From calculation to trading: the relevance of explication in an experiment to establish a marketplace for aviation greenhouse gases emissions offsetting credits

Abstract

The assembling of markets for greenhouse gas (GHG) emissions involves the bringing together of numerous social, legal, and scientific elements. This paper explores the experimental nature of carbon market design through a study of the development of a platform for the trading of aviation-related GHG emissions offsets. Utilizing an action research approach, the study traces the progression of the initiative presented, from the development of software applications for real-time emissions measurement and the forecasting of future emissions of aircraft to the development of a prototype for the trading of emissions offsetting credits. This tracing highlights the importance of the metrological devices developed in terms of the visibility of the environmental, operational, and financial risks facing the aviation industry and how this visibility, in turn, surfaces the need for the trading of emissions offsets. The article argues that these metrological devices help establish a new calculative space that enables the estimating of future demand for emissions offset credits, the identification of surplus and deficit actors, and the revealing of new and uncodified financial assets and liabilities. The market design experiment also revealed deficiencies in the existing mechanisms that render emissions credits tradeable, prompting an exploration, by the participants in the initiative, of blockchain-based tokenization as a potential technological solution to these regulatory and policy deficiencies. Beyond the empirical account, the paper contributes to theoretical discussions by introducing the concept of *explication* in market design experimentation and clarifying its meaning and relevance to such experimental settings.

Introduction

For a market to be established, complex social, legal, and scientific sociotechnical processes need to be in place through which agreements about the measurement and comparability of the goods being exchanged can be arrived at by the exchanging parties and the exchange of one good for another can take place in an efficient and uncontested way (Callon 1998; Callon 2009; Callon et al. 2021; Callon and Muniesa 2005; Cooper 2015; MacKenzie 2009a; MacKenzie and Millo 2003; Millo et al. 2005). While a crucial part of the establishment of any formalised market involves the creation of metrological infrastructures that can enable the commensurability necessary for an exchange to take place (Callon 1998; Callon 2009; Cooper 2015; Lohmann 2005; MacKenzie 2009a), it is the fitting together of such an infrastructure with numerous other elements (e.g. existing markets, devices, calculative agencies, institutions, technologies, practices) that needs to take place for a functioning marketplace to be established.

Such attempts at assembling markets and marketplaces are particularly visible in the many current initiatives to establish market-based mechanisms for the control of greenhouse gas emissions (Callon 2009; Cooper 2015; Lohmann 2005; Lohmann 2009; MacKenzie 2009a). As Callon (2009) explains, due to the novelty and uncertainty involved in the legal, scientific, and social aspects of emissions trading, the assembling of markets for emissions is unavoidably experimental, with many of their features being determined as outcomes from the process of assembling rather than through purposeful design. It is, therefore, through the process of assembling, that many aspects of the design of a market become explicit.

The article presents such an experiment through an account of an initiative to establish a platform for the trading of greenhouse gas emissions associated with aviation. Using an action research approach (Avison et al. 1999; Checkland and Holwell 2007), the account traces how the team developing the proposed trading platform progressed from developing a way of measuring aircraft emissions in real-time from publicly available data and regulatory models and formulas, to forecasting future emissions of aircraft fleets and airlines in a number of different aircraft configurations and business and operational scenarios. It then goes on to describe the visibility that these metrological outputs, combined with the regulatory model used to limit aviation emissions (ICAO CORSIA), provided in terms of future environmental, operational, and financial risks for different participants in the aviation industry. This, in turn, made explicit to the various participants in the aviation industry (e.g. airlines, fleet financiers, aircraft lessors) the implications to them of these risks as well as the need for a way to be able to trade regulatory accepted emissions permits and offsets.

The establishment, through emissions measurement and forecasting, of aggregates composed from individual aircraft data and the translation of those aggregates into current and future operational and financial risks through their confrontation with the ICAO CORSIA regulatory model, established a new calculative space (Callon and Muniesa 2005; Ehrenstein and Muniesa 2013; Muniesa et al. 2007) within which surplus and deficit actors could be identified and current and future demand for emissions permits and offsets estimated, with implications for the operating and financial strategies of the various industry participants (fleet financiers, aircraft lessors, airlines).

Out of this new calculative space, in addition to possible new financial assets and liabilities being surfaced (e.g. stock of emission permits and credits; current and future payments for emitting GHGs above the regulatory limits), the need for a system of exchange between surplus and deficit actors in terms of these assets and liabilities was also rendered explicit. At the same time, however, deficiencies in key mechanisms that could render emissions credits tradeable were also rendered explicit, surfacing new issues that any market design would have to deal with in order to establish a viable marketplace. These new design issues related to problems with the quality of offseting credits (are CO2 sequestration from projects on the ground genuine) and the property rights associated with emissions credits to be traded. The experiment thus revealed how the absence of a single overarching repository where the creation, issuance, transfer, and extinguishing of credits (when they have been 'spent' as part of regulatory compliance) would be definitively recorded, could result in double counting and double spending of offsetting credits. This, in turn, challenged the efficacy of offsetting credits in terms of emissions abatement in the eyes of potential marketplace participants and raised significant fears relating to the potential for reputational damage to the entities buying, selling, holding, and using such credits. This resulted in the platform developers exploring ways that technological solutions based around blockchain-based tokenisation might be able to resolve the flaws in the *in vitro* design of GHG market mechanism components established by public policy makers and regulators in order to make the credits truly tradeable.

In addition to providing an in-depth empirical account of an attempt to establish a marketplace for emissions trading and of the complex techno-institutional articulations involved in such an experiment in market design (Callon 1998; Callon 2009; Callon et al. 2021), the research presented also discusses the theoretical relevance of the concept of *explication* (Marres 2012; Marres 2020; Muniesa and Linhardt 2011) in such processes of market design experimentation and attempts to give the concept a clearer outline. This, in turn, contributes to broader debates around how theoretical views of the world can adapt to the concrete interrogations of those views and the knowledge that underpins them when they encounter that world.

Market design as experimentation

One of the key premisses of the social studies of finance literature is that markets and marketplaces are not a given or spontaneous form of organization of human interactions governed by natural laws, but instead should be considered as complex sociotechnical systems composed as much by material devices and equipment as institutions and designed in ways that condition their outputs and outcomes (Callon 1998; Callon et al. 2021; Callon and Muniesa 2005; MacKenzie 2009b). An important task of research, therefore, is to account empirically for how markets are established and why they take the forms and produce the outcomes they do.

One area that has received considerable research attention already has been around how governments participate in shaping markets and, in particular, how principles and values are presented, translated and mobilized as part of such processes. This has been theorized extensively in, for example, research work by (Fligstein 1996) or (Ingram and Rao 2004). This analysis places governmental regulation at the heart of an economic-political interface that allows the wielding of significant influence over the practices and norms of market actors. This line of theorising, which focuses on the processes of institutionalisation, examines the ways in which the political sphere impacts the shaping and altering of financial institutions.

Such a theoretical perspective implies that regulators delimit the scope of markets and argues that governments play central roles in shaping crucial legal and social institutions such as property rights, governance structures and rules of exchange. This, however, neglects an important potential avenue through which the shaping of markets by regulators, but also other actors, can take place through the design and development of sociotechnical devices (Muniesa et al. 2007). Taking into account market devices when analysing markets and their establishment enables a more distributed view of the shaping of markets through the shaping of technological and other devices that operate in markets. Such market devices, for example, can shape practices at a day-to-day micro level in ways that would have been too resource-consuming and would have likely been perceived as too intrusive had they emanated directly from a regulator. Hence, to improve our understanding of the shaping of markets, it is important to analyse the processes through which market technologies also participates in the establishment of markets.

Processes of scientific and technological development and innovation beyond markets also involve the assembling of sociotechnical entities and they rely on a series of events that can be regarded as being part of public experiments (Collins 1988; Evans and Collins 2007; Shapin 1992). Seen is such a way, the experiments test, ultimately, whether or not the novel arrangements proposed by, for example, scientists or engineers and supported by theory, would bring about a new scientific fact or technological innovation that would embody more faithfully a set of theory-driven principles. The experiments, therefore, embed the initial normative or theoretical claims to validity into the questions about the actual viability of the scientific fact or technological innovation. Similarly with markets, market experiments are needed to test whether or not the novel arrangements proposed by, for example, a regulator and supported by economic theory would bring about markets that would embody more faithfully a set of ideological and theory-driven principles about markets. In this case, the experiments embed the normative or theoretical claims to validity of the proposed design into questions about the operational viability of the technological market devices being proposed.

The implication of this conceptualization for understanding how, for example, financial markets became automated is that automated markets are not simply an outcome of technological determinism, nor that market technology is prescribed by regulatory and theoretical directives. Instead, the emergence of such markets comes about out of complex and iterative processes through which the regulatory worldview and economic theory motivate the development of technological devices and rules (Muniesa 2011; Muniesa et al. 2007; Pardo-Guerra 2010). These, once put into motion, launch, in effect, a market experiment on a 'one-to-one' scale through a number of 'trials of strength' (Latour 1987; Latour 1993). Such public experiments, in turn, contribute to an identifiable historical narrative of iterative trial and error patterns: a model of a market is proposed discursively by one of the actors (economists or regulator) and is subsequently 'experimented' through actual procedures and devices being designed, constructed, and implemented, with the empirical material collected via the experiment then fed back to a new model or configuration of the market.

In this article, we seek to surface the way the process of assembling a market takes place and how it can be explained by treating such initiatives as a series of events that can be regarded and analysed as being part of a type of 'public experiment' (Callon 2009; Muniesa et al. 2007). Drawing from some of the central tenets of science and technology studies, these market experiments can be seen as testing how a progressively more explicit model of market organization embodies a set of policy and theory-driven principles (Muniesa and Linhardt 2011). As Muniesa (2007) suggests, it is through such an experimental process that different (even frequently conflicting) normative claims from the different actors who have stakes in the development of a market are embedded and thus 'realised' in the resulting market structure. Furthermore, it is through this 'realisation' that their normative claims and the theoretical assumptions that underpin them are also tested and given more or less validity (Muniesa et al. 2007).

Carbon markets as public (in vivo) experiments

Because of the complex interactions between science, politics, and economics that characterise the attempts to establish market mechanisms for carbon emissions abatement, as Callon (2009) observes "not even the best specialists, can be entirely sure in advance of the organizational forms and material arrangements needed to establish a market's functioning" (Callon 2009, p. 536). As a result, such markets can only be described and analysed as *in vivo* and not *in vitro* experiments (Callon 2009; Muniesa et al. 2007). Furthermore, for a particular market design or configuration to be validated, the design needs experimentation, which, in turn, acts back on design (Callon 2009). Considering carbon market design as a real-time scale-one experiment, therefore, it is possible to understand how the experiment itself helps redefine relations between science, politics and economics, and, in the process, provides insights as to how the boundaries between these different domains can be drawn (Callon 2009, p. 536).

According to Callon (2009), many of the important questions concerning the modalities of collective experimentation are also relevant to our understanding of the role of carbon markets, their design, and their ways of functioning (Callon 2009, pp. 538-539). These include questions such as: how do theoretical models and practical solutions mutually interfere with and enhance one another? how is the collective work of market experimentation and design organized? what conflicts run through it? what mechanisms of coordination are used between the various stakeholders? how are different knowledges and know-how brought together, experiences capitalized on, and evaluations made?

One of the key questions among those above is to identify who the actors who have an interest in the resulting market are and what brings about their involvement. All the actors involved are likely to have "their own expectations, conceptions, projects and interests, on the basis of which they promote different modes of structuring and organization" of the market (Callon 2009, p. 540). Studying carbon markets and their dynamics serves to further the analysis and understanding of the processes through which a large number of different actors from diverse temporal and spatial horizons, working on the conception and explication of new market arrangements can be brought together in order to become participants in the market being established.

Another key question concerns what controversies relating to a particular design are about, how they relate to that design, and how these together relate to the different actors likely to be associated with the functioning of the market (Callon 2009; Panourgias 2015). For example, the relevant calculative equipment needed to measure operations contributing to climate change is found in a controversial and unstable form in the case of carbon markets (Callon 2009). What the market is and what it does cannot be separated from the multiple scientific and metrological controversies concerning it and the different views about their validity the different actors involved bring with them. Carbon markets, therefore, can only develop legitimately and efficiently if they render such controversial events visible and debatable as part of the experimentation associated with their establishment (Callon 2009). In the process, they will help to resolve issues relating to whether these controversies should be addressed politically, economically or techno-scientifically (Callon 2009).

According to (Callon 2009), treating carbon markets as an *in vivo* experiment also helps to understand how an imprecise controversy is transformed into well-defined problems which can be addressed by specific purposeful actions. Because such processes are "never completely consensual nor total", it is important to follow how multiform problematization leads to the establishment of a "network of problems" whose content and extension evolve in relation to the translations that are attempted between problems, some of which are qualified as technical and others as economic or political (Callon 2009, p. 543). Furthermore, the formulation of these problems is not entirely endogenous, as the way in which the problems are eventually formulated, the course of action chosen in relation to them, and the solutions proposed and implemented come up against existing sociotechnical configurations and will inevitably also be affected by them as well as contribute to changing them. In the transformation of issues into networks of problems in the case of carbon markets, the resolution of these problems is accompanied by, at least, a partial reconfiguration of economics, politics and science, and the relations between them. By answering the questions that appear, or are put to them, those who design and implement carbon markets, in effect, test the fault lines of the existing arrangements and distinguish eventually between, for example, what should be considered as a political issue and what can be left to the market. As a result, as market experimentation progresses, new forms of organization and sociotechnical arrangements of markets are invented as unexpected questions arise, to which answers and, at least, temporary solutions are needed (Callon 2009).

In the research undertaken, the unfolding of such issues is traced through an initiative to develop a platform for the trading of voluntary market GHG emissions offsetting credits by aviation industry participants, as part of a GHG emissions abatement programme instituted by the International Civil Aviation Organization (ICAO), a UN agency responsible for enabling and regulating aviation between its member states. Through this tracing, the way broad issues provoked by the development of the trading platform and its supporting software applications unfold is presented, as is the way they get framed as actionable problems. The positioning of key actors with an interest in these issues is also presented, as are the relations of these issues with other existing sociotechnical arrangements. This then makes it possible to see empirically how the boundaries of what are considered technical/scientific, political, and economic problems and issues in the attempted establishment of that market are arrived at.

An action research approach for studying market design

Action research is an approach to research in which the researcher, rather than being an outside disinterested observer, enters the real-world situation of the phenomenon being studied in order to both act on it, usually for the purpose of bringing about some kind of real-world improvement, and at the same time acquire knowledge about the phenomenon being studied from this immersion in it (Avison et al. 1999; Checkland and Holwell 2007). Such a method is often adopted when the researcher aims at solving practical problems through the research undertaken, with the new insights generated from the engagement with the research setting informing new approaches towards solving the practical problems associated with that research setting (Avison et al. 1999; Checkland and Holwell 2007). It has proved a particularly useful approach to designing and developing technological artefacts and systems and is credited with bridging artificial divides between practice and theory (Avison}. As our empirical goal is to describe the assembling a marketplace for GHG emissions credits trading as an *in vivo real-time experiment* in which the resulting market would be the outcome as well as the object of investigation, an action research approach was chosen.

In practice this involved a multi method approach for data collection relating to the initiative being described and which included: a) acquiring and analysing emissions reduction treaties and emissions trading schemes documentation, b) organizing and participating in stakeholder meetings and workshops, c) participatory observation, and d) semi structured interviews.

The research team worked closely with a prominent international financial services company, which we will refer to as FCOE (pseudonym) and which was interested in developing and possibly operating the trading platform being developed. The research team's engagement with FCOE commenced in January 2020 as part of a four-year collaborative research project funded jointly by government and industry and focused on technological innovation and disruption in financial services. The project's objectives were to both advance scientific knowledge creation and facilitate the development and commercialisation of highly innovative products and services.

Data was gathered over a 10-month period, with members of the research team being embedded within FCOE and engaged with the FCOE innovation team over this period. Researchers attended meeting and observed the perceptions of the innovation team and other relevant stakeholders towards the measurement, forecasting, and trading systems being designed and developed. The assembled material, evidence, and embodied lived experience of the development team were used to assemble a narrative account of the project and its different stages as it unfolded from research and design towards the development of a minimally viable product (MPV), which in software development is similar to the notion of a prototype.

In terms of a business case for the proposed trading platform, FCOE were focussed on the secure tokenization, trade and management of decarbonization assets, and the case being presented was developed in that direction. More specifically, it aimed to explore the potential of a decentralised finance approach to GHG offset trading operationalised via a private blockchain MPV,. Using this distributed ledger approach was seen as a way of overcoming some of the shortcomings of market based GHG emissions reduction mechanisms.

Emissions trading background

The trading of greenhouse gas (GHG) emissions permits and credits has been an outcome of the various initiatives at global, regional, and national level to restrict the emissions of GHGs blamed for global warming and climate change. These initiatives have taken the form of upper limits (or caps) on the emissions of GHGs by productive agents as a result of their activities. The allocation of these permits is then undertaken in such a way that agents with less polluting ways of carrying out their activities end up with a surplus of permits to emit GHGs which they can either use in the future or sell to those with a deficit, while those with more polluting ways of carrying out their activities are penalise by having to purchase further permits, over and above those already allocated to them, in order to cover their excess emissions. These additional permits would then need to be purchased from the issuing authority, or alternatively, from other agents with a surplus, incurring extra costs and, therefore, being penalised. In most cases, in order to accelerate the rate of reduction of GHGs, the emissions limits are lowered over time, with fewer permits issued year-by-year or, alternatively, changing the allocation mechanism to paid-for permits allocated through competitive auctions.

Different industries or areas of productive activity are likely to have their own particular implementations of such ‘cap-and-trade’ schemes with different emissions limits covering different GHGs, different number of permits and ways of issuing them, and different rates of tapering of the number of free permits issued over time. In some there is provision for the use of offsetting credits from GHG reductions in other areas of activity or even removal of existing GHGs from the atmosphere (e.g. planting of forests). In others, offsets are not accepted. In some cases, the schemes are mandated through laws and regulations while in others they may be voluntary among members of industry bodies.

Emissions trading schemes for aviation

One of the industries associated with significant and growing GHG emissions is aviation (European Commission 2022). Different emissions regimes apply to the industry in different jurisdictions. In Europe, for example, aviation emissions are governed, since 2012, through the EU Emissions Trading System (EU ETS), which governs emissions from a number of productive sectors. Under the EU ETS, all airlines operating in Europe, European and non-European alike, are required to monitor, report and verify their emissions, and to surrender tradeable allowances they receive from the EU ETS covering a certain level of emissions from their flights per year against those emissions (European Commission 2022). Under the scheme, the number of free allowances allocated to aircraft operators will be reduced progressively to reach full competitive auctioning rather than free allocation by 2027. (European Commission 2022).

Outside the EU, the main emissions trading scheme for aviation is the Carbon Offset and Reduction Scheme for International Aviation (CORSIA) being developed and implemented by the International Civil Aviation Organization (ICAO), a UN body responsible for enabling and regulating international aviation.

The CORSIA scheme was agreed by the members of ICAO in 2016 as a way of offsetting with emissions units from the carbon markets the amount of CO2 emissions that cannot be reduced through the use of technological improvements, operational improvements, and sustainable aviation fuels (International Civil Aviation Organization 2019).

The CORSIA scheme will start with a pilot phase from 2021 to 2023, followed by a first phase from 2024 through to 2026, and a second phase from 2027 through to 2035. The pilot and first phase will be voluntary.

Emissions from all aircraft operators performing international flights between two states where both the origin and destination States participate in CORSIA are covered by the offsetting requirements of the Scheme. In contrast, emissions from international flights between two States where the origin and/ or destination States do not participate in CORSIA are excluded from the offsetting requirements of the Scheme. The route-based approach ensures that all aeroplane operators with flights on the same international routes are treated equally, irrespective of whether the States to which they are attributed participate in CORSIA (International Civil Aviation Organization 2019).

The aims of the scheme is to promote the ***carbon-neutral growth*** of the aviation industry from 2020, by using the emissions at that point in time as the ceiling for emissions going into the future, as illustrated in **Error! Reference source not found.** below.

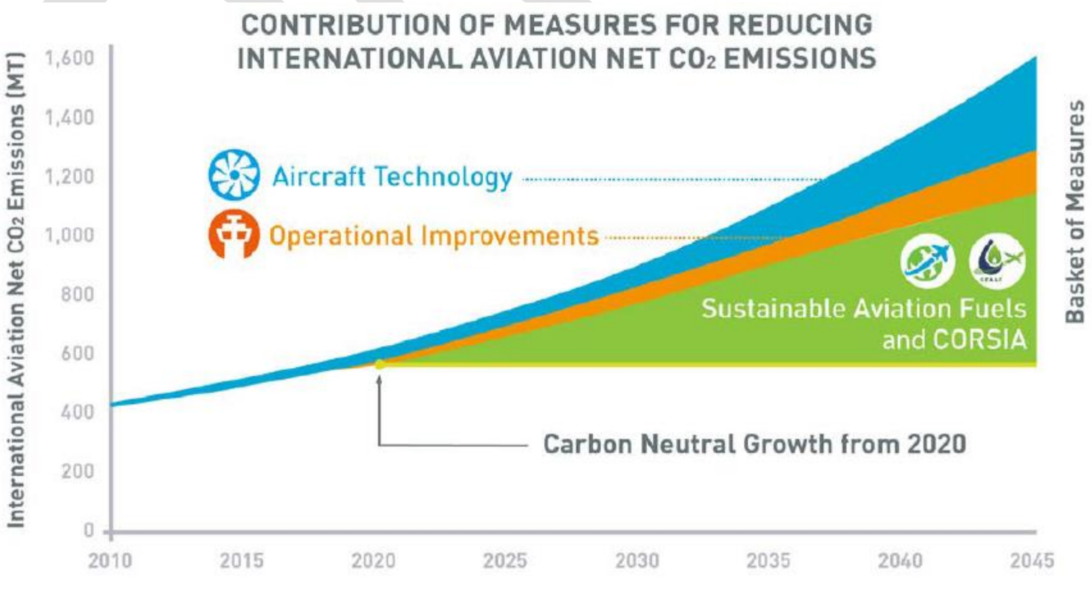

Figure 1: Relative contributions from operational, technological, and offsetting needed to achieve carbon neutral growth according to CORSIA (source: International Civil Aviation Organization (2019)

ICAO estimated that between 2021 and 2035, the international aviation sector would have to offset about 2.5 billion tonnes of CO2 emissions to achieve the carbon neutral growth envisaged in the CORSIA plan (International Civil Aviation Organization 2019).

As can be seen from the figure above, quite a large proportion of the necessary emissions reductions for carbon-neutral growth to be achieved as per the plan will come from CORSIA-eligible offset credits from other activities outside aviation. To be CORSIA-eligible, these credits need to originate from countries that participate in the Paris Agreement and are also taking part in CORSIA. More importantly, these credits need to be "reliably accounted for to avoid them being counted twice" (European Commission 2022).

The CORSIA scheme uses an aviation industry average growth factor in order to arrive at the actual emissions that will need to be mitigated in order to achieve ***carbon-neutral growth*** as illustrated in **Error! Reference source not found.** below, which shows how the offsetting requirements for CORSIA are calculated in the various phases of the scheme, moving gradually from a *sectoral* growth factor to an *individual operator* growth factor in the process.

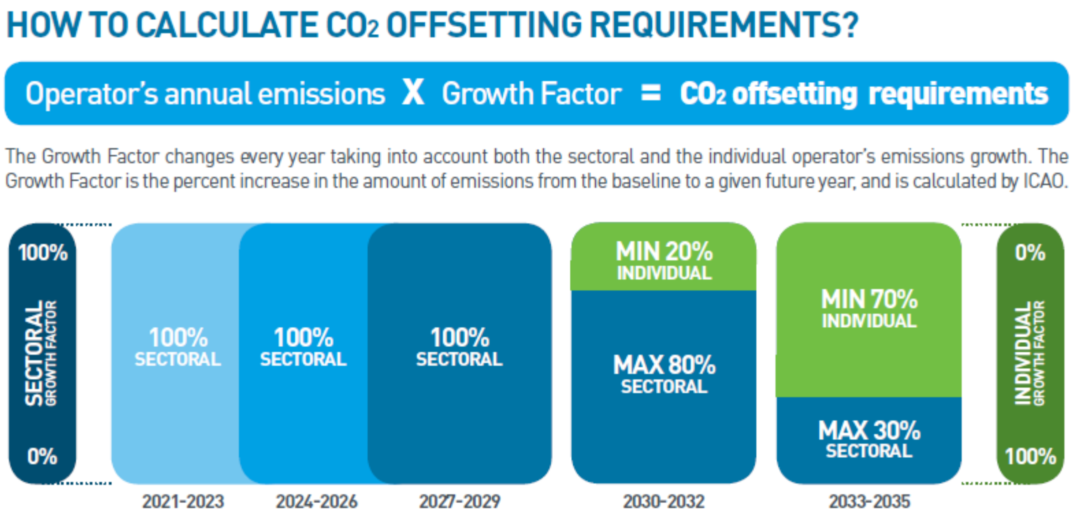

Figure 2: Dynamic model for the calculation of CORSIA offsetting requirements for airlines (source: International Civil Aviation Organization (2019)

According to ICAO, as of June 2019, 80 States – representing 76.63% of international aviation Revenue Tonne-Kilometres (RTKs) – have announced their intention to participate in CORSIA (International Civil Aviation Organization 2019).

The EU ETS provisions for aviation will operate in parallel to CORSIA. Under this arrangement, the EU will apply CORSIA provisions to flights that are outside the EU ETS and depart or arrive in countries which apply CORSIA (European Commission 2022).

Developing emissions analytics for aviation

The Platform for Analysing Carbon Emissions (PACE) was co-developed by international financial and payments services provider Fexco Group and Avocet, which provides aviation risk management and consultancy services to many of the leading aircraft owners, financiers, and investors in the aviation sector.

The thinking behind PACE is that it would be able to act as a benchmark for analysing actual and predicted CO2 emissions across the aviation sector according to Country, Portfolio (e.g. lessor, bank, credit export agency), Airline Operator, Aircraft type, Airport, Route City Pair, ETS Scheme, Aircraft Category, and Manufacture and thus make possible the running of various operational and growth scenarios based on actual flight data rather than on estimates based on calculations from fuel measurements before and after flights. PACE "automatically compiles aircraft utilization data for financiers, lessors, investors and insurers and leverages a blend of industry standard and proprietary methods to provide consistent, comparable, and reliable analytics" on the emissions performance of aircraft and fleets and link these to associated financial risks (Fexco 2021).

One important feature of PACE is a powerful forecasting engine which uses machine learning and artificial intelligence to predict future aircraft and flee utilization and performance and accompanying future financial exposures relating to CO2 emissions to enable aircraft and fleet performance to align with international, regional, and national reduction schemes and targets.

This regulatory compliance, with different schemes covering different jurisdictions such as the EU ETS, a newly established UK ETS covering the UK, similar ETSs in Korea, California as well as CORSIA create the potential for significant present or future financial risks for aviation industry participants, which PACE aims to help participants to identify and manage in a timely way. This is done by PACE being able to analyse emissions at ETS scheme level and then calculate the overall credit risk exposure at the aircraft portfolio level as well as *aircraft operator fleet lien exposures*, which is a lien that may have arisen as a result of unpaid amounts attributable to a particular aircraft in an operator's fleet.

The financial risk in these cases would be associated with the cost of acquiring the necessary permits and/or credits in order to continue operating, particularly in a situation where the market prices of these permits and/or credits are increasing, or, alternatively, if holding many permits/credits acquired at a high price when the market price then falls.

Translating emissions into financial risk and the need for emissions trading

The need to be able to buy and sell emissions permits and credits stems directly from this need to manage the financial risks associated with particular future operational scenarios and their associated emissions.

On the side of Fexco it was decided that the emissions trading side of the platform should be established as a separate but linked project from PACE, under the name Viridi. The Viridi project is being co-developed with SMBC Aviation Capital, one of the largest aircraft leasing companies in the world and will use a private blockchain-based tokenization approach to ensure the rigorous registration, verification, issuance, tracing, counting, and extinguishing of the emissions permits and credits that participants want to buy, sell, or trade on the platform.

This involves the close integration of the platform with the registries recognised by different trading schemes (e.g. VERRA, Gold Standard, and the Union Registry) in order to enable the rigorous checking and verification of the credentials of credits and permits before they are admitted for trading on to the platform. The prevention of double counting and double spending will also involve close integration with the process associated with the surrendering of permits and/or credits when the permit/credit holders' emissions have to reported to relevant ETSs and associated approved permits/credits for those schemes cancelled.

The platform would allow the issuance on to the platform of emission permits from ETSs and of offsetting credits from standards-compliant (e.g. VERRA, Gold Standard) emissions abatement projects by platform participants which are checked and verified in terms of their claims before they are made available for trading. The issuance/verification process involves the association of a particular quantity of permits/credits with a cryptographic token or number of tokens, which can then be held in an electronic wallet, sold, bought, or retired/perished, once the associated permit/credit is used to cover for a particular quantity of GHG emissions reported to a relevant ETS. This process is illustrated in **Error! Reference source not found.** below.

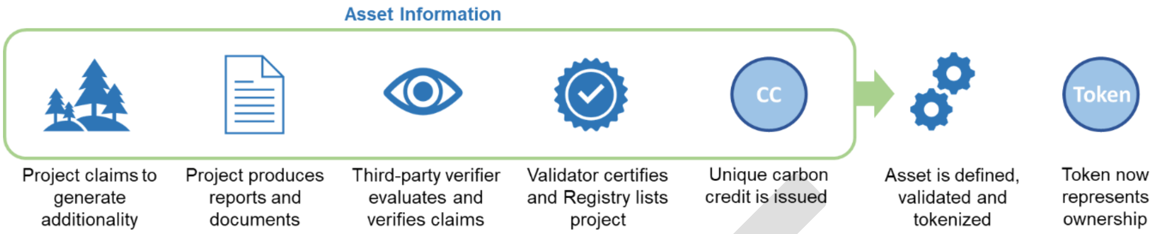

Figure 3: Emissions offset credit creation process and its linking to digital token creation (source: project presentation)

Different issued tokens and the permit/credit information and accreditation associated with them would be viewable by users in a virtual 'shop window' which is searchable/filterable according to criteria set by the users and with accompanying ratings and other metrics through which their quality and suitability for the compliance and other purposes of the users could be judged and comparability between the different permits/credits enabled in order for users to be better able to evaluate them. They would be able to compare their prices and qualities and come to a decision on whether to buy, hold, or sell them according to their needs. The possible interactions of the users with the tokens and associated permits/credits can be seen in detail in **Error! Reference source not found.** below.

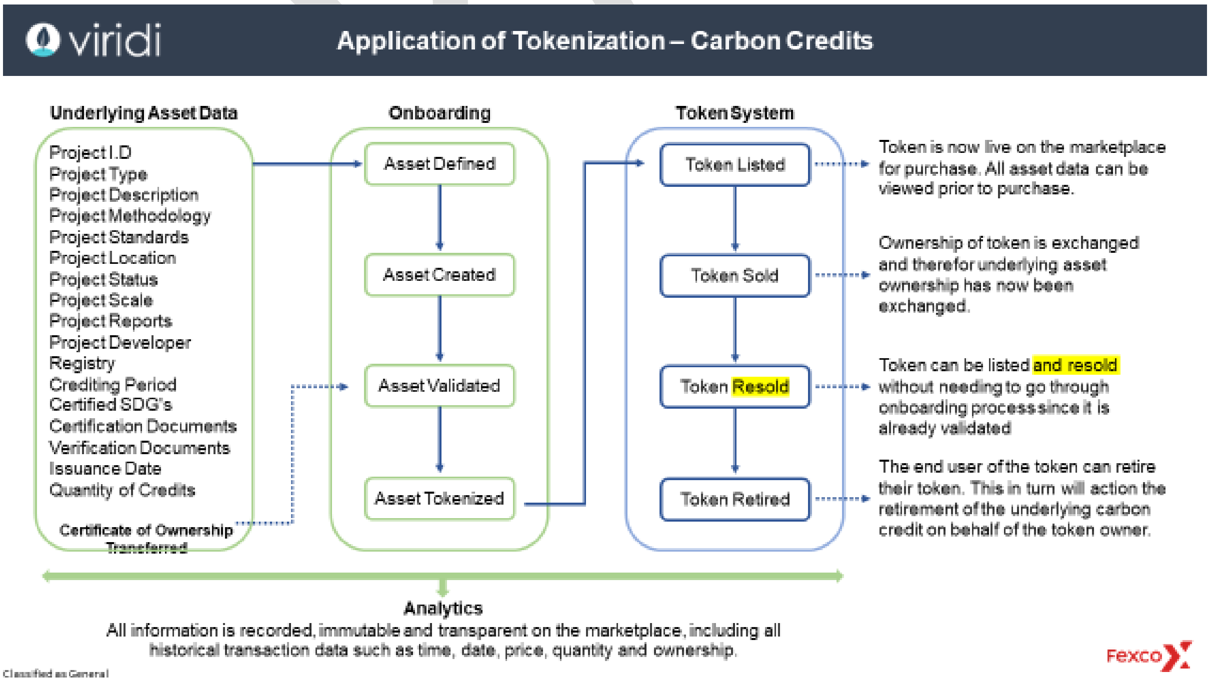

Figure 4: Data, process and architecture diagram for carbon credit tokenization (source: project presentation)

Due to the blockchain technology underpinning the operation of the trading platform, once permits/credits have been associated with a token and the token issued on to the platform, all the transactional information associated with the token and associated permits/credits would be entirely visible and traceable to participants and double counting and double spending prevented. The entire lifecycle of the permits/credits and associated digital tokens through hypothetical interactions with different groups of platform participants is illustrated in **Error! Reference source not found.** below.

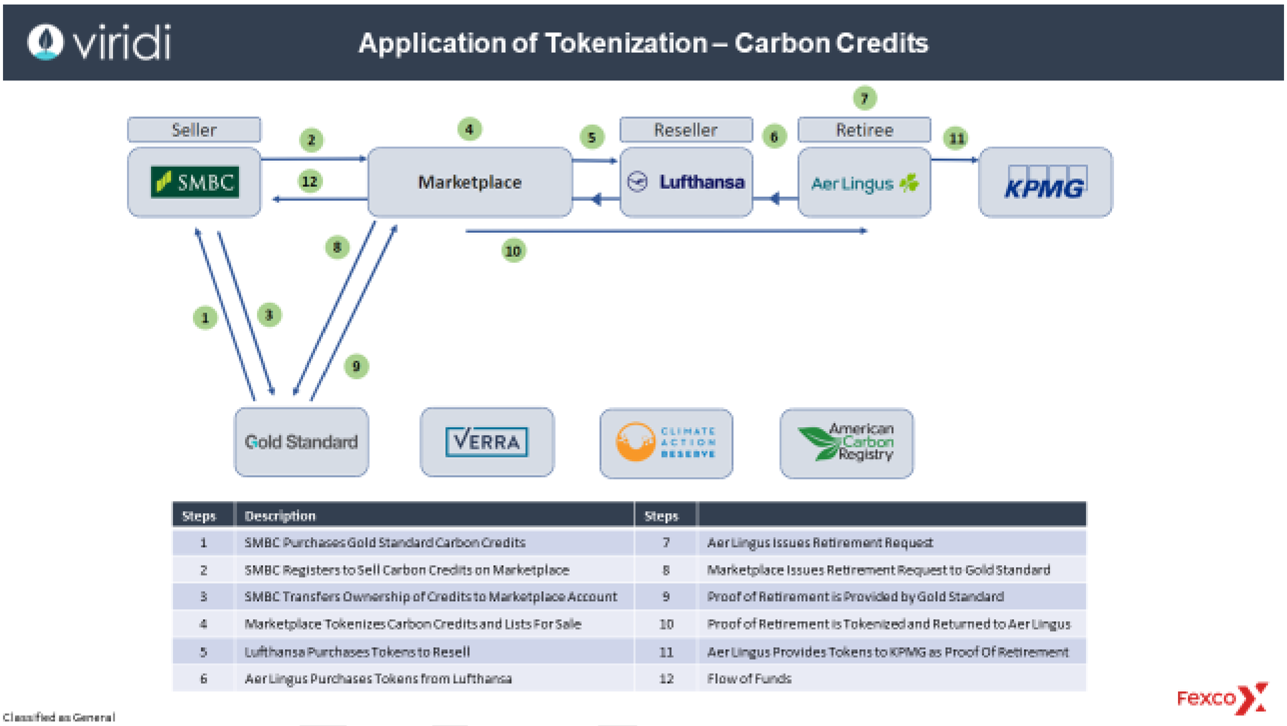

Figure 5: Proposed tokenization process for carbon credits on the Viridi emissions trading platform (source: project presentation)

The actors, issues, and links to the existing world surfaced by the experiment

As outlined previously, the initiative studied is analysed as a type of *in vivo* experiment through the tracing of a) the way broad issues provoked by the development of the trading platform and its supporting software applications get framed as actionable problems, b) the positioning of key actors with an interest in these issues in relation to those issues, and c) the relations of these issues with other existing sociotechnical arrangements. This then makes it possible to see empirically how the boundaries of what are considered technical/scientific, political, and economic problems and issues in the attempted establishment of that market are arrived at.

Figure 6 below shows the results of this tracing and how the development of the emissions trading platform MPV interacts with the world around it, generating issues around which different actors – human and non-human – position themselves and define problems that need to be solved in order for the new marketplace being proposed to come into existence. It is through this interrogation of the world around it that the MPV sets in motion, that key issues emerge and are gradually defined more clearly and associated with actionable problems that need to be solved. It is in this way that the process of market design can be considered as a real-time and real-life public experiment through which, both the existing reality and the new one that may result from the introduction of a new marketplace become more explicit as more and more previously obscured details of these realities come into view and demand concrete responses.

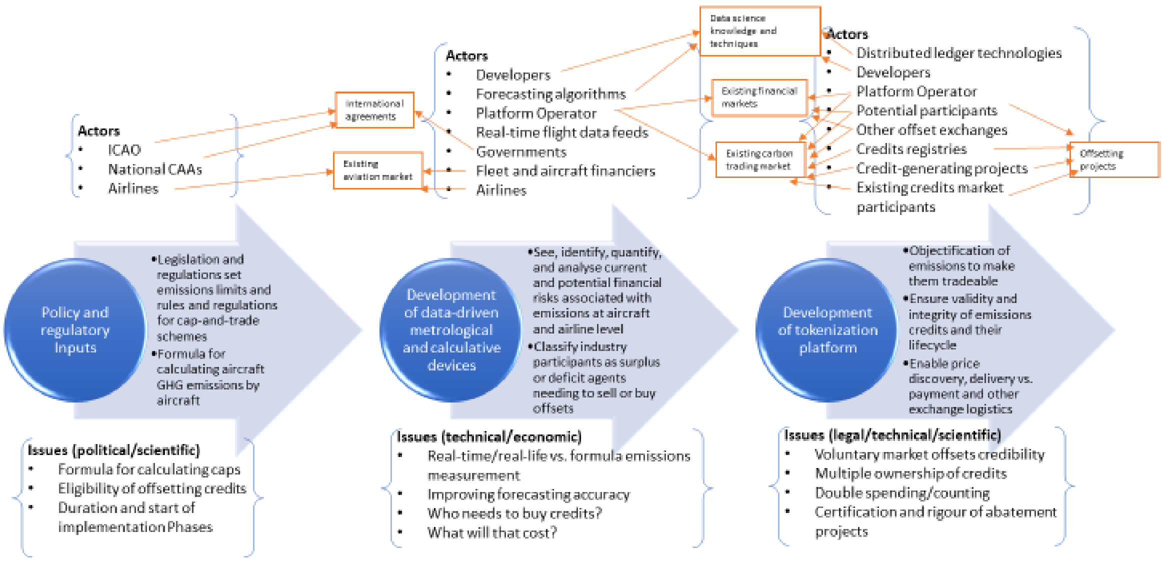

Figure 6: Explication resulting from the development of the trading platform MPV

Stage 1: A formula needs data

Looking at the first stage of the tracing, which was undertaken empirically through a detailed reading and summarizing of relevant regulatory documentation in order to present to the development team and sponsors of the project a use case for the trading platform, it is possible to see a) how the institutional framing of the CORSIA emission cap-and-trade took place, b) the political and scientific aspects of the issues this raised (e.g. negotiations between ICAO member states and their CAAs around the formula to be used to define the caps and eligible offsets), and c) the links through the key actors involved to existing markets and legal agreements and treaties. Furthermore, it can also be seen that policy and regulatory intentions in establishing an institutional basis for the market-based GHG reduction mechanism in question are not enough in themselves to bring about a market. It is necessary for those institutional building blocks (e.g. rules, and formulas) to be translated into concrete real-life data that can used by potential market participants to calculate the implications of these regulatory and scientific provisions for them and the others in their industry and to come to a conclusion as to the necessity, as seen through that reasoning, to be able to trade the instruments set out in the institutional framework emerging from the political/scientific debates informing the work of the regulator (in this case ICAO).

Stage 2: Ordering data in a 'calculative space'

This need to go from a cap calculating formula to actual real-life emissions data, sets in motion a shift of the experiment into a second stage and of the key issues from being predominantly political/scientific to predominantly technical and economic. The shift, identified empirically through the reactions of project sponsors and potential platform participants to the presentation of the use case developed in the first stage from the relevant regulatory documentation, took place because the theoretical formula for calculating the emissions of an aircraft or an airline needed to be translated to real emissions from actual aircraft, based on real-time flight data to be of practical use to aviation market participants. Furthermore, a need for forecasts through which the evolution of emissions of aircraft and fleets over time and into the future was made visible, was also surfaced through these presentations. These are crucial steps in terms of establishing what Callon and Muniesa (2005), Muniesa et al. (2007), and Ehrenstein and Muniesa (2013) refer to as a "calculative space" within which choices can be ordered, ranked, and valued and the action of potential market participants informed. It is through this calculative space that a crossover between the proposed market and the existing markets within which the prospective platform participants already transact and compete in is established (as indicated be the arrows linking actors involved in the experiment to the existing sociotechnical world in Figure 6). For example, aircraft and fleet financiers that took part in presentations of the real-time emissions measurement and forecasting elements of the platform were interested in using the current and future emissions of their clients as calculated by the measurement and forecasting applications of the platform to calculate the potential financial risk these clients may face as a result of their emissions and adjust their risk premiums accordingly for financing aircraft acquisitions by these clients. Furthermore, they also saw the potential of changes in weather patterns due to climate change as also having an impact on the operational and emissions performance of aircraft owners and operators from the real-time real-life emissions data provided by the platform and were interested in adjusting their risk models accordingly to also take into account such factors when calculating the terms under which to supply finance to their clients. So, through the internal risk models and their participation in the aviation market and existing financial markets of the aircraft financiers, the emissions measurement and forecasting data assembled by the platform became entangled with many other existing markets. Through these entanglements, then, these participants were able to order their choices, rank them, and valued them in order to take action across the various markets they participated in.

At this second stage, beyond the fleet financiers, all potential platform participants that are able to access all the data for all aircraft owners and/or operators available on the platform would be in a position to assess the demand for offsets from when the CORSIA scheme came into operation and then into the future according to many parameters (composition of fleets, flight routes, aircraft loading, weather patterns and so on), but also identify who the deficit and surplus agents in the existing aviation market might be according to different future fleet composition and operational scenarios.

Stage3: The need to trade and the problems in doing so

In the third and final stage of the experiment, the needs for trading of offsets that was surfaced by the establishment of the calculative space in stage 2 prompted the need for developing a trading facility for offsets through which deficit and surplus agents could adjust their emission-related operational and financial risks. The design and development of this part of the platform also revealed many previously obscured issues relating to GHG emissions abatement market mechanisms that included voluntary market offsets and that came to the surface through the research, assembling, and presentation by the development team of the creation and issuance processes for such voluntary emissions offsets. It quickly became apparent, as much from the project team's research as from the interactions generated from the presentation of the material to the potential platform owners and operators as well as to potential market participants that took place over a one-day dedicated workshop and numerous subsequent meetings and presentations, that there were risks of double counting and double spending of offsets from the voluntary market due to the lack of a single central repository where every transfer of ownership would be recorded and offsets 'spent' for compliance purposes cancelled/withdrawn. This was considered by potential market participants as representing a significant reputational as well as financial and operational risk.

In addition, potential market participants were also unsure about the true contribution of offsetting projects to real-world emissions reductions and put-off owning and trading them by the lack of standardised and comparable information about their quality and the rigour of the verification, certification, and potential impairment of offsetting projects on the ground from which individual credits were generated.

These concerns then fed back to the platform design and development, informing the development team's efforts to come up with technical ways of overcoming these limitations in property rights and quality information associated with voluntary market offsets surfaced by the experiment. This then informed the team's decision to develop a trading platform based on a private blockchain through which a work-around the double counting and double spending issues surfaced could be addressed. Using a private blockchain for the trading part of the platform would mean that the anonymised ownership, transfer, and spending of offsets -or a fraction of one – issued on the platform would be visible to all participants through the platform's distributed ledger, preventing any possibility of double ownership and also ensuring that once an offset was 'spent' in order to meet relevant cap limits by its owner, it was then extinguished and could no longer be traded or used for reporting purposes. So, as long as the relevant due diligence was performed on an offset before it was issued, in digital token form, on the trading platform, there could be confidence that it was not double owned, double counted, or double spent. Furthermore, the issuance process was designed in such a way as to require the provision, by the issuer, of the maximum amount of relevant information about the offset and the real-world GHG sequestration projects it was generated from. This was also supplemented by an AI content analysis facility that would rank the quality of the issued offsets according to quality criteria dynamically tracked by the AI algorithm. In this way, the trading price would also reflect the relative quality of the different offsets as well as their headline GHG emissions reduction quantities.

So, one can see in stage 3 a shifting of the issues and debates around the design of the marketplace from economic and technical in stage 2 towards legal, technical ,and scientific in stage 3.

The relevance of the notion of explication in market design experimentation

The notion of explication as proposed by Marres (2012) and Muniesa and Linhardt (2011) relates to attempts to theorise how human and technological agencies shape, or format, each other in situations of sociotechnical assembling. The research presented shows how this concept also provides a useful approach to analysing public experiments associated with market design. In doing so, the research presented not only extends the application of this concept to a different empirical setting, but also helps to further clarify and stabilise our understanding and use of it.

What the empirical case presented shows is that, in order to understand better the sociotechnical shaping that takes place in (and through) such experiments in market design, it is useful to focus on how market design as a public experiment contributes to an iterative process through which the development of increasingly more tangible and detailed models of the market organization proposed are introduced and experimented with and how, from that experimentation, procedures and devices are constructed and implemented that interrogate existing sociotechnical arrangements that they must interact with.

In general, experiments seeks to establish, through a combination of embodied expertise, knowledge, techniques, and imagination, as well as through the development and use of devices, a new account of a reality. New concepts, theorizations, measurements, and understandings are likely to result, as well as devices and apparatuses, whether the experiment is perceived as being successful or not. As seen in the case presented, any resulting novel sociotechnical elements generated from the experiment (e.g. concepts, theories, insights, devices, apparatuses, experimental techniques) have to take their place in the existing and known sociotechnical world inhabited by hybrid agencies (human and non-human). In this sense, an experiment is similar to a technological innovation, with both establishing new sociotechnical entities that need to take their place in the existing world as it is at that point in time. Numerous new sociotechnical entities generated by the experiment have to be fitted together with existing entities in a process of mutual adjustment which may result in a comfortable coexistence or a trial of strength (Latour 1987; Latour 1993) – or trial of explication – through which a new entity may displace an existing one depending on the outcome of such trials. This material interrogation of existing entities is common to both scientific experiments or the development of a prototype in technological innovation. In both cases, these material interrogations result in making more explicit many underlying sociotechnical aspects of both the existing world and the one informing the experiment or prototyping, both of which, prior to that interrogation, had remained out of view (implicit).

Explication builds on the existing descriptions of iterative process of experimentation through which, at the end of each iteration the empirical material collected via the experiments is fed back to a new iteration of the new sociotechnical reality to be established, in this case a new market in the making. Explication as a concept helps us describe how, through this iterative process, previously obscured 'folds' of the techno-institutional market arrangement being assembled become observable and their implications knowable through the trials resulting from materialisations coalescing around even small sociotechnical components of this market. These materialisations, which are not necessarily physical, create the necessity for specific *material* rather than *discursive* responses from the world around them both technological and institutional (Barry 2002). The new sociotechnical entity being introduced to the world and/or its components, start to make explicit their needs from, and consequences for, the technological and institutional world around them, and start to set limits on possible events (Barry 2002). This creates a concrete interrogation of the existing world – both conceptual and material – surrounding the market shaping initiative.

What the case presented shows is that explication is crucial to both the planning and inspiration necessary for both the designers and users of a market under development to formulate their plans, strategies, and positions vis-à-vis the expanded and transformed marketplace arrangements being pursued and to respond to them. Out of the experiments and the explication and trials of explicitness they engender, designers, users, regulators, and the other agencies involved are changed, both cognitively and in terms of their perceptions of themselves and of the role they should/could/would perform in the new configuration of techno-institutional arrangements proposed. It is in this way that a new distribution of roles, actions, and attributes among the human and non-human elements of the newly ensembled market are attempted. As these modified 'roles' gradually become woven into the devices and systems of the new market configuration proposed.

Conclusion

The aviation emissions analysis and trading platform studied is till in the early stages of its development. Prototypes and beta versions are operational and important anchor sponsors and backers in the aviation industry are involved in its on-going development. There is, however, a long way until such a platform can assume the status of an operating aviation industry emissions marketplace.

This journey towards becoming – or not – a viable marketplace will not only depend on the design and functionalities of the platform itself and its ability to satisfy the needs of potential market participants from many different parts of the aviation industry, but also on the development and potential success of other initiatives with a similar motivation.

One such alternative initiative is the Aviation Carbon Exchange (ACE), which aims to provide an exchange for airlines, airports, and other aviation industry participants to buy and sell CORSIA-eligible emissions offsets from emissions abatement projects around the globe, searchable by project region, price, type, standard, and vintage. The initiative is being co-developed by the International Air Transport Association (IATA), which is the trade association for the world's airlines representing some 290 airlines, and Xpansiv, which specialises in the development of ESG-commodities trading solutions (International Air Transport Association 2022). While this initiative focuses more on the trading of the offsetting credits and less on the analytics and management of the emissions themselves, it has some important infrastructural aspects in that it utilises the existing IATA Clearing House and Settlement System which is already used for the easy and risk-free settlement of payments among aviation industry entities (International Air Transport Association 2022). In addition, through the relationship with Xpansiv and its CBL unit, which provides integrated access to the offsetting registries (e.g. VERRA, Gold Standard), ACE is able to offer access to all credits generated by standards-compliant emissions reductions projects on the ground. While the integration of the exchange with these existing financial and compliance infrastructures provides some significant advantages in terms of installed-base and network effects, the costs of participating in them are substantial.

Another potential alternative infrastructure is Air Carbon Exchange (ACX), which combines the traditional commodities exchange model with blockchain-based tokens to securitize emissions credits and enable the trading of these asset-backed tokens (AirCarbon 2022). Again, this potential alternative infrastructure is concerned more with the trading of the emissions credits as a financial asset and is disconnected from the analysis and management of the emissions themselves as well as the offset generation and retirement process associated with the generation and use of the credits.

Finally, the European Energy Exchange, the key trading venue for EU ETS permits, also announced in May 2022 its intention to develop a Voluntary Carbon Market (VCM) to meet the demand from corporates seeking to offset their emissions and which will include CORSIA-eligible Verified Emission Reduction units (European Energy Exchange 2022). While the details of this proposed marketplace are still unclear, it appears that the model is one along the lines of a commodities and derivatives exchange based on contracts. Again, it seems that the approach will be one based more on trading concerns rather than the analysis and management of the emissions resulting from aviation operations.

As these concurrent initiatives unfold and evolve, they will also make the issues, needs, and features of different market designs and the assumptions behind them and the reality they seek to fit into more explicit. Those that manage to answer the issues that this raises and to fit into the reality their design presumes, whether this is in terms of GHG reductions, assembling enough participants and liquidity, or fitting in with existing structures and institutions, will have a better chance of becoming established and a part of a new market reality they have helped bring about. In the process, they will also put in place a particular balance of priorities between political, economic, and scientific issues and parameters within which the resulting market – or markets – for aviation GHG emissions will operate and stabilise. There is no inevitability in that, however. It is just as conceivable that through the kind of explication described in the case presented, flaws in the entire premiss of market-based mechanisms for aviation GHG emissions abatement are surfaced that cannot be overcome. Maybe the reductions needed to avoid climate change need to be much bigger from the aviation industry, calling for much more radical solutions and interventions. Or maybe approaches based on taxation rather than market-based mechanism might be preferred. No matter what the actual result, it is the way of analysing the process of market construction and the explication that is generated in the process that is of interest and that can help demystify processes of marketisation, whether one is supportive or critical of them.

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