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Carbon offsets compatible with the Paris Agreement to limit global warming: Call for a direct action

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ABSTRACT

The societal commitment to combat climate change is reflected in the Paris Agreement with the primary focus to mitigate climate change by reducing or limiting greenhouse gas emissions. To facilitate the achievement of emission reduction targets, innovative carbon crediting and offsetting mechanisms have been developed. These mechanisms enable stakeholders to offset their emissions by using carbon offset credits if needed. These carbon offset methodologies can be classified into two main categories. The first category involves directly reducing greenhouse gas emissions from the environment through green and emission-capturing solutions, such as reforestation and carbon capture and storage. The second category focuses on achieving a relative reduction in carbon emissions by using or investing in technologies with lower carbon intensity compared to business-as-usual practices, such as renewable energy. The reduction achieved in this second category is assumed to be equivalent to not emitting the calculated amount of emissions. However, both categories generally do not address the emissions' sources directly. This study introduces a third approach by proposing the creation of a carbon offset market at the emissions' source, offering a novel way to directly tackle the origins of carbon emissions. This approach aims to prevent emissions from being released in the first place, directly addressing the source of emissions. It aligns with the precautionary principle, which advocates for proactive measures to prevent harm. This approach should not be confused with the non-consumption approach, which is a top-down strategy focused on reducing demand. Instead, it is a bottom-up approach that seeks to reduce the supply of emissions. This study developed a four-step methodology for implementing a carbon offset market at the source, starting with fixing fossil fuel extraction per producer, then fixing the profit margin per unit of extraction, then calculating the carbon content per unit of fossil fuel, and finally creating a carbon offset market at the source where one can offset their carbon footprint by paying an amount equivalent to the profit from fossil fuel extraction to the producer in exchange for a reduction in an equivalent amount of fossil fuel extraction. It also offers insights into emission reductions potential through this approach, along with cost calculations per unit of reduction based on historical records, literature data, and statistical databases. The main advantage of the proposed approach is its bottom-up focus on reducing the supply of emissions, which leads to tangible and quantifiable reductions in real time. This method eliminates potential loopholes in traditional methodologies, ensuring that the reductions are both immediate and verifiable.

1. Introduction

The impacts of climate change trace back to the Industrial Revolution, a period marked by the introduction of greenhouse gases into the atmosphere (Brooke, 2014; Goodbody, 2018; Graven et al., 2020; Mitchell, 1989). Initially, there was optimism that technological advancements would eventually provide solutions to this growing issue, leading to a prolonged period of neglect (Alexander and Rutherford, 2019; Basiago, 1994; Gonella et al., 2019). However, the outbreak of two world wars resulted in widespread destruction and catalyzed international cooperation toward stability and conflict reduction (Dai et al., 2017; Morris, 2013; Morsink, 1993). This newfound peace allowed humanity the freedom to address various issues, enhance the quality of life, and make daily existence more comfortable (Sugiura et al., 2010). While challenges like the Cold War, oil crises, and nuclear incidents arose, the overall climate remained peaceful, fostering exponential technological growth that reduced costs and improved living standards (Painter, 2014). This progress, while enhancing quality of life,

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also escalated consumption patterns, altering the atmosphere, and increasing greenhouse gas emissions (Driga and Drigas, 2019; Lamb et al., 2021; Rosa et al., 2015). Unfortunately, climate change was largely disregarded to support global economic expansion, with World GDP skyrocketing from around 9 trillion in 1950 to over 100 trillion by the early 2010s (Lubin, 2018). Concurrently, the global population surged from 2.5 billion in 1950 to over 7 billion in 2020 (Statista, 2023b; UN, 2024; Wilmoth et al., 2021). With rising population figures, elevated consumption standards, and minimal concerns about resource extraction limits, greenhouse gas emissions from fossil fuels surged from 6 billion tons of CO_2 in 1950 to over 35 billion tons of CO_2 in 2020 (Friedlingstein et al., 2022). This unprecedented emission surge has led to an approximate temperature increase of 1.2 ° Celsius from pre-industrial levels (EEA, 2024; Gillett et al., 2021; Intergovernmental Panel on Climate, 2023).

Climate change exerts profound and extensive impacts across multiple dimensions (Carleton and Hsiang, 2016). It drives a surge in temperatures, intensifies extreme weather occurrences, leads to rising sea levels, triggers biodiversity decline, and fuels concerns surrounding food and water availability, public health, and economic stability. Moreover, it compounds existing social disparities and poses threats to human survival (Page, 2007; Welzer, 2015). Several notable instances of climate change repercussions have captured global attention including the rapid Arctic sea ice melt due to rising temperatures (Screen and Simmonds, 2010), which disrupts polar ecosystems and amplifies global sea-level rise through a self-reinforcing feedback loop; the heightened devastation of Hurricane Katrina in 2005 (Brunkard et al., 2008), exacerbated by warming ocean waters; the increasingly severe and frequent California wildfires (Palinkas, 2020), linked to prolonged droughts and elevated temperatures; the widespread coral bleaching events in the Great Barrier Reef (Berkelmans et al., 2004), stemming from warming ocean temperatures; the release of significant methane, a potent greenhouse gas, as permafrost thaws in regions like Siberia and Alaska (Anisimov and Zimov, 2021; Knoblauch et al., 2018); Cape Town severe water crisis in 2017–2018 (Calverley and Walther, 2022), known as "Day Zero," driven by droughts exacerbated by climate change; and the 2019–2020 Australian bushfires (Chester, 2020; Deb et al., 2020), fueled by record-high temperatures and prolonged droughts. These manifestations of climate change result in the loss of both environmental and human lives while diminishing overall quality of life.

Human society has recognized the pressing need to address climate change and its profound economic implications (Adger et al., 2009; Amen et al., 2008; Charnock and Thomson, 2019; Stern et al., 2022). Climate issues have garnered widespread attention, prompting both developed and developing economies to implement carbon emission reduction policies and commit to carbon neutrality goals to tackle the looming threats posed by rapid climate shifts (Dissanayake et al., 2020; Huang and Zhai, 2021; Huisingh et al., 2015; Iqbal et al., 2023; Wang and Su, 2020). Numerous initiatives have been launched in response to this global challenge (Damtoft et al., 2008). Notably, the Kyoto Protocol, established in 1997 and enacted in 2005, stands as a pivotal international accord (Gupta, 2016). Its primary objective was to enforce binding emission reduction targets for developed nations, known as "Annex I" countries, during a commitment period spanning from 2008 to 2012 (Missfeldt and Haites, 2001). However, due to limited success, the international community embarked on a new endeavor—the Paris Agreement (Falkner, 2016). Ratified in 2015, this agreement builds upon the Kyoto Protocol foundation but adopts a more adaptable approach. Under the Paris Agreement, each country submits its Nationally Determined Contributions (NDC), outlining voluntary emission reduction objectives and strategies (Mills-Novoa and Liverman, 2019). The overarching goal is to restrict global warming to well below 2 ° Celsius above pre-industrial levels, with an aspirational target of limiting it to 1.5 ° Celsius (Hoegh-Guldberg et al., 2019; Rogelj et al., 2016). Furthermore, various complementary policies and initiatives have been launched to drive progress in this direction. These include the Sustainable Development Goals (SDGs) initiative (Fuso Nerini et al., 2019), Renewable Energy Targets (Baruch-Mordo et al., 2019), Carbon Pricing mechanisms (Ji et al., 2018), Energy Efficiency Standards (Wiel and McMahon, 2005), Reforestation and Afforestation projects (Trabucco et al., 2008), Clean Transportation Initiatives (Banister, 2011), and Climate Resilience Planning (Kim, 2018) aimed at reducing climate change impacts. Collectively, these policies and agreements exemplify a global commitment to combat climate change, transition towards a low-carbon economy, and fortify resilience against the consequences of a changing climate. Successful climate action necessitates collaboration on the international stage, effective national policies, and proactive local initiatives, all converging in the overarching mission to address climate change comprehensively.

Among various mechanisms established to combat climate change, one notable approach being carbon offsetting (Bumpus and Liverman, 2008; Hyams and Fawcett, 2013). Carbon offsets serve as a means to mitigate the environmental impact of greenhouse gas emissions (Lovell and Liverman, 2010). It involves investments in projects or activities aimed at reducing or eliminating an equivalent amount of greenhouse gases from the atmosphere. The Kyoto Protocol, one of the earliest international policy frameworks addressing this issue, played a pivotal role in introducing the concept of carbon offsetting by establishing Clean Development Mechanism (CDM) (Gillenwater and Seres, 2011; Pfaff et al., 2000). The World Resource Association has defined a single unit of carbon offset as equivalent to the reduction, avoidance, or sequestration of one metric ton of carbon emissions (Wei et al., 2021). Many countries, including the European Union (EU), have embraced carbon offsetting as a flexible mechanism to achieve carbon emission reductions (Wara and Victor, 2008). The European Commission, for instance, issued Directive 2004/101/EC, which guides companies in implementing carbon offsetting by utilizing emission reduction data verified by Kyoto greenhouse gas reduction projects (de Cendra de Larragán, 2010). On the national level, numerous countries have established carbon offset markets that include various components such as Carbon Credits (Dhanda and Hartman, 2012; Tuerk et al., 2009). These markets employ a market-based approach to facilitate the trading of carbon credits, distinguishing between compliance and voluntary markets (Corbera et al., 2009). Robust verification and certification processes are in place to prevent greenwashing and misleading claims about environmental benefits (Nygaard, 2023). At the individual level, there is a growing trend of individuals voluntarily engaging in carbon offsetting as an expression of their commitment to environmental protection (Haya et al., 2020; Segerstedt and Grote, 2016). An increasing number of organizations are offering voluntary carbon offsetting schemes to their users as a means of compensating for GHG emissions (Becken, 2004; Dhanda and Hartman, 2011; Gössling et al., 2007; Mair, 2011; Zhang et al., 2018).

In the corporate sector, numerous companies have taken steps to disclose their products' carbon footprints, alongside their long-term strategies to achieve carbon neutrality (Boiral et al., 2024; Kreibich and Hermwille, 2021; Lee, 2011; Liu et al., 2023). These initiatives collectively signify a global effort to address climate change by carbon offsetting, combining international policy frameworks, national markets, and individual and corporate actions to reduce greenhouse gas emissions and combat climate change effectively. However, the effectiveness of these carbon offsetting mechanisms remains debatable (Calel et al., 2021; Dhanda and Hartman, 2011; Kollmuss and Lazarus, 2011; Pearse and Böhm, 2014). Carbon offset strategies are rooted in the principle of acknowledging the "business as usual" scenario and then taking deliberate measures to reduce emissions (Lovell and Liverman, 2010). This approach differs from reducing emissions at their source. Carbon offset methodologies can be broadly categorized into two main approaches. The first category involves directly mitigating greenhouse gas emissions within the environment through environmentally friendly and emission-capturing solutions, such as reforestation and carbon capture and storage (Lefebvre et al., 2021). These strategies fall under the removal category, aimed at eliminating existing emissions for e.g., by capturing and storing carbon dioxide underground (Benson and Orr, 2008). The second category is centered on achieving a relative reduction in carbon emissions by adopting or investing in technologies characterized by lower carbon intensity compared to conventional practices, such as renewable energy sources (Arnette, 2017; Lo, 2023). The reduction achieved through this approach is considered equivalent to the avoidance of emitting a specific quantity of greenhouse gases. Essentially, these strategies are reduction-oriented, focusing on reducing future emissions relative to the business-as-usual scenario, all while maintaining existing consumption patterns. However, both categories generally fail to address the sources of emissions directly, resulting in only fractional and less quantifiable reductions. This shortfall is evident in the continuous rise in global temperatures and the yearly increase in greenhouse gas emissions. Pearse and Böhm (2014) outlined several reasons why current carbon markets are unlikely to lead to radical emissions reductions. These include issues such as the creation of loopholes for polluters, corruption, and the failure to address the root causes of emissions, resulting in limited long-term impact on climate change. This ongoing trend underscores the urgent need for innovative, practical solutions at the grassroots level to drive real, substantial reductions in emissions.

This study proposed a distinct approach—the creation of a carbon offset market at the source. This aims to preemptively prevent emissions from entering the atmosphere, addressing the root cause of emissions at their origin. This approach aligns harmoniously with the precautionary principle, advocating proactive measures to avert harm rather than reacting to it. It is important to note that this approach differs from the non-consumption strategy, which operates from the top-down by reducing demand. However, reducing the demand for one consumable may inadvertently increase demand for another, leading to the "rebound effect" and resulting in less net reduction in emission (Chakravarty et al., 2013; Colmenares et al., 2020; Font Vivanco et al., 2022; Ottelin, 2016). Instead, it adopts a bottom-up perspective, focusing on reducing the supply of emissions. This study main objective is to propose a comprehensive four-step methodology for the establishment of a source-based carbon offset market, starting with fixing fossil fuel extraction per producer, then fixing the profit margin per unit of extraction, then calculating the carbon content per unit of fossil fuel, and finally creating a carbon offset market at the source where one can offset their carbon footprint by paying an amount equivalent to the profit from fossil fuel extraction to the producer in exchange for a reduction in an equivalent amount of fossil fuel extraction. Furthermore, it will shed light on the calculation of potential emissions reductions achievable through this approach, including an assessment of the associated cost calculation per unit of reduction. The scope of this study is confined to defining the new approach and providing an overview of its implications using aggregated statistical data over time to contextualize and illustrate the proposed approach, highlighting its advantages. It does not address broader implementation challenges or potential limitations related to market dynamics or the economic impacts on global energy markets, which will be explored in future research.

2. Methods

The idea of carbon offsetting has undergone significant evolution in recent decades, with recent years witnessing substantial efforts to establish more stable, reliable, and effective global carbon offset markets. These efforts are aimed at preventing greenwashing (de Freitas Netto et al., 2020) and ensuring verifiable claims that accurately capture the complex nature of carbon offsetting, providing valuable information for decision-makers. The scientific community and international organizations have contributed significantly to carbon offset research, marking a notable progression from the first recorded carbon offset publication in 1991 to an annual average of approximately 200 publications in recent years (Wei et al., 2021). However, this study takes a specific focus on the creation of a source-based carbon offset market, utilizing readily available data. Consequently, comparisons between this approach and others fall outside the scope of this research. The methodology is structured as follows: Section 2.1 outlines the fossil-based carbon emissions data sources, and Section 2.2 outlines the Proposed Methodology for establishing a source-based carbon offset market.

2.1. Data sources on fossil-based carbon emissions

Carbon dioxide emissions stand as the leading catalyst of global climate change, demanding immediate attention in both quantification and mitigation. To compile this information, data was sourced from online platforms like Statista and Our World in Data, that aggregate statistical data pertaining to carbon emissions from fossil fuels (Bowman, 2022; Ritchie, 2018). This comprehensive dataset encompasses changes over time, emissions across various regions, fossil fuel consumption per capita, the breakdown of fossil fuel consumption by type, its significance in the context of global primary energy sources, as well as oil production and demand. This wealth of data serves as a critical resource for gaining insights into and advancing the development of source-based carbon offset markets. It offers valuable insights into understanding the potential to mitigate the impact of emissions and reduce their associated consequences. However, the scope of this study is limited to defining the new approach and providing an overview of its implications using aggregate statistical data over time to contextualize and illustrate the proposed approach, rather than addressing broader implementation with detailed data sources. Therefore, only statistical data is utilized in this study.

2.2. Proposed methodology to create a carbon offset market at source

To create a carbon offset market at the source as shown in Fig. 1, this study recommends a four-step methodology.

Fixed fossil fuel extraction per producer: The initial step pertains to fossil fuel producers. To engage in the market, these producers are required to set an annual, fixed limit on their fossil fuel extraction. This limit serves as a crucial measure to curtail overall fossil fuel extraction, thereby laying the groundwork for carbon offsetting initiatives

Declare profit margin per unit extraction: In the second step the producer must publicly declare the profit earned per unit of fossil fuel extraction. This information provides transparency and allows for the calculation of financial contributions towards carbon offsetting.

Declare carbon footprint per unit of fossil fuel extraction: In the third step, the producer is required to disclose the potential global average life cycle carbon footprint associated with each unit of its fossil fuel extraction by carbon coefficient content. This declaration is instrumental in calculating the necessary offset to counterbalance the carbon emissions stemming from fossil fuel use. This encompasses the carbon footprint linked to carbon coefficient content of the fossil fuel disregarding the extraction of fossil fuel, its transportation, processing and other supply chain related emissions before reaching to final consumer but include its use, leading to emissions. Supply chain emissions are excluded because these emissions would not occur without the extraction of fossil fuels. Including these emissions in the calculations could lead to an overestimation of the emissions reduction, as it assumes that the supply chain emissions might not occur, thereby disregarding the potential rebound effect. Consequently, this approach simplifies the calculation by excluding these emissions, as their inclusion could introduce additional uncertainty into the equation.

Create carbon offset market at the source: In the fourth step, there will be a carbon offset market where individuals, organizations, or countries can offset their carbon footprint by calculating the equivalent amount of fossil fuel emissions produced. This can be done by determining the profit generated per unit of fossil fuel extraction and then paying that amount to the producer in exchange for a reduction in an equivalent amount of fossil fuel extraction.

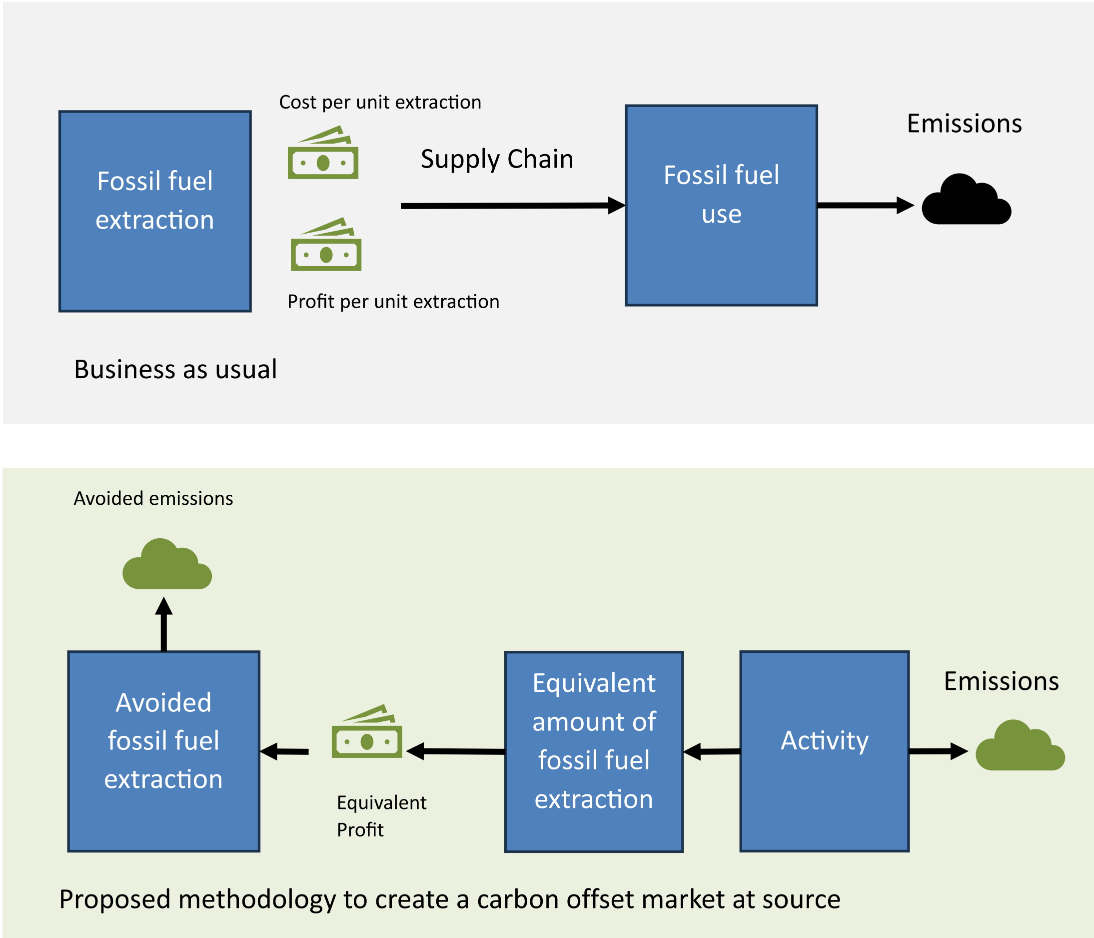

Fig. 1. Proposed methodology for creating a carbon offset market at the source. It illustrates the process where emissions from an activity are first calculated and then offset by determining the equivalent amount of fossil fuel extraction. The profit that would have been generated from this extraction is calculated and paid to the fossil fuel producer in exchange for reducing extraction. By limiting fossil fuel extraction, emissions are directly reduced, as the unextracted fuel no longer contributes to carbon emissions. This approach directly links carbon offsetting to fossil fuel supply reduction, ensuring a measurable and tangible impact on overall emission level.

By creating such a market, it becomes possible to directly reduce carbon dioxide emissions at the source by reducing fossil fuel extraction. This approach provides real-time visibility and accountability for carbon emissions reduction, making it potentially more effective and impactful compared to other carbon offset methods such as renewable energy or tree plantation.

3. Results and discussion

In this section, the study discusses the proposed methodology and its application analysis. The result section is structured as follows: Section 3.1 discuss the fossil based carbon emissions and its contributors, Section 3.2 delves into the process of fixing fossil fuel extraction per producer, Section 3.3 details the calculation of profit per unit of extraction, Section 3.4 elaborates on the calculation of carbon footprint per unit of fossil fuel extraction, Section 3.5 explores the development of the carbon offset market at the source, Section 3.6 explores the advantages and challenges of the proposed methodology and finally, Section 3.7 explores the future scope of the study.

3.1. Fossil based carbon emissions and its contributors

Prior to the industrial revolution, global CO_2 emissions from fossil fuels were relatively minimal compared to today's levels (Andres et al., 1999). The growth in these emissions remained gradual until the mid-20th century. In 1950, the world emitted approximately 6 billion tons of CO_2. By the year 2000, this figure had soared to more than four times that amount, reaching over 25.50 billion tons. Emissions have since continued to surge, surpassing 37.15 billion tons annually in 2022 (Friedlingstein et al., 2023; Statista, 2023a).

Historically, global emissions were predominantly attributed to Europe and the United States, which jointly accounted for over 85 % of annual emissions until 1950 (Budget, 2023; Ritchie and Roser, 2020). However, recent decades have witnessed a substantial shift, marked by a significant increase in emissions across the rest of the world, notably in Asia, with China taking a prominent role (Gregg et al., 2008; Lamb et al., 2021; Li et al., 2016). In terms of fossil fuel consumption per capita in 2022, the United States leads with 63,836 kWh, followed by Australia at 54,286 kWh, while China ranks fifth with 25,344 kWh (Our World in Data, 2024). Fossil fuel consumption by type is dominated by oil, amounting to 52,970 TWh, followed by coal with 44,854 TWh and gas with 39,413 TWh in 2022. In 2019, coal, oil, and gas collectively accounted for approximately 84 % of global primary energy sources. However, it is imperative that we swiftly decrease this percentage over the coming decades by replacing these fossil fuels with low-carbon energy sources (Araújo and de Medeiros, 2021; York, 2012). Regarding oil production from 1998 to 2022, there was an increase from 3545.4 million metric tons to 4407.2 million metric tons, with the past five years showing stability around 4400 million metric tons (Energy Institute, 2024). A similar trend is observed in the demand for crude oil worldwide, which rose from 83.65 million barrels per day in 2005 to 99.57 million barrels per day in 2022 (OPEC, 2024).

These trends indicate that although carbon offsetting mechanisms have been in place for the past two decades, they have failed to directly address the sources of emissions. As a result, the production of fossil fuels continues to increase, contributing to a steady rise in carbon emissions. This points to the need for more direct solutions that tackle the root causes of emissions. Pearse and Böhm (2014) highlighted several reasons why existing carbon markets are unlikely to bring about significant emissions reductions. The persistence of this trend emphasizes the necessity for innovative and practical solutions at the grassroots level to achieve meaningful reductions in emissions. In response, this study proposes the creation of a carbon offset market at the source to directly address the origins of emissions.

3.2. Fixing fossil fuel extraction per producer

The first step involves fixing fossil fuel extraction per producer, targeting fossil fuel producers specifically. To participate in the carbon offset market, these producers must establish an annual, unchanging limit on their fossil fuel extraction. This limit serves as a critical measure to restrain overall fossil fuel extraction, laying the foundation for carbon offsetting market at the source.

It is important to note that the fossil fuel extraction landscape can exhibit changes over time due to various factors such as mergers and acquisitions, the emergence of new players, and the discovery of new oil and coal reserves and refineries. This dynamism can indeed pose challenges to the task of fixing fossil fuel extraction per producer. For instance, in 2020, global discoveries of crude oil and natural gas amounted to 12.5 billion barrels of oil equivalent, underlining the continuous nature of such discoveries (Rystad Energ, 2023). The distribution of proved oil reserves worldwide in 2020, categorized by region, reveals significant concentrations: the Middle East at 48.3 %, South and Central America at 18.7 %, North America at 14 %, Europe and CIS at 9.2 %, Africa at 7.2 %, and Asia Pacific at 2.6 % (OPEC, 2023a). Additionally, when considering the distribution of oil reserves by country, prominent countries include Venezuela at 17.5 %, Saudi Arabia at 17.2 %, Canada at 9.7 %, Iran at 9.1 %, Iraq at 8.4 %, Russia at 6.2 %, Kuwait at 5.9 %, the United Arab Emirates at 5.6 %, the United States at 4 %, Libya at 2.8 %, and Nigeria at 2.1 % (OPEC, 2023b). However, in terms of leading oil-producing countries as of 2022, the United States tops the list with a daily output of 17,770, followed by Saudi Arabia at 12,136, Russia at 11,202, and Canada at 5576 barrels per day (Energy Institute, 2023). Furthermore, when examining the leading oil and gas companies based on market capitalization as of June 2023, notable contenders include ExxonMobil from the United States with 352.79 billion U.S. dollars, Chevron, also from the U.S., with 241.7 billion U.S. dollars, Reliance Industries of India with 164.7 billion U.S. dollars, Royal Dutch Shell from the UK with 155.58 billion U.S. dollars, PetroChina from China with 151.78 billion U.S. dollars, Total Energies from France with 117.3 billion U.S. dollars, ConocoPhillips from the U.S. with 101.97 billion U.S. dollars, and many others (Financial Times, 2024). When it comes to coal, the leading coal-consuming countries worldwide in 2022 (measured in exajoules) are China, ranking first with 88.41, followed by India with 20.09, the United States with 9.87, and Japan with 4.92. In terms of the share of proved coal reserves worldwide from 1991 to 2020, the distribution by region in 2020 was as follows: Asia Pacific held 42.8 %, Europe & CIS accounted for 30.6 %, North America represented 23.9 %, Middle East & Africa had 1.5 %, and Central & South America held 1.3 %. As for the market capitalization of the leading coal companies globally (measured in billion U.S. dollars), the list includes China Shenhua Energy Co from China with 88.06, Glencore from Switzerland with 70.47, Yankuang Energy (Yanzhou Coal Mining) from China with 22.78, Coal India from India with 18.36, along with several other smaller companies. These figures from Statista and Our World in Data collectively depict the intricate and evolving landscape of fossil fuel extraction and market dynamics.

This study introduces a simplified approach to address uncertainties and future implications within the fossil fuel industry by establishing a direct link between extraction and reserves. Under this proposal, companies involved in extracting fossil fuels from designated sites are mandated to fix their annual extraction levels in accordance with their reserve holdings. This approach primarily concerns companies engaged in fossil fuel extraction, with refining and other downstream processes excluded from this framework. Recognizing that the initial step in the use of fossil fuels is extraction, this study advocates for all fossil fuel extraction companies to set extraction limits relative to their reserves for market participation. A minimum extraction threshold value relative to their reserves is established as a prerequisite for market entry, below which individual companies can determine their specific extraction limits. This ensures that all participating extraction companies adhere to their agreed-upon extraction levels, preventing over-extraction. It is crucial to note that if an extraction company acquires another entity not originally within the market framework, the acquired company must reassess its extraction limits based on the date of acquisition by the acquiring company. This prevents situations where one company continues extraction and subsequently acquires another entity already participating in the market, which could distort extraction limits. This study suggests that the limit should be recalculated based on the date of acquisition and the acquired company's extraction capacity, accounting for whether it is high or low.

As a result of this approach, each fossil fuel extraction company is assigned an annual extraction limit relative to its reserves, thereby becoming a participant in the global carbon offset market at the source. This ensures a more controlled and sustainable approach to annual fossil fuel extraction within the industry.

3.3. Calculating profit margin per unit fossil fuel extraction

The second step entails the declaration of profit per unit of fossil fuel extraction by the fossil fuel producer. This crucial disclosure publicly reveals the profit generated for each unit of fossil fuel extracted. Such transparency is essential as it enables the calculation of financial contributions required for carbon offsetting initiatives. By openly declaring their profit margins, producers contribute to a more accountable and responsible approach to carbon emissions offsetting at the source.

Crude oil prices are influenced by a multifaceted interplay of factors. Central to this dynamic is the balance between oil supply and demand, where any shifts in either can exert substantial pressure on prices (Krichene, 2002). Geopolitical tensions, conflicts, and disruptions in major oil-producing regions can swiftly disrupt supply, causing price spikes (Kissane, 2021). OPEC and non-OPEC policies, notably production decisions, play a pivotal role in shaping global oil supply (Roeben, 2024). Economic conditions, such as global growth and inflation, impact oil demand, while currency exchange rates can alter the purchasing power of oil-importing countries (Boroumand et al., 2019). Additionally, environmental regulations, technological advances in oil extraction, weather-related disruptions, and speculative activities in futures markets all contribute to oil price fluctuations. Furthermore, the ongoing transition towards cleaner energy sources and the energy policies of nations have introduced a long-term dimension to oil price dynamics (Solomon and Krishna, 2011). Thus, oil prices represent a complex interplay of economic, geopolitical, environmental, and technological factors, making them highly volatile and subject to constant scrutiny.

Historically, crude oil prices have undergone significant fluctuations. Until the early 1970s, oil prices remained relatively stable. However, a series of transformative events, including the OPEC oil embargo in 1973 and the Iranian Revolution in 1979, caused substantial spikes in oil prices, leading to what are commonly referred to as "oil shocks" (Hamilton, 2013; Issawi, 1978; Smith, 2022). The subsequent decades saw periods of price decline, interrupted by spikes during geopolitical conflicts like the Gulf War in 1990–1991 (Lieber, 2019). Nevertheless, prices generally remained lower than the peaks of the 1970s. The early 2000s witnessed a gradual increase in oil prices, driven by increasing global demand, especially from emerging economies such as China and India (Beirne et al., 2013; Leung et al., 2011). Prices reached historic highs in mid-2008 but subsequently experienced a sharp decline during the global financial crisis later that year (Aleklett et al., 2010). Over the following years, prices recovered and exceeded $100 per barrel. Another notable era of volatility occurred in the 2010s. Oil prices surged at the beginning of the decade but then plummeted in mid-2014 due to a combination of factors, including oversupply and weak demand. Prices remained relatively low for several years before undergoing a moderate recovery. The COVID-19 pandemic in 2020 had a profound impact on oil prices, resulting in a historic collapse in demand and a brief period of negative oil prices in 2020 (Gharib et al., 2021; Le et al., 2021). Subsequently, prices rebounded as economies began to reopen, and demand partially recovered. It is crucial to acknowledge that crude oil prices are subject to an intricate web of influences, and analyzing historical trends provides valuable insights into how these multifaceted factors have driven price fluctuations. However, forecasting future oil price movements remains a formidable challenge due to the ever-evolving nature of these variables.

Historical coal prices also have exhibited a dynamic pattern over the past few decades, shaped by an intricate interplay of economic, environmental, and regional factors (C. Wang et al., 2024). Throughout the 1990s and early 2000s, coal prices generally remained stable, reflecting consistent demand primarily for electricity generation. The mid-2000s marked a turning point when prices began to climb, driven by surging demand from rapidly industrializing nations like China and India, alongside the rising costs of oil, which prompted adoption of coal as an energy alternative (Ding et al., 2017; T. Wang et al., 2024). Later, coal prices had soared to historic highs, influenced by global economic growth and increased energy needs (Khan et al., 2021). However, the global financial crisis of 2008 caused a temporary drop in prices. As the 2010s unfolded, coal prices gradually declined due to concerns about pollution and climate change, coupled with a shift toward cleaner energy sources and competition from abundant natural gas supplies (Houser et al., 2017; Liang et al., 2012; Nalbandian and Dong, 2013). The 2020s continued this trend, with coal prices further decreasing, exacerbated by the economic impacts of the COVID-19 pandemic, which curtailed demand and led to oversupply in coal markets. These fluctuations underscore the intricate nature of coal pricing, varying by region, coal type, and evolving environmental regulations

This study proposes that participants in the global carbon offset market at the source should disclose both their extraction costs and their desired profit margins per unit of extraction of fossil fuel. While extraction costs may differ among various producers, their expected profits can also fluctuate based on the standardized market price. A country with lower extraction costs but a standardized market price may yield greater profits than others. Thus, this study suggests that all participants reveal their anticipated profits from each unit of extraction, fostering consensus on a standardized profit margin. Importantly, this profit margin need not be tied exclusively to the cost of fossil fuel. Consequently, it can be stable and subject to monthly updates. As a result of this step, all producers aiming to participate in the market would collectively determine their standardized profit margins per unit of extraction. This approach contributes to transparency and equity in the carbon offset market. Consequently, the result of implementing this step is that all participating producers would collectively determine their standardized profit margins per unit of extraction on a monthly basis.

3.4. Calculating carbon footprint per unit of fossil fuel extraction

The third step involves the declaration of the carbon footprint per unit of fossil fuel extraction. In this crucial phase, fossil fuel producers are mandated to reveal the potential global average life cycle carbon footprint associated with each unit of their fossil fuel extraction, calculated based on fossil fuel carbon coefficient content. This disclosure serves as a vital component in determining the required offset to counterbalance the carbon emissions generated by fossil fuel use. It encompasses the carbon footprint linked to the carbon coefficient content of the fossil fuel, irrespective of factors such as extraction, transportation, processing, and other supply chain activities before reaching the end consumer and contributing to emissions. It is important to note that this approach simplifies the calculation process, to reduce a degree of uncertainty by disregarding emissions associated with supply chain activities of fossil fuel.

In this study, fossil fuels are categorized into two main types: crude oil and coal. To calculate carbon dioxide emissions per barrel of crude oil, this study employs a straightforward formula (US EPA, 2024). This calculation involves multiplying the heat content (5.80 mmbtu per barrel) by the carbon coefficient (20.33 kg carbon per mmbtu), the fraction oxidized (assumed to be 100 percent), and the ratio of the molecular weight of carbon dioxide to that of carbon (44/12). Consequently, the carbon footprint for crude oil is determined to be 432.3513 tons of CO_2 per barrel. For coal, calculation is based on the average heat content of coal consumed by the electric power sector in the U.S. in 2020, which stood at 20.84 mmbtu per metric ton. The average carbon coefficient for coal combusted for electricity generation in 2020 was 26.12 kgs of carbon per mmbtu, with the fraction oxidized assumed to be 100 percent. Similar to the crude oil calculation, this study determines carbon dioxide emissions per ton of coal by multiplying the heat content, carbon coefficient, fraction oxidized, and the ratio of the molecular weight of carbon dioxide to that of carbon (44/12). This results in a carbon footprint of 1.996 tons of CO_2 per metric ton of coal.

This study employs a simplified approach for calculating carbon footprints, focusing solely on the carbon content of fossil fuels without including supply chain emissions. However, it is worth noting that a more comprehensive approach could involve accounting for the complete life cycle carbon emissions from fossil fuels, including supply chain related emissions from extraction to use. In such a comprehensive approach, standardization would be essential to ensure consistency for all participants in the market, accounting for various fuel types and supply chain variables. In this study's simplified approach, the carbon footprint is established as 432.3513 tons of CO_2 per barrel of crude oil and 1.996 tons of CO_2 per metric ton of coal for carbon offset calculations.

3.5. Developing carbon offset market at the source

The fourth and final step involves the establishment of a carbon offset market at the source. In this step, a market is created where individuals, organizations, or countries can offset their carbon footprint by calculating an equivalent amount of fossil fuel being extracted and used leading to emissions. This is achieved by determining the profit generated per unit of fossil fuel extraction and then compensating the producer for a reduction in fossil fuel extraction equal to this amount.

Participants in this market will have to fix their annual fossil fuel extraction and calculate the carbon footprint per unit of fossil fuel extraction. They will also regularly update their profit margin per unit of extraction on a global scale. This data provides the cost per unit of carbon footprint associated with fossil fuel extraction. To purchase carbon offsets in this market, individuals or entities need to calculate the amount of carbon they wish to offset. They then determine the corresponding fossil fuel extraction, based on the carbon footprint of different types of fossil fuels, and calculate the profit margin associated with that extraction. By paying this profit margin to the producer, they can request a reduction in fossil fuel extraction equivalent to the offset they seek.

It is important to note that the carbon offset, in terms of reduced fossil fuel extraction, cannot be stockpiled or reserved by the buyer;

instead, it is submitted to the government when a buyer claims a carbon reduction. The government is responsible for overseeing and validating these carbon offsets. This approach ensures a reliable and transparent method for quantifying carbon reductions, minimizing the risk of greenwashing.

3.6. Advantages and challenges of the carbon offset market at the source

Carbon offsetting, while adopted as a measure to mitigate the environmental impact of activities, is not always as effective as it may appear in its current applications. However, the proposed methodology of a carbon offset market at the source aims to enhance its effectiveness substantially. The intention is for individuals and organizations to incorporate carbon offsetting into a comprehensive sustainability strategy centered around emission reductions at the source. In this approach, carbon offsetting becomes an integral component of the overall solution. This shift in perspective aligns more closely with the goal of achieving meaningful and lasting reductions in carbon emissions. Carbon offsetting should be viewed both as a standalone solution and as a complementary tool to other climate change mitigation strategies. As a standalone solution, it offers a direct means of reducing carbon emissions, independent of other activities. This implies that carbon offsetting can be used not just to balance out the carbon footprint of specific actions, but also as an effective method to reduce emissions overall. As a complementary tool, it provides a way to offset emissions when certain activities are unable to reduce their carbon footprint fully. In this dual role, carbon offsetting becomes a versatile tool—either to directly mitigate climate change or to compensate for the environmental impacts of other activities that cannot achieve full emission reductions on their own.

One key argument for the proposed methodology lies in the persistence of high emissions. Despite the implementation of carbon reduction targets over the years, carbon emissions continue to rise steadily. Efforts to curtail emissions through various means, such as green and emission-capturing solutions, technology-driven reductions in carbon intensity, and demand-side reductions in consumption, have proven increasingly challenging. This study suggests that it may be time to embrace a bottom-up approach focused on reducing the supply of emissions. Such an approach could yield tangible, quantifiable reductions in emissions, rather than relying solely on the perception of reduction without seeing substantial changes on the ground. One prominent issue with current carbon offset mechanisms is the presence of significant non-additionality (Cames et al., 2016). This means that some offset projects may not be genuinely additional; they might have proceeded without the offset funding, often as part of other sustainability initiatives (Probst et al., 2023). However, they are still included in carbon offset calculations, resulting in what appears to be multiple benefits but not actual additional carbon removal from the atmosphere (Cavanagh and Benjaminsen, 2014). For instance, if a reforestation project was already planned and financed, purchasing offsets for it does not lead to extra carbon removal. This multiplicity of counting creates a sense of achievement but not actual multiple benefits, as one project is counted numerous times. Another concern lies in long-term reliance within current offset mechanisms. Investing in existing carbon offset projects typically yields reductions over an extended period, often spanning many years. This extended timeline may not be suitable for addressing the emissions that are being generated today. There is a pressing need for solutions that provide more immediate and reliable results. This study proposes that such a solution may involve reducing emissions at the source rather than relying on carbon offsets, which can seem like an indefinite solution.

The current offset market often also suffers from a lack of transparency in calculation methodologies. Ineffective offsetting can stem from a lack of transparency and accountability within offset projects. When it is unclear how offsets are calculated or what their real impact is, it can erode trust in the entire offsetting process. The proposed methodology aims to address this issue by offering clear and easily understandable calculations without any ambiguity involved. Furthermore, there is a concern about questionable offset projects within the current offset market. Not all offset projects are of equal quality; some may be poorly managed, have unclear benefits, or even inadvertently harm the environment. It is becoming increasingly challenging to distinguish reputable offset projects from less credible ones. This problem is mitigated in the proposed methodology, where the market avoids overestimated projects. The issue of uncertain permanence also plagues the current offset market. Projects like tree planting can be undone by events like wildfires or deforestation, raising doubts about the long-term effectiveness of offsets. In contrast, the proposed methodology is based on source reduction, ensuring that once the offset is paid, it is removed without dependence on external factors. This enhances the reliability of the offsetting process.

Another significant issue with current carbon offset practices is market volatility. Carbon offset prices can fluctuate widely, making it challenging for companies to plan and budget for their offsetting efforts. These rapid price changes introduce uncertainty into offsetting initiatives. However, the proposed methodology offers more stability. It is updated monthly, making it less susceptible to sudden fluctuations and better suited for long-term agreements. Moreover, a major drawback of current carbon offsets is their limited scope. Many offset projects focus exclusively on one type of greenhouse gas or a specific emission source, often overlooking the broader impact of other emissions. This narrow focus can restrict the overall effectiveness of offsetting. In contrast, the proposed methodology is source-based and thus includes all types of emissions, providing a more comprehensive approach. Furthermore, the current projects are prone to overestimating impact. There is a tendency to overstate the effectiveness of carbon offset projects. It is crucial to ensure that offsets are accurately calculated and genuinely compensate for emissions, which is a key feature of the proposed methodology.

While this study highlights the advantages of the proposed approach, it is important to note that the scope of this study is limited to defining the new method and providing an overview of its implications using aggregate statistical data over time. However, implementing such changes may present direct and indirect challenges and limitations. One significant challenge will be the dynamics of fossil fuel demand and supply. By implementing carbon offsetting at the source, fossil fuel supply will decrease, leading to higher prices that could impact energy markets differently across developed and developing countries. Another potential hurdle involves achieving consensus among fossil fuel producers regarding participation and determining the terms and regulations of the market, including enforcement mechanisms. While some stakeholders may support the initiative due to its potential to combat climate change, others might resist, particularly fossil fuel producers concerned about market competition and profitability. As with any new approach, there will be winners and losers, making it essential to conduct a thorough stakeholder analysis and explore various scenarios through simulations to fully understand the challenges and implications. However, these considerations are beyond the scope of this study and are not covered in this study.

3.7. Future scope

The future scope of this study includes areas not covered in the current research, such as broader implementation challenges and potential limitations related to market dynamics and the economic impacts on global energy markets. Carbon emissions are a global issue, and there are both direct and indirect links between various factors. Reducing fossil fuel extraction can decrease supply, which may, in turn, raise the price of fossil fuels in the market. There are also issues regarding market participation, whether voluntary or mandatory, as well as the level of regulations and government interventions. Political forces, energy security concerns, and price fluctuations in the market also need to be considered. These aspects require detailed evaluation using recent data sources and the involvement of key stakeholders in the proposed approach. In future research, these factors will be discussed in depth, assessing their implications on the existing fossil fuel industry, energy sector, and climate change. This continuation of the study will analyze the broader impacts and challenges associated with the proposed approach, offering a more comprehensive view of its real-world application and outcome.

4. Conclusions

This study highlights the limitations of the existing carbon offset mechanisms in effectively reducing carbon emissions and emphasizes the need for new, innovative, and practical solutions at the grassroots level to achieve real and substantial reductions in emissions. To address this need, the study introduces a novel approach: the creation of a source-based carbon offset market. This approach is built on a four-step methodology. First, it involves setting fixed limits on fossil fuel extraction per producer. Second, it calculates the profit per unit of extraction. Third, it determines the carbon footprint associated with each unit of fossil fuel extracted. Finally, it establishes a carbon offset market directly at the source, incorporating mechanisms for buying, selling, and verifying carbon offsets. This market-based solution aims to create more effective carbon reduction strategies by addressing emissions directly at the point of fossil fuel production.

This study only provides a theoretical framework for the application of the proposed methodology, using aggregate statistical data over time to contextualize and illustrate the approach while highlighting its advantages. However, it does not address broader implementation challenges or potential limitations related to market dynamics or the economic impacts on global energy markets. These aspects require stakeholder analysis and simulation studies with various scenarios to explore the practical implications of the proposed approach. Such investigations are part of the future scope of this study.

This innovative approach adopts a bottom-up strategy, focusing on curbing the supply of emissions by addressing their origin to achieve meaningful reductions. It offers a promising solution to enhance the effectiveness of carbon offsetting, which traditionally focuses on indirect emission reductions. By directly reducing the supply of fossil fuels, this method targets the root cause of emissions, making it a more impactful alternative to conventional carbon offset mechanisms. In conclusion, this study suggests that carbon offsetting should be focused on source-level emission reductions. By doing so, we can work towards achieving more meaningful and lasting reductions in carbon emissions.

Disclosure statement

During the preparation of this work the author(s) used ChatGPT 3.5 in order to improve grammar. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication

CRediT authorship contribution statement

Rahul Aggarwal: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability statement

All data generated during this study are included in this published article.

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