics, and tax policies. In an attempt to explain issues around tax compliance in Somalia, Isak & Mohamud (2022) noted that the country has been experiencing civil unrest since 1991. This resulted in social, economic, and political instability, and the destruction of governance systems, including the taxation culture. So, informality is located in an operating environment characterized by limited administrative capacity and the high costs involved in enforcing compliance, all hindering the proper management of the taxation system. Furthermore,

economic instability resulting from civil unrest challenges the smooth management of administrative systems. This challenge is not peculiar to Somalia, but African countries such as Cameroon, Burundi, Chad, Niger, Somalia, Ethiopia, Mali, and Mozambique recorded intra-state conflicts in 2019 alone. During conflicts, some economic players take advantage of the chaos to evade taxes.

Bussy (2023) introduced a new dimension to understanding informal sector operations by highlighting the *'trade evasion channel'*. Through this channel, some firms manipulate their reported imports and exports to understate taxable profits and evade Corporate Income Taxes (CIT). This is facilitated by poor record-keeping and the lack of professional audits, as informal businesses often operate outside formal regulatory frameworks. The sector's fluidity and intense competition further complicate accurate bookkeeping, as price negotiations are common (Dube & Casale, 2019). Consequently, formal businesses often subcontract to the informal sector, allowing tax authorities to focus on formal enterprises while tax evasion thrives unnoticed. This channel suggests that the formal sector appears to be producing a paltry output while goings-on in the informal sector are not closely monitored, yet a significant percentage of the economic activity will be taking place in the often unnoticed, 'organism-like' informal sector.

Apart from the deliberate tricks used by informal operators to evade tax channels, their operations are difficult to tax because they are disorderly. In light of this challenge, Verberne & Arendsen (2019) labelled the informal sector as *'hard-to-tax'* considering its operational characteristics (that is, its nature, size, composition, and location). For example, Moore (2023) noted that most informal sector operations are characterized by players who are using survivalist strategies to eke a living and are, in some cases, ignorant of taxation issues. Some of these players operate in their backyards not known to tax administrators. So, taxing this sector is a mammoth task amid these challenges that make it difficult to systemize their operations. Where the operations are somewhat orderly, players' psychographics (that is, their attitude, knowledge, and perception) toward tax compliance must be improved (Eriksson Baaz et al., 2018; Hilson, 2020; Hilson et al., 2023). The next sub-section discusses the quality of human factors and their inherent influence on the intention to comply.

Tax morale and the intention to comply

Sebele-Mpofu (2020) described tax morale as the intrinsic motivation of informal operators to pay taxes, reflecting an internal sense of confidence or discipline to act in a certain manner. This suggests that tax morale is influenced by behavioral, normative, and control beliefs or assumptions. Behavioral beliefs pertain to the perceived costs and benefits of acting in a particular way. Similarly, Rahou & Taqi (2021) framed this concept as a cost-benefit analysis regarding the use of

tax revenues. For instance, when operators perceive that the benefits of paying taxes outweigh the costs, they are more likely to adopt a positive attitude toward contributing to public funds. Hilson's (2020) position supports this perspective, concluding that both tax collectors and taxpayers are often inclined toward mutually beneficial arrangements. Many informal operators, recognizing the advantages of working within a structured and regulated system, are eager to participate in such frameworks. Thus, attitude plays a critical role in tax compliance, reflecting an individual's evaluation of the process. The stronger the belief that compliance will yield greater benefits, the stronger the intention to comply, and vice versa.

Behavioral beliefs are influenced by social pressure and control beliefs. Informal operators often share ideas, experiences, knowledge, tools, and skills within their operational environments (Sebele-Mpofu, 2020). This interaction creates direct or indirect pressure among peers regarding tax compliance. An individual's intention to pay taxes is shaped by the general social pressure exerted by other operators, who influence the approval or disapproval of such actions. Eriksson Baaz et al. (2018) and Hammond et al. (2023) similarly argued that this pressure arises through shared knowledge as operators interact and network daily in their workplaces. Informal sector players often regulate one another, fostering solidarity under the principle of *'injure one, injure all'*, a trait that differentiates them from formal sector operators. Furthermore, Sebele-Mpofu (2020) highlighted that informal operators also share beliefs about how tax revenue is used by the government for public goods and services in their areas of operation. These shared perspectives often lead to unified attitudes, where individuals' intentions to comply are influenced by perceived social pressure. Collectively, informal sector participants evaluate the fairness of the tax system and their capacity to pay, considering the benefits they expect from compliance (Hilson, 2020; Verberne & Arendsen, 2019).

Despite the general social pressure exerted by peers, individual economic players are influenced by their own perceived constraints on the intention to comply. Differences in backgrounds among economic players lead to variations in their compliance intentions (Sebele-Mpofu, 2020). For instance, some individuals possess greater tax knowledge due to higher levels of education, while others benefit from political connections. These variations reflect control beliefs, which pertain to the perceived influence of internal and external factors in facilitating or hindering tax compliance. Verberne & Arendsen (2019) illustrated this through the differing perceptions of authorities' enforcement power, often influenced by an individual's connections with enforcement officers. Similarly, Akpan et al. (2022) discussed how the tax system and tax collectors exhibit gender bias, highlighting how differences in gender, social standing, and political affiliation shape individuals' tax morale and intention to comply. These internalized control beliefs play a critical role in shaping compliance behavior.

Knowledge of past and current taxation strategies

Countries with high levels of informality have made numerous attempts to tax the informal sector, but many of these efforts have fallen short of expectations (see Charlot et al., 2016; Eriksson Baaz et al., 2018; Dube & Casale, 2019; Bertinelli et al., 2020; Chan et al., 2020; Schipper, 2020; Elgin et al., 2022; Anyidoho et al., 2023; Akor et al., 2024). Evidence suggests that the poor performance of these strategies often stems from their lack of alignment with the diverse and heterogeneous nature of the informal sector (Verberne & Arendsen, 2019; Aruoba, 2021). For instance, Dube & Casale (2019) highlighted that the Zimbabwean government introduced a presumptive tax for the informal sector in 2005, relying solely on a survey of informal public transport operators. It was incorrectly assumed that this approach would be effective across all informal sector variants. To broaden the tax base, additional variants of informality were added to the tax schedule without empirical justification. This initiative saw limited success, as presumptive tax relies on estimated indicators rather than measurable bases. Applying assumptions from the informal transport sector to other variants proved to be a significant miscalculation, leading to implementation challenges.

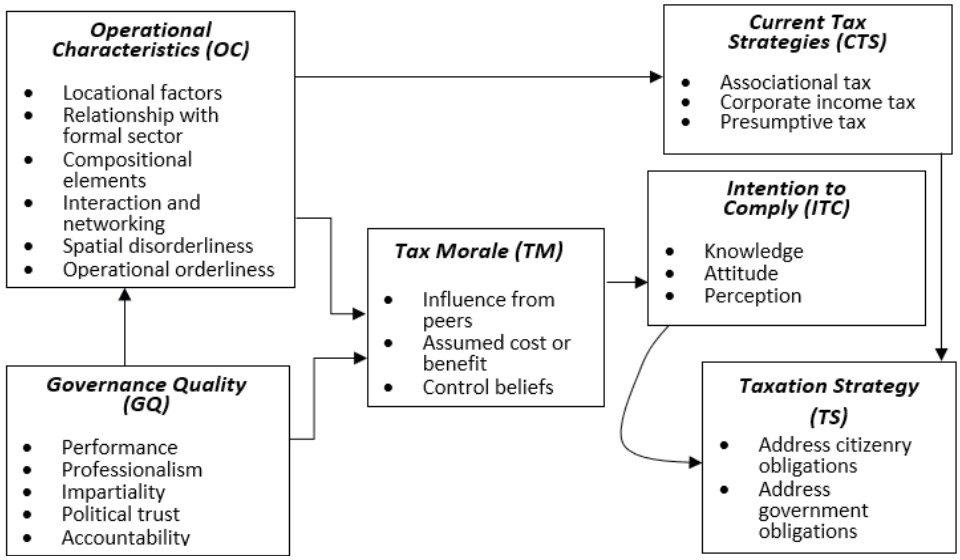
Another example of an ineffective taxation strategy in the informal sector is CIT, analyzed by Bussy (2023) using the *'trade evasion channel'*. As previously mentioned, CIT functions optimally under ideal conditions, where accurate record-keeping and honest reporting of economic activities are upheld. However, achieving this in the informal sector is highly challenging due to its unique operational dynamics and the poor governance quality outlined earlier. These factors make it difficult to enforce CIT effectively, further complicating efforts to integrate the informal sector into the formal tax system.

This underscores the need for taxation strategies specifically tailored to the informal sector, informed by lessons from past and current approaches. Hammond et al. (2023) sought to understand the reasons behind the poor performance of previous taxation strategies targeting the informal sector. They identified perceptions of tax administration as the most significant barrier to the success of tax policies. Repeated unsuccessful attempts to tax the informal sector may have eroded trust in tax administrators, contributing to low tax morale among informal sector operators. This lack of trust and low morale likely hinders compliance. Thus, an in-depth examination of past taxation strategies, particularly in terms of compliance outcomes, is crucial for developing more effective approaches tailored to the unique dynamics of the informal sector.

Discussion and conclusion

Since determinants of tax compliance in the informal sector have numerous explanatory factors, some emanating from the taxpayers' side and some from the tax collector's side, there is a need for a halfway-through approach, incorporating the expectations of both parties in designing a workable taxation strategy. Most traditional approaches to taxation have failed on the count of compliance because they are top-down driven, with limited room to incorporate the taxpayers' views. Against this background, Meagher (2018) and Verberne & Arendsen (2019) have argued that gaining a bottom-up understanding of taxation in the informal sector and improving tax morale is key to designing an effective taxation strategy. This review has revealed that the key variables driving and restraining tax compliance by players in the informal sector include their operational characteristics, governance quality, tax morale, and current tax strategies, and how they culminate into an all-inclusive taxation strategy. Figure 3 shows the interdependence of these factors.

Figure 3. Conceptual orientation of tax compliance constructs



Source: Own study (2024).

Sebele-Mpofu's (2020) study on the determinants of taxation strategy highlighted the intrinsic connection between governance quality, tax morale, and tax compliance. The research noted that tax morale impacts tax compliance, while governance quality, in turn, affects tax morale. Such scholarly work is valuable,

as it offers insights into the relationship between urban informality and tax compliance. Sebele-Mpofu's contribution is crucial for developing a well-rounded understanding of the factors influencing tax compliance. However, questions remain about the comprehensiveness of her analysis.

Firstly, her study did not explore how the unique operational characteristics of the informal sector influence tax morale. For example, Verberne & Arendsen (2019, p.6) characterized the informal sector as *"hard-to-tax"* due to its distinct features, such as its nature, size, and location. This suggests that the way informal operators interact and network in their daily activities could partially shape their intentions to comply with tax obligations. Secondly, the study did not assess the effectiveness of past and existing taxation strategies. Studies by Dube & Casale (2019), Verberne & Arendsen (2019), and Bussy (2023) have shown that past and current taxation strategies have struggled to effectively levy the informal sector. In light of this, Isak & Mohamud (2022) emphasized the need to align the growth of the informal economy with taxation efforts, advocating for building society's capacity to pay taxes rather than solely focusing on the state's ability to enforce tax collection. In response, the present study incorporates these two dimensions, operational characteristics, and current tax strategies, into Sebele-Mpofu's conceptual model, refining and mapping multiple pathways that link these factors, thus creating a socially binding framework that comprehensively captures all the determinants.

The preceding paragraphs explored the determinants of tax compliance in the informal sector through a systematic review of 28 papers published between 2015 and 2024, sourced from Scopus and WS databases. This review was driven by the recognition that few studies have thoroughly investigated this issue, despite tax compliance being a critical factor in the success of taxation strategies within the informal economy. This approach is grounded in post-colonial perspectives on informality and the CST, which views informality as a quasi-permanent phenomenon that, while distinct in its operational characteristics, must still contribute to public revenue. The analysis identified key factors shaping taxation strategy and the intention to comply, including governance quality, operational characteristics, tax morale, and the structure of previous and current taxation strategies. Figure 3 illustrates the various pathways linking these factors, providing a framework for statistically analyzing their interaction.

Although there is a negligible difference between the number of studies that qualitatively and quantitatively analyzed these relationships (see Table 1), Moore (2023) highlighted the lack of statistical data on the functioning of national tax administrations in economies with high informality. While quantitative analyses are limited and often not comprehensive, the financial issues within the informal economy, by their very nature, require quantitative examination to inform policy. To address this gap, this study systematically explored the factors underlying tax compliance in the informal sector and organized them into a conceptual model to

facilitate statistical analysis. This thorough approach provides a robust foundation for evaluating the performance of the conceptual model.

This study's key contribution to the literature on financial issues in the informal economy is its development of a conceptual model for tax compliance, synthesized from studies conducted over the past decade. The model integrates a measurement framework of six factors (OC, GQ, TM, CTS, ITC, and TS) with a structural path illustrating their interrelationships. Unlike previous fragmented studies, which have limited cohesive insights into policy and practice, this model provides a comprehensive approach to understanding tax compliance in the informal sector. Additionally, it extends the conventional CST, which does not clarify how formal and informal economic players must contextually contribute to the fiscus, by proposing a viable taxation framework for the so-called *'hard-to-tax'* sector (Verberne & Arendsen, 2019). As such, this study underscores the contextual nature of tax compliance and introduces the missing dimension of informality to taxation theory and practice.

From a practical perspective, the present study clarifies the determinants of tax compliance in the informal sector. Historically, taxation strategies for the informal economy have been modeled after formal sector frameworks, overlooking key operational differences. This study highlights tax evasion tactics unique to the informal sector, such as the *'trade evasion channel'* reported by Bussy (2023). By identifying these tactics, the study advocates for tailor-made and flexible taxation approaches that could improve compliance. Furthermore, given that tax policies are heavily regulated at both central and local government levels, this study has significant policy implications. Its findings offer a foundation for legislative debates on tax compliance determinants, potentially informing the development of standalone statutes or statutory instruments specific to formal and informal sectors. These policy insights contribute to more equitable and effective tax regulations, improving both compliance and overall tax system performance.

Future research can build on this study's conceptual model by quantitatively assessing the measurement framework for the six factors using Confirmatory Factor Analysis (CFA). Essentially, CFA ensures the reliability and validity of these factors by evaluating their respective indicators, as illustrated in Figure 3. For instance, governance quality can be assessed through indicators such as performance, professionalism, impartiality, political trust, and accountability. Additionally, the structural framework can be assessed by examining the statistical significance of relationships between latent variables (six factors) and the predictive strength of the conceptual model.

A key gap identified in this study is the lack of research on the potential of digital tools to enhance taxation transparency and efficiency, with 28 reviewed papers not addressing this aspect. Future studies could explore financial inclusion and digital taxation within the informal sector, potentially offering sustainable and

practical insights to improve tax policy and practice. Furthermore, beyond distinguishing the informal sector from the formal sector, there are variations within the informal sector that remain unexplored in this study. For example, its variations across primary, secondary, and tertiary levels of production. Future research could delve into these differences to provide context-specific policy recommendations tailored to the operational characteristics of each segment.

This study is also limited by its focus on literature from the past decade, which primarily addresses the symptoms of informality. Instead of narrowly focusing on these symptomatic issues, future research can investigate the root causes of informality. Addressing these underlying factors could lead to more effective and long-term solutions, ultimately reducing the persistence of informal economic activities. For example, this study briefly touched on corruption in tax administration but does not deeply explore the broader political economy of taxation, including elite capture and institutionalized corruption. Given that issues of governance and corruption are deeply embedded in institutional change processes, future studies can examine these dynamics at a systemic level. Such research could help create a foundation for implementing the recommendations of this study. Overall, this study provides a comprehensive review of tax compliance in the informal sector while setting a clear research agenda synthesized from a decadal (decade-long) systematic review.

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