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Supply-chain sustainability under the EU system of carbon pricing and trading

Abstract. As global climate change continues, policymakers at various levels of government have taken up the great challenge of decarbonisation and adopted tools to help reduce greenhouse gas emissions. Environmental policy, including climate policy, is explicitly aimed at promoting environmental protection and conservation, but it also carries economic and social effects. Academic interest in sustainable supply chains has grown significantly in recent years. Social aspects, as well as the integration of the three dimensions of sustainability, are still rare. The purpose of this study is: (1) to review the most recent literature on greenhouse gas emissions policies, particularly pollution taxes and pollution rights trading schemes; (2) to investigate the European Union Emissions Trading System (EU ETS) with a focus on market and price development; (3) to identify possible effects of this system on supply-chain sustainability; (4) to offer inspiration for further research into the links between the EU ETS and sustainable development of the supply chain. The article concentrates on the impact of the cap-and-trade scheme on the three pillars of sustainable development: the environmental, economic and social dimensions. The findings of this study prove that this scheme has significantly affected not only upstream regulated sectors, but also downstream companies in the supply chain as well as households. In addition, our investigation suggests the presence of trade-offs between the environmental (climate) and socio-economic goals of sustainable development as a result of applying the EU ETS.

Key words: emission allowance pricing, carbon tax, emissions trading system, Europe, Poland

Synopsis. Wraz z postępującymi zmianami globalnego klimatu decydenci na różnych szczeblach władzy podjęli ogromne wyzwanie dekarbonizacji i przyjęli narzędzia pomagające ograniczyć emisję gazów cieplarnianych. Polityka środowiskowa, w tym klimatyczna, ma jednoznacznie na celu promowanie ochrony i zachowania środowiska naturalnego, ale niesie ze sobą również skutki gospodarcze i społeczne.

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Zainteresowanie badaczy zrównoważonymi łańcuchami dostaw znacznie wzrosło w ostatnich latach. Aspekty społeczne, jak również integracja trzech wymiarów zrównoważonego rozwoju, są jednak nadal rzadkością. Celem niniejszego opracowania jest: (1) dokonanie przeglądu najnowszej literatury na temat polityki w zakresie emisji gazów cieplarnianych, w szczególności podatków od zanieczyszczeń i systemów handlu prawami do zanieczyszczeń; (2) przedstawienie unijnego systemu handlu uprawnieniami do emisji (EU ETS) z uwzględnieniem rozwoju rynku i cen uprawnień; (3) określenie potencjalnego wpływu EU ETS na zrównoważony rozwój łańcucha dostaw oraz (4) zaoferowanie inspiracji do dalszych badań powiązań między EU ETS a zrównoważeniem łańcucha dostaw. Artykuł koncentruje się na kwestiach środowiskowych, ekonomicznych i społecznych związanych z systemem ograniczenia emisji i handlu uprawnieniami w kontekście łańcucha dostaw. Wyniki naszego badania wskazują, że system ten znacząco wpłynął nie tylko na regulowane sektory wyższego szczebla, ale także na przedsiębiorstwa niższego szczebla w łańcuchu dostaw, a także na gospodarstwa domowe. Ponadto sugerują one, że realizacja EU ETS powoduje powstawanie konfliktów (*trade-offs*) pomiędzy celami środowiskowymi (klimatycznymi) a społeczno-ekonomicznymi zrównoważonego rozwoju.

Słowa kluczowe: ceny uprawnień do emisji, podatek węglowy, system handlu emisjami, Europa, Polska.

JEL codes: Q52, Q58, D23, F18, H23

Introduction

Since pollutant emissions are believed to be a significant driver of global climate change, they are at the forefront of ongoing academic and political debates on sustainable development, especially concerning its ecological dimension. One of the main concerns today is carbon emissions from supply chain operations, which is why many governments have introduced measures to promote fuel and energy conservation and emissions reduction. Much of the economic output is organised around a complex system of interdependent supply chains. As extreme weather events caused by climate change become more frequent or severe, they upgrade the risk of events more intensive than production assets can withstand, thus increasing the likelihood of supply chain disruptions. At the same time, supply chains are sensitive to both environmental regulatory constraints and the evolving carbon markets. In this context, the impact of the European Union system of carbon-cutting, carbon-pricing and carbon trade on the supply chain is becoming a hot topic. There are also relevant questions about how Russia's ongoing aggression against Ukraine has affected the European carbon market and whether this conflict justifies rethinking the European Union's primary climate policy tool – the Emissions Trading System (EU ETS).

The link between emission trading schemes and supply-chain sustainability based on environmental considerations has been well covered in the literature. There are, however, relatively few studies that address all three dimensions of sustainable supply chain development. The main contribution of our research [to the literature] is to explain the impact of the EU ETS on environmental, economic and social dimensions of sustainable development of supply chain entities.

A typical supply chain is understood here as an arrangement of raw materials suppliers, manufacturers (producers), distributors (retailers and wholesalers) and consumers linked by the downstream flow of transformed goods and services and the upstream flow of money, as well as the associated flow of information in both directions of the supply chain. While there are various sustainability concepts, the main one is the triple-bottom-line approach, in which minimum environmental, economic and social outcomes must be achieved.

Review of the literature

The economic and social rationale for imposing prices on carbon emissions

Carbon pricing is widely recognised as an essential tool for meeting the 2015 Paris Agreement's climate change mitigation goals by preventing or reducing the emission of greenhouse gases (GHG) into the atmosphere. Economists consider environmental pollution as a classic example of a negative externality (i.e., an unintended consequence of production or consumption that reduces another agent's profits or utility – injures, harm or costs being thrown upon people not directly concerned with production or consumption) [Pigou 1932]. Because the market price of carbon-intensive goods and services does not account for the social costs of climate change impacts, greenhouse gas emissions are viewed as a negative externality [Nordhaus 2015]. Examples of such external costs include decreased quality of life of communities around the supply chain, cost of stress and public health damages associated with exposure to air pollution, heatwaves and droughts, material losses from floods and rising sea levels, as well as inequalities between the poor and wealthy persons or regions when coping with those damages. Carbon pricing is, therefore, an instrument that captures the negative externalities of greenhouse gas emissions (i.e., indirect costs borne by those harmed by the pollution and climate change). This tool binds negative externalities to sources through a price, usually in the form of the price of emitted carbon dioxide (CO_2).

Ronald Coase represents another stream of literature that views environmental contamination as primarily a problem of uncompleted or ill-defined property rights to the relevant economic resources. According to Coase, "if the factors of production are thought of as rights, it is easier to understand that the right to do something that has a harmful effect (such as producing smoke) is also a factor of production". This means that one may use a right to deny someone unpolluted air. "The cost of exercising a right (using a factor of production) is always the loss which is suffered elsewhere in consequence of the exercise of that right – the inability to (…) breathe clean air" [Coase 1960, p. 44]. In the case of air-related environmental problems, it is difficult to imagine how property rights could be effectively defined and enforced. Market mechanisms alone are unlikely to prevent the depletion of the Earth's ozone layer. In such cases, economists accept the likely need for government regulatory interventions.

Carbon pricing strategies are conceptually rooted in neoclassical economics. Climate change is seen as a problem of market failure or imperfections; the price of carbon is to correct market signals [Rosenbloom et al. 2020]. This policy instrument's high cost-

effectiveness potential is one of its primary drivers because it integrates climate change into company and household decision-making processes, influencing those entities' production, investment and purchasing decisions.

Carbon pricing has several economic justifications [Stavins 2019, Teixidó et al. 2019, Hepburn et al. 2020, Bourgeois et al. 2021, Khan and Johansson 2022, Parry et al. 2022]. Among others, these include:

- Reduction of CO_2 emissions cost-effectively: pricing promotes the full range of behavioural responses for reducing energy use and shifting to low-carbon fuels;
- Clean energy investment: the expectation of rising fuel prices incentivises innovation and adoption of new low-carbon technologies – i.e., induces low-carbon technological change (e.g., solar, wind, and other low-carbon technologies);
- Fiscal: carbon pricing mobilises a valuable source of public revenue that can be used to achieve various economic, social and ecological goals;
- Co-benefits for the national environment (improved human health through reduced local air pollution).

The typical economic approach to designing a carbon pricing focuses primarily on problems of efficiency, effectiveness and equity (fairness), taking into account how it will affect economic growth and how the costs and benefits will be distributed, which will determine who benefits and who bears the consequences of such a policy. As for the distributional effects, carbon pricing ultimately burdens consumers and poor households more than affluent households, as the former generally devote a larger share of their income to cover their energy needs [Grainger and Kolstad 2010, Farrell 2017, Stede et al. 2021].

On the other hand, behavioural economics and political economy focus on political acceptability imperatives (i.e., how to recycle revenues originating from carbon pricing to secure policy acceptance by citizens) [Klenert et al., 2018, Frondel and Schubert 2021]. Carbon pricing tends to have diffuse benefits and concentrated costs; thus, in the political process, the scattered beneficiaries are less likely to support it than carbon-intensive companies are likely to oppose it [Klenert et al. 2018]. In 2021, the global revenues from this source were considerable, at around 84 billion USD, 60% higher than in 2020 [World Bank 2022b], and are expected to increase. Therefore, how they have been used plays a crucial role in the public perception of climate policy and its instruments.

Countries face many choices in designing ways to put a price on carbon emissions, but a critical choice is between carbon taxes and emissions trading schemes (ETSs). Both operate on the "polluter pays" principle, which effectively encourages switching to more sustainable energy sources and reducing emissions-intensive activities [Black et al. 2022].

Types of main explicit carbon pricing instruments

The two different perspectives (Pigou's and Coase's positions) have led to two economic responses or policy prescriptions for climate change: carbon taxes versus tradable carbon rights. On the one hand, following the lead of Arthur Cecil Pigou, who saw pollution as a cost imposed on the rest of society, regulators could ensure that emitters would internalise (compensate) the damages they caused by charging a tax on each unit of pollution, equal to the marginal social damages at the efficient level of pollution control [Pigou 1932]. On the other hand, they could solve the problem of pollution by clarifying poorly defined rights of property [Coase 1960].

Table 1 compares the two major approaches to carbon pricing: carbon taxes and a cap-and-trade system.

Table 1. Main forms of carbon pricing

	Carbon taxes	Emissions trading systems (cap-and-trade)
Nature	Puts an explicit price on each tonne of GHG emitted. The tax rate is set directly by the regulatory authority.	The regulatory body stipulates the overall allowable quantity of GHG emissions allotted to participating emitters; covered entities can buy additional allowances or sell excess allowances; market auctioning is a principal allocation method.
Advantages	Administratively simple and relatively straightforward to implement; can rely on the existing tax infrastructure; stable price signal; relatively efficient revenue source that enables policymakers to reduce more distortive taxes.	More temporal price flexibility for regulated entities; certainty on emission levels (provided the penalty for overage is high enough to deter companies from opting to pay); a counter-cyclical policy instrument (when an economy goes into recession, the demand for, and price of, allowances falls).
Drawbacks	Limited flexibility for companies to manage compliance costs in the short-term; less certainty of emission levels; difficulty in setting the correct tax rate.	Administratively complex; less certainty on price levels as the carbon price is set by the market – risk of high price volatility; too high carbon caps can hinder economic development.

Source: own compilation based on [Stavins 2019, Waltho et al. 2019, Gadde 2022, Khan and Johansson 2022].

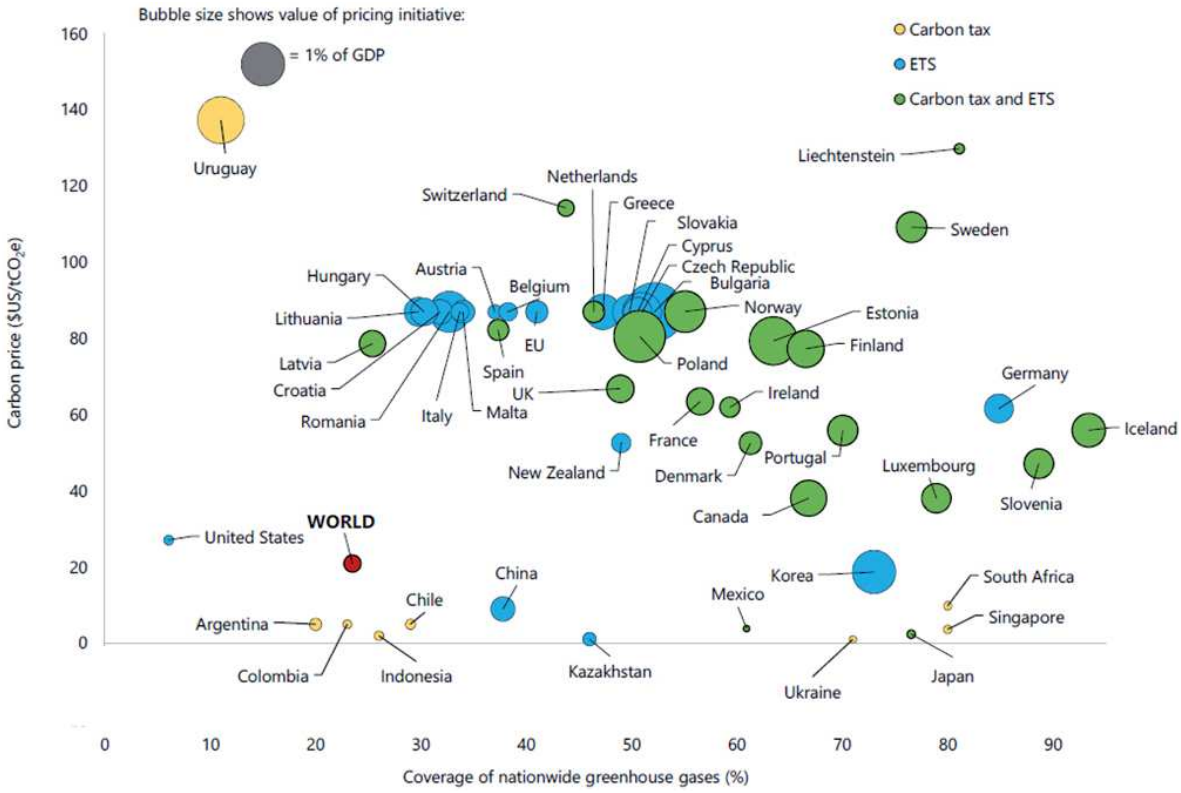

Figure 1. Regional, national and subnational carbon pricing schemes by country, 2022

Rysunek 1. Ponadnarodowe, narodowe i subnarodowe systemy opłat za emisję gazów cieplarnianych według krajów, 2022

Source: [Parry et al. 2022, p. 2]

In 2022, globally, 70 carbon pricing initiatives were in operation. By 2022, as many as 47 national and 36 sub-national jurisdictions had implemented or planned carbon pricing instruments, including ETS and taxes. These mechanisms could have covered 11.86 GtCO2e, representing about 23.2% of global GHG emissions. Since January 2021[3], the EU ETS (regional initiative) has operated in 30 national jurisdictions: all 27 EU member states and Iceland, Liechtenstein and Norway. In 2022, around 3.18% of global GHG emissions were included in the EU ETS [World Bank 2022a]. Figure 1 provides up-to-date information on existing carbon pricing initiatives around the world.

The European Union Emissions Trading System

The EU ETS was launched in 2005 and has since been "the cornerstone" of the EU's strategy to decarbonise the economy and a flagship element of EU climate policy, covering about 45% of the EU's greenhouse gas emissions. This cap-and-trade mechanism is in line with the "polluter pays principle". The overall volume of greenhouse gases (GHGs) that compliance power plants, industrial factories and the aviation sector can emit is restricted by a cap on the number of emission allowances. This quota gradually decreases each year to ensure a reduction in total emissions. Regulated emitters engage in activities such as receiving, purchasing, selling and exchanging emission allowances. Each allowance grants the holder the right to emit either one tonne of carbon dioxide (CO_2) or an equivalent amount of nitrous oxide (N_2O) and perfluorocarbons (PFCs).

Since 2013, an emission limit has been set for the entire EU. As of 2021, around 57% of the EU-wide cap for stationary installations is auctioned, with the rest available for free. Free allowances account for 82% of the aviation cap, while 15% of these are auctioned [European Commission 2021c]. The European Commission believes that auctions are the most transparent method of allocating emission allowances and that their sufficiently high price in the emissions market motivates polluters to invest in clean, low-emission technologies.

To meet their legal obligations, supply chain actors must reduce their emissions through environmentally sustainable actions, such as implementing energy efficiency measures, deploying carbon capture and storage systems, or investing in other emissions-reducing technologies. Bearing additional financial costs of allowance purchasing and operation restructuring, they may lose market share to rival companies outside the EU ETS. By exploiting cross-country regulatory differences, they may also consider relocating production and distribution facilities (investment leakage) to unregulated or less-stringent regions based on various criteria, including environmental and economic dimensions [Koch and Basse Mama, 2019, Schoubben 2020].

A vital element of the EU ETS is the Market Stability Reserve (MSR) implemented in 2015 to address the structural oversupply of allowances, which amounted to a whole year's worth of pollution by the covered sectors (Decision (EU) 2015/1814, 2015). In 2019, the MSR started its operation, actively sucking surplus pollution permits out of the market. From 2023 onwards, it will also delete or cancel emission allowances held in reserve. The European Commission has proposed to reform the MSR to sell some of the

[3] On 1 January 2021, a UK ETS replaced the UK's participation in the EU ETS.

allowances it contains[4] to finance the REPowerEU plan proposed in May 2022 – a solution to rapidly reduce the EU's dependence on Russian fossil fuels in response to Russia's invasion of Ukraine and accelerate the green transformation [European Commission 2022e]. Some believe that a larger supply of allowances could increase the amount of climate pollution that is permitted under the system, lower carbon prices, reduce the proceeds from auctions that are collected by member states or used to fund climate-friendly innovation, and weaken incentives for businesses to decarbonise [Stoefs and Ruggiero 2022]. A key role in REPowerEU is to be played by the EU ETS Innovation Fund programme launched by the European Commission to support the deployment of innovative clean tech manufacturing and innovative electrification and hydrogen applications. The estimated maximum budgetary envelope for the implementation of the Innovation Fund for 2022 has been set at 3.12 billion EUR and will be financed (among other sources) by revenues from the auctioning of the allowances destined for the Innovation Fund (European Commission, 2022f).

The political conflict around EU climate policy, clearly visible between the ambitious Western and Northern member states and the less wealthy, more sceptical Eastern member states, including Poland [von Homeyer et al. 2022, International Energy Agency 2022] exemplifies differences in national and sub-regional economic and political interests. Given the ongoing global changes and problems within and around the EU, some investigators [Filipović et al. 2022, Radovanović et al. 2022] claim that there is a lack of adequate understanding and monitoring of the effects of each Green Deal action and quantitative indicators for environmental, economic and social pillars pose a potential threat to sustainable development and the EU unity. According to them, the Green Deal focuses inadequately on social aspects directly related to the decarbonisation process.

Research aims and methods

The research aims: (1) to survey the literature developed over past years on GHG emission policies, particularly those concerning pollution taxes and pollution-rights trading schemes; (2) to examine the European Union's Emissions Trading Scheme (EU ETS) with focus on market and price developments; (3) to identify possible effects of the EU ETS on the sustainability of the supply chain; (4) to propose areas and issues for further research into the links between the EU ETS and sustainable development of the supply chain.

Theoretically, carbon pricing is considered from the perspective of property rights, public goods, political economy and sustainable development concepts. In line with those aims, the research methods include a content review of the selected scientific articles and documents, as well as an analysis of the time series on European Union allowances (EUA). The study used simple econometric tools, namely the coefficient of variation (CV), to check the variability of carbon emission prices and a Pearson's correlation to check the relationship between selected variables.

[4] The European Commission proposed to increase the Recovery and Resilience Facility's (RRF) financial envelope with 20 billion EUR in grants from the sale of EU ETS allowances held in the MSR to be auctioned in a way that does not disrupt the market [European Commission 2022d].

The data was derived from publicly available sources: the World Bank, the European Commission – the European Union Emission Trading Scheme, the European Energy Exchange and the European Environmental Agency.

Results and discussion

The EU ETS' allowances in circulation on the European carbon market

By 15 May each year (starting in 2017), the European Commission shall publish the total number of carbon emission allowances in circulation. This figure determines whether some of the allowances intended to be auctioned should be placed into or released from the MSR. On May 2022, the European Commission published the total number of allowances in circulation in 2021, amounting to around 1.45 billion (in 2020, around 1.58 billion). As long as this amount exceeds the threshold of 833 million allowances, a particular share of the total number of allowances in circulation is placed in the MSR each year. In opposite, allowances are released from the MSR if the total number of allowances in circulation is lower than 400 million units. For 2019–2023, this deduction percentage is set at 24% of the total number of allowances in circulation. A corresponding amount will be deducted from the auction volumes of the member states, the three EEA-EFTA countries and of the United Kingdom (in respect of the generation of electricity in Northern Ireland). Auction volumes from September 2022 to August 2023 were to be reduced by about 347.8 million allowances [European Commission 2022b]. In 2021, the MSR holdings accounted for about 14% of the allowances supply (Table 2).

Table 2. The total number of EU ETS' allowances in circulation in 2021
Tabela 2. Całkowita liczba uprawnień EU ETS znajdujących się w obiegu w 2021 roku

Supply	**Number of allowances**
a) Banking from the period 2008–2012 (allowances issued during 2008–2012 of the EU ETS, which were not surrendered to cover verified emissions or cancelled)	1,749,540,826
b) Allowances allocated for free for the period 1/01/2013–31/12/2021, including from the new entrants' reserve	7,141,195,439
c) Unallocated allowances pursuant to Articles 10a(7), 10a(19) and 10a(20) of Directive 2003/87/EC	886,806,455
d) Allowances deducted from c) in order to be auctioned in 2020 for the Innovation Fund	–50,000,000
e) Allowances deducted from c) and placed in the new entrants' reserve in 2021	–200,000,000
f) Total number of allowances auctioned between 1/01/2013 and 3/12/2021, including early auctions	6,598,419,287
g) Allowances used for flexibility under Regulation (EU) 2018/842 (included in f)	7,213,787
h) Allowances deducted from auctioning volumes during the period 2014–2016	900,000,000
i) Allowances deducted from auctioning volumes in 2019–2021 pursuant to the previous Commission Communications	1,095,875,607
j) The number of allowances monetised by the European Investment Bank for the purposes of the NER300 programme	300,000,000

Table 2. cont.

k) International credit entitlements exercised by installations in respect of emissions up to 31/12/2020	497,248,017
Sum (supply)	18,919,085,631
Demand	
(a) Tonnes of verified emissions from installations under the EU ETS between 1/01/2013 and 31/12/2021	14,836,567,505
(b) Allowances cancelled in accordance with Article 12(4) of Directive 2003/87/EC by 31/12/2021	621,882
Sum (demand)	14,837,189,387
Number of allowances in the Market Stability Reserve	2,632,682,071
Total number of allowances in circulation	**1,449,214,173**

* The total number of allowances in circulation: TNAC = Supply – (Demand + allowances in the MSR)

Source: [European Commission 2022b].

The EU ETS has been put under probe by three large shocks affecting the demand for and supply of emission allowances: (1) a temporary negative allowance demand shock due to COVID-19 lockdowns reducing energy demand; (2) a positive or negative allowance demand change because of overlapping policies from the NextGenerationEU recovery stimulus package; (3) a permanent negative allowance supply adjustment because of more ambitious emissions reduction target of 61% by 2030 compared to 2005 levels, as part of the proposed 'Fit for 55' package, which implements the goals of the European Green Deal [Bruninx and Ovaere 2022].

The EU emission allowances auctions and prices

Auctioning is the default method of allocating allowances within the EU ETS. Most countries participating in this mechanism auction their emission allowances on the European Energy Exchange – EEX in Leipzig [EEX 2022]. It has been awarded the role of the Common Auction Platform (CAP) to auction EU general allowances (EUAs) and EU aviation allowances (EUAAs) on its spot market on behalf of 25 EU member states and three EEA/EFTA states (Iceland, Liechtenstein and Norway), as well as for the Innovation Fund and the Modernisation Fund. Germany and Poland have opted out of this platform. Germany has nominated EEX as its opt-out platform, while Poland will use it until further notice. In December 2020, Poland concluded an agreement with the EEX to use the CAP3 to auction its portion of allowances. This exchange also conducts emissions auctions for the UK regarding electricity generation in Northern Ireland. The EEX is now the auction platform which covers the entire auction volume under the EU ETS. Table 3 provides an overview of the results of auctions by the CAP for the participating member states and Poland. The total auction volume (Column 2 in the table) represents the supply of allowances, while the total bid volume (Column 3) represents the demand for them.

The total revenues from the auctions of general allowances from 2013 to September 2022 reached about 112 billion EUR. Considering (exclusively) the fourth trading period (January 2021–September 2022), these total revenues amounted to about 63.7 billion EUR.

Table 3. The results of the auctions of general allowances (EUAs) at EEX
Tabela 3. Wyniki aukcji uprawnień do emisji ogólnych (EUA) na giełdzie EEX

Period	Total auction volume of EUAs[1]	Total bid volume of EUAs	Total revenue (EUR)	Average			
				Cover ratio[2]	Number of bidders	Number of successful bidders	Auction clearing price (EUR)[3]
1	2	3	4	5	6	7	8
09/22	37 259 000	71 870 500	2 583 969 930	1.9	18.6	13.8	69.35
08/22	20 192 500	63 544 000	1 759 853 265	3.1	16.4	9.4	87.15
07/22	32 862 000	73 215 500	2 674 980 145	2.2	20.8	14.8	81.4
06/22	30 567 500	69 774 000	2 530 757 385	2.3	20.4	14.3	82.79
05/22	37 900 500	87 512 000	3 220 253 025	2.3	21.6	16.2	84.97
04/22	34 216 500	74 920 000	2 736 312 345	2.2	23.0	15.7	79.97
03/22	41 277 000	92 255 000	3 076 655 035	2.2	21.7	16.0	74.54
02/22	35 812 500	48 004 000	3 229 534 010	1.3	22.4	19.2	90.18
01/22	27 148 000	39 669 000	2 248 786 940	1.5	24.1	19.9	82.83
12/21	26 358 000	37 589 000	2 127 412 425	1.4	19.5	16.8	80.71
11/21	43 483 000	63 439 500	2 843 456 625	1.5	20.7	17.4	65.39
10/21	38 452 000	62 101 000	2 284 052 960	1.6	21.9	17.5	59.40
09/21	40 527 000	64 777 000	2 489 433 875	1.6	21.3	16.8	61.43
08/21	26 656 500	58 272 500	1 502 176 915	2.2	22.0	15.9	56.35
07/21	53 050 500	78 671 000	2 834 823 470	1.5	24.9	20.0	53.44
2021	482 490 000	775 121 500	25 581 263 350	1.6	23.4	17.9	53.02
EU ETS Phase IV (2021–2030)							
2020	560 046 500	951 992 500	13 723 091 055	1.7	24.3	18.2	24.50
2019	460 978 500	906 546 500	11 357 236 835	2.0	24.1	17.2	24.64
2018	642 477 000	1 662 693 000	9 917 590 730	2.6	25.6	18.0	15.44
2017	648 415 500	1 761 212 000	3 744 838 845	2.7	21.2	14.6	5.78
2016	474 261 000	1 092 400 000	2 496 870 295	2.3	19.0	13.4	5.26
2015	413 874 000	1 337 010 500	3 154 940 925	3.2	18.3	13.3	7.62
2014	335 052 000	1 796 711 000	1 977 712 120	5.4	17.6	11.9	5.90
2013	530 488 000	1 761 639 500	2 349 853 340	3.3	18.4	13.2	4.43
EU ETS Phase III (2013–2020)							

Aviation allowances are not included; [1]volumes are planned to be auctioned for the whole year; [2]cover ratio: the ratio between the total bid volume and the auction volume; [3]the average auction clearing price: price determined upon closure of the bidding window, it is weighted by the volumes of the respective auctions.

Source: [European Commission 2022a].

Looking at Poland alone, from 12 November 2012 (start of Phase III) to the end of Q3 2022, the country collected approximately 17.38 billion EUR in auction revenues from general allowances and about 25.43 million EUR from aviation allowances (European Commission, 2022a). In 2019, Poland issued 166 million ETS allowances (12.6% of the EU total), of which 62.8% were auctioned – thereby generating revenues for the country. In total, Poland received about 8 billion EUR of auctioning revenues between 2013 and 2020 [Haase et al. 2022].

The auction coverage ratio provides information about the actual auction demand for the allowances in relation to their supply on the primary market by comparing the total number of bids in the auction to the total number of available EUAs. The lower this ratio, the lower the relative demand for EUAs – which is a negative market signal and may contribute to a drop in EUA prices, and vice versa. In 2020 and 2021, the cover ratio continued to decline, with average ratios of 1.7 and 1.6, respectively, down from 2 and above in previous years (Figure 2). This may have enabled some market participants to exercise market power or game auctions in the subsequent period.

In the period 2013–2017, the annual average prices of general allowances remained low at 4 to 7 EUR per metric tonne of carbon. In the following years, they soared to double-digit levels from below 16 EUR in 2018 to over 90 EUR in February 2022 (Figure 2). The primary driver of the large EUA price increase in 2018 was likely anticipation of the MSR debut in January.

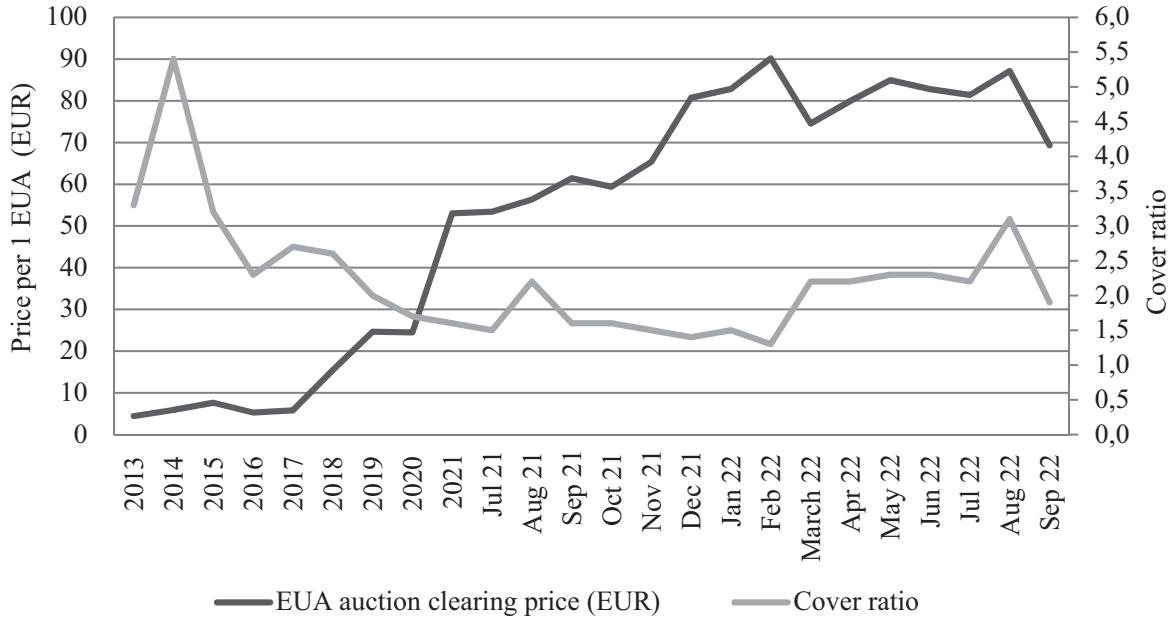

Figure 2. The clearing prices of emissions general allowances and coverage rate at EEX, 2013–2022

Rysunek 2. Ceny rozliczenia i wskaźnik popytu do podaży uprawnień do emisji ogólnych na EEX, 2013–2022

Source: own compilation based on [European Commission 2022a].

The acceleration of the EUA price increase has occurred since early 2021. This trend reflects several factors, including the start of the EU ETS Phase IV (the period from 2021 to 2030), which entails a shrinking amount of EUAs over time and updated

parameters for the MSR [Simõe 2022]. As a result of economic sanctions on Russia, gas prices have increased significantly in recent years, pushing electricity producers to switch from gas to coal-fired power generation, which emits more CO_2, which has increased demand for carbon permits. An ongoing military conflict poses potential risks to further carbon emission market volatility. The obtained coefficient of variation (CV) for prices of general allowances, calculated using monthly data from July 2021 to September 2022, was about 15.8%. Results reveal that for the period from 2013 to 2021, the CV equalled 92.5%, indicating high volatility of EUA price. High price variation threatens the financial sustainability of regulated entities.

Regarding the relationship between coverage ratio and EUA auctioning price, our study found a positive Pearson's correlation ($r = 0.31$) for the period from July 2021 to September 2022, suggesting the existing forces of the law of demand.

Several researchers and experts [Friedrich et al. 2020, Jeszke and Lizak 2021] believe that the 2020–2022 price increase of EUA could have been caused not only by fundamental factors and various policies, but by market speculation. According to the European Commission, increased interest in the ETS from non-compliance entities, such as investment funds, may have supported the price rally. Market intelligence, similarly, claims that exchange-traded funds (ETF) and other investment funds may play an increasingly important role in the ETS market [Ampudia et al. 2022]. The results of Friedrich and co-authors, who found evidence of a long period of explosive behaviour in allowance prices – starting from March 2018, when the reform was adopted – suggest that this reform has sparked activity by market speculators resulting in the steep upward trend in prices [Friedrich et al. 2020]. An example of market actors that buy EUAs, treating them as a possibility to take profit, is KraneShares Global Carbon Strategy ETF (KRBN). In 2022, its Carbon Allowance Futures portfolio contained about 60% of EUA 2023 and 2024 futures worth about 400 million USD [KRBN 2022].

EU ETS and supply-chain sustainability

The implication of the Sustainable Development Goals for companies, and consequently for supply chains, is a set of criteria they must meet, referred to as the triple bottom line approach [Elkington 1999]. As mentioned earlier in this paper, the sustainable development conceptual framework recognises the interdependence of at least three dimensions: economic, environmental and social, focusing on the "balancing" between profit, people and the planet. Interventions in one area can affect adversely or positively outcomes in other areas (trade-offs versus reinforcing effects). We believe that improving performance within an individual dimension at the expense of another dimension goes against the idea of sustainability.

Therefore, one can wonder if carbon pricing, like that examined in the current study, is a potential method for enabling significant environmental improvement without jeopardising economic performance and social advancements, at least in some participating member states. This is especially true for Poland, which has the most emission-intensive energy sector in the EU when considering CO_2 emissions per unit of the produced energy because the country relies on coal. In Poland, there is also a large share of energy-intensive or carbon-intensive industries and much lower energy efficiency than in Western

European countries, where much less energy is consumed to produce a given unit of Gross Domestic Product [Krzemiński, 2020].

Carbon pricing is generally seen as one way to support Sustainable Development Goal 13 ('Climate action') by incorporating the costs of climate change into the price of fuels and other energy-intensive goods and services. It sends a price signal to sectors, industries and households, encouraging them to change their behaviour.

Regarding the environmental issue, namely carbon dioxide emissions, the empirical evidence available in the literature proves that the EU ETS has impacted them extremely negatively. Martin and co-authors, who reviewed the scientific literature on the ex-post evaluation of this system, point out that emissions in regulated energy and industrial sectors decreased by about 3% in Phase I (2005–2007) and during the first two years of Phase II (2008–2012) compared to estimated emissions from normal operations [Martin et al. 2016]. Similarly, Bayer and Aklin found that the emission cut in sectors covered under the EU ETS was higher compared to non-compliant sectors, despite low carbon prices. According to them, between 2008–2016, the system saved about 1.2 billion tonnes of CO_2 (3.8% of total EU-wide emissions) relative to a world without carbon markets or almost half of what EU governments promised to reduce under their Kyoto Protocol commitments [Bayer and Aklin 2020]. In addition to the environmental aspect, the EU's increasing climate aspirations could interfere with the economic and social aspects of sustainability.

Summing up, carbon restrictions and pricing on GHG emissions offer a financial incentive that permeates across the supply chain and maybe the entire economy, resulting in emission reductions or improving removals. As the EU ETS cap is reduced over time, the total emissions are expected to fall. It is, however, apparent that the 2022 invasion of Ukraine has put Europe in a serious gas crisis, which has led to the reactivation of coal units and an increase in coal imports.

Considering the second dimension, one cannot forget that in a market economy, the economic goal of the supply chain is to maximise its long-term economic performance; to be cost-efficient and profitable throughout the system, which covers the integration of suppliers, manufacturers, logistic operators, distributors, retailers, and finally consumers. Addressing the complex links between ETS and sustainable supply chains, it should be noted that the system covers the upstream sectors[5] listed below [European Commission, 2022c]:

- the power generation sector – electricity and heat generation (CO_2);
- energy-intensive industries: oil refineries, steel works, production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals (CO_2);
- commercial aviation within the European Economic Area (CO_2);
- production of nitric, adipic and glyoxylic acids and glyoxal (nitrous oxide N_2O);
- production of aluminium (perfluorocarbons PFCs).

The sharp rise in overall production costs, faced by both European-regulated industries and unregulated ones that use raw materials and products further down the supply chain, is one of the negative direct economic consequences of the EU ETS. This cost

[5] The participation in the EU ETS is generally mandatory for companies in these sectors. The European Commission is considering including transport and buildings (residential and commercial) in the ETS to accelerate emission reductions in these sectors.

effect could make their products either less competitive or uncompetitive within the internal market and for export. Researchers point out that the EU ETS-based carbon price raises the costs of energy-intensive production at the member states, thus risking industrial activity relocation outside the EU and EEA. Several authors [Wagner and Timmins 2009, Mulatu 2017, De Beule et al. 2022] report that the cross-country institutional (regulatory) heterogeneity opens the door for opportunistic behaviour by multinational enterprises or foreign direct investment, including escaping to "pollution havens", as compliance with stringent environmental regulation is often costly. Responding to the threat of carbon leakage[6], the European Commission is introducing the Carbon Border Adjustment Mechanism in October 2023, on which a political agreement was reached in 2022 between the European Parliament and the Council [European Commission 2021a].

As for positive economic effects, one of them is derived from the possibility of selling unused emission allowances. In addition to providing an incentive to cut emissions to save allowances, the revenues collected can be invested in green technologies. Another example is the development of green finance or financing tools supporting mitigation actions that address climate change. The adoption of new, environmentally friendly technologies and equipment by supply chain entities, forced by the EU ETS, requires them to use additional external financing. Just as important as greening the supply process is the demand side of the supply chain. Its operation is only justified when the products or services are finally accepted by customers and financially affordable.

Empirical literature shows mixed results concerning the EU ETS effects on firm economic and financial performance. Marin and co-authors studied the economic situation of regulated enterprises (employment, labour productivity, wages, turnover, added value, investment, total factor productivity and return on investment) in the first (2005–2007) and second (2008–2012) phases of the scheme implementation and did not prove its negative consequences. Their findings, based on a large panel of European companies operating in the manufacturing sector, suggest that they have responded to the EU ETS by passing the costs on to their customers on the one hand and improving labour productivity on the other [Marin et al. 2018]. The assessments made by Chang and co-authors show that green finance enhances green technology innovation in eight out of ten selected European countries [Chang et al. 2022].

However, the recent high volatility of allowance prices and the risk of their sudden escalation can threaten the economic and financial sustainability of the supply chain as a whole, its sectors and individual entities (producers and consumers). Short-term, sharp price increases may indicate that businesses along the supply chain are dealing with rapidly growing prices without having enough time to adapt their production capacities. With higher prices of allowances, companies may also decide to reduce production in order to sell unused allowances to make a profit. As we noted earlier, the increase in these prices is detrimental to the Polish economy, as it is mainly based on coal – the combustion of which contributes to high CO_2 emissions.

[6] Carbon leakage – moving EU-based companies with carbon-intensive production to countries with less stringent climate policies than the EU, or replacing EU goods and precursors by more carbon-intensive imports.

The dynamic EUA price increase is reflected in increased energy bills for enterprises and final consumers (households), as the EU ETS has an impact on power costs in the long run. The prices of electro-fuels produced using electricity similarly depend very much on the electricity prices. The European Commission's proposal to extend emissions trading (not covered by the existing EU ETS) to the transport (road and maritime) and building sectors [European Commission 2021b] would push up the average spending on gas-fired household heating as well as impose higher costs on both fossil fuel vehicles [Stenning et al. 2020] and ships that use energy with high GHG emissions [Lindstad et al. 2021]. The volatility in EUA prices can have negative effects, such as inefficient operations and investments (if reductions are made in response to temporary high prices), uncertainty in both investments and prices for energy and energy-intensive goods or services, as well as financial risks and losses for companies with a shortage of allowances [Schatzki and Stavins 2018]. Regarding additional financial effects, when stationary and aircraft operators governed by regulations do not surrender enough allowances to cover all their emissions in the previous year, they will risk heavy penalties [EUR-Lex 2021]. They will be fined 100 EUR for each missing allowance, equal to a tonne of CO_2 emitted.

In other words, regulations that raise the price of carbon allowances effectively boost the cost of capital for businesses that use a lot of carbon, as well as the production costs for other businesses in the supply chain. This raises the cost of living for families.

From the societal perspective, the implementation of the EU ETS, on the one hand, results in a social burden at various stages of production; on the other hand, it generates social benefits. The high energy costs induced by the system, combined with the very low incomes of some households, generate a problem of energy poverty that affects almost every aspect of a decent life. This is against SDG 1 – "No poverty", and SDG 7 – "Affordable and clean energy". In the medium to long term, carbon taxes are believed to have regressive distributional effects, disproportionately harming low-income households who are most financially strapped and vulnerable populations.

As it concerns individual companies, especially carbon emitters, they could face boycotts of their products by customers or non-governmental organisations if environmental or social problems (such as attempts to bypass the system) are reported in their supply chain. Additionally, these companies' reputations would suffer as a result.

We should highlight the issue of political and citizen acceptability of tightening and widening ETS. If the adverse social effects are not dealt with in time and efficiently or if funds from carbon pricing are not spent on compensation measures, it will be risks of the lack of public acceptance and backlash. There are already forewarnings [Messad 2022, Rosario 2022] that rising energy costs driving inflation as well as a proposal by EU lawmakers to include homes in the carbon market will cause social dissatisfaction and instability throughout Europe.

The positive social-side effect is connected with the beneficial effects of less emission on the health and well-being of the population. The reduction of emissions, if successful, could decrease the number of deaths and illnesses from air pollution and contamination (Goal 3 – "Good health and well-being"). It will improve human capital in the supply chain.

Conclusions

Concerns regarding global climate change, considered a serious market failure, have led to international consensus and cooperation to decline greenhouse gas emissions from the energy, industrial, transport, and other sectors. Governments have introduced various policy tools, including carbon pricing (carbon taxes and emissions trading), to address the emission problem and, thus, achieve related sustainable development goals.

This paper looks at the EU ETS – a multinational cap-and-trade scheme introduced in 2005, which is seen as the cornerstone of the EU's transition to climate neutrality by 2050 and a 50–55% reduction in emissions in 2030 compared to 1990. Within this system, certain entities have to act with compliance to environmental requirements, eventually causing positive or desired and negative or undesired effects along the supply chain. Considering this background, this study tries to identify the consequences of the EU ETS for supply-chain sustainability, bearing in mind its three main dimensions. According to our results, the system in question has significantly impacted not merely the upstream sectors covered by regulations, but also downstream entities in the supply chain as well as consumers.

It is clear that environmental sustainability considerations under the carbon market-based mechanism have imposed GHG emission constraints on supply chains. As far as the economic aspect is concerned, the EU ETS directly affects the performance of compliance companies and sectors (power plants, large industrial emitters, and domestic aviation) in two main ways. Firstly, it imposes extra costs on operators emitting above the established threshold as well as financial risk related to the high volatility of allowance prices. Secondly, the pressure exerted by regulations, emission allowances prices and fines for non-compliance may spur investments in cleaner technologies and technological innovation not yet exploited – potential sources of their competitive advantage. Referring to the ongoing debate about the actual ultimate payers of the price of carbon allowances, our findings suggest that it is consumers. The increase in energy commodity prices caused by the system affects downstream entities, most notably low-income households. Responsibility for mitigating GHS emissions lies with the producer, but costs are passed on to consumers through the supply chain.

We note that sustainability requires a nexus between the environment (energy transition) and social justice. The latter aspect is explicitly connected with energy poverty due to rising electricity and heating or cooling costs and mobility poverty due to higher transportation costs. Social justice, however, extends beyond poverty and concerns socio-economic inequality more generally. National governments can compensate impacted entities for their losses through targeted transfers using the proceeds from auctioning allowances, addressing the wealth-distribution consequences of the system. Revenue recycling is, however, restrained by regulations according to which half of the auctioning proceeds from stationary installations and all from the aviation sector must go to climate action. The Social Climate Fund, linked to the proposed new ETS for buildings and transportation sectors, would use a substantial portion of its revenues to mitigate social impacts on vulnerable populations through direct income support.

In our opinion, as the EU's climate ambitions grow, the associated economic and financial impacts – as well as cross-country inequalities and social injustices – do not

seem to be easily reconciled with the sustainability environmental dimension. A tougher climate policy could erode the competitive advantage of trade-exposed and energy-intensive industries that face intense competition in global markets. In response to a cutback in the volume of EU emission allowances and the apparent increase in their price, producers might choose to reduce GHG emissions not by expected decarbonisation practices (low-carbon technologies) but by shrinking or eliminating industrial activity. Europe is not the only one in the world, so companies based in EU ETS member states are linked to and dependent on their counterparts abroad through international supply chains. Despite taking part in the EU ETS, each member state has established national environmental policy measures and regulatory instruments, just like other nations throughout the world. Some financial investors and market speculators could affect carbon allowance prices too. All of these and other factors can affect national supply chain participants and their three-dimensional sustainability. Finally, the economic and social impacts of higher carbon and energy prices due to Russia's aggression against Ukraine may make EU climate action more complex and costlier.

This article does not address or investigate in more depth several issues that deserve attention. To better understand the relationship of the cap-and-trade system with supply-chain sustainability, advanced research is needed, including using econometric modelling. We propose a further, more detailed exploration of this system in such areas as: (1) sectoral and geographical actor behaviour within the system, including emission allowance markets, to explain how specific compliance entities and allowance market intermediaries affect GHG emissions and investment in their abatement; (2) interactions between energy markets, inflation and the EU ETS; (3) justice considerations surrounding the system to help understand trade-offs between climate and non-climate goals of sustainable development as well as distributional effects between participating countries and individual entities in the supply chain; (4) the impact of the Russia-Ukraine war on EU climate policy.

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