Economy and Society

ISSN: 0308-5147 (Print) 1469-5766 (Online) Journal homepage: https://www.tandfonline.com/loi/reso20

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To cite this article: John Chung-En Liu (2017) Pacifying uncooperative carbon: examining the materiality of the carbon market, Economy and Society, 46:3-4, 522-544, DOI: 10.1080/03085147.2017.1408250

To link to this article: https://doi.org/10.1080/03085147.2017.1408250

Published online: 11 Jan 2018.

Economy and Society Volume 46 Numbers 3–4 August–November 2017: 522–544
https://doi.org/10.1080/03085147.2017.1408250

Pacifying uncooperative carbon: examining the materiality of the carbon market

John Chung-En Liu

Abstract

This paper scrutinizes how greenhouse gases are 'pacified' so that they can become tradable in the carbon markets. To advance the economization programme and other materialist frameworks, I argue that the existing literature does not pay enough attention to the diverse modes of carbon accounting and, in particular, carbon measurement – the most basic step – is overlooked and undertheorized. Drawing from the 'critical metrology' approach, I suggest that we need to take carbon's diverse materialities seriously in the study of marketization processes. Some carbons are more cooperative than others. I, therefore, argue that it is important to conceptualize 'pacification' as a dynamic process that is mediated through materials of varying capacities as well as standards and technologies. The empirical case examined here concerns carbon measurement standards at coal-fired power plants – an 'extreme case' in the sense that coal is well-understood and relatively easy to measure. My findings indicate that, even for one of the most 'cooperative' carbons, measurement uncertainties are significant and pose challenges for the marketization of carbon emissions. While human actors work to cope with these uncertainties, the contours of the market are ultimately constrained by carbon's materiality.

Keywords: carbon markets; critical metrology; carbon measurement; materiality; economization; coal-fired power plants.

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Introduction

With the proliferation of carbon markets,[1] social scientists have delved into the contentious politics in constructing, maintaining and reforming such markets (Böhm, 2009; Bulkeley *et al.*, 2016; Meckling, 2011; Newell *et al.*, 2012; Stephen & Lane, 2014). The politics of such markets, however, does not exist only between social actors – the state, business and NGOs – it can also be technical. When building a carbon market, one particular challenge is to mould carbon emissions – colourless, odourless and elusive as they are – into a tradable object. Seemingly mundane and tedious, such work can often be full of contestation in newly structured markets. In general, however, the existing literature has paid much less attention to the materials and technologies involved in carbon market construction than to social institutions.

Contemporary social theories on materialism open the door to examine the potential power of *things* to influence the configuration of economic processes (Bakker & Bridge, 2006; Bennett, 2009; Braun & Whatmore, 2010; Marres & Lezaun, 2011). Within economic sociology, there has also been a growing emphasis on materiality among various theoretical orientations (Çalışkan & Callon, 2009, 2010; Kaup, 2015; Pinch, 2008; Pinch & Swedberg, 2008). This materialist theoretical lens sees that social existences involve not only human actors and their relations, but also objects.

In the study of how 'matter' matters, there has been a vibrant stream in agri-food research that highlights how humans and non-humans interact to create commodities and markets. One classic example is how Bill Cronon (1991) describes grain futures trading in Chicago – futures trading is made possible only through standardization in grain qualities and the storage of grain in steam-powered grain elevators. More recently, there are empirical cases including apples (Legun, 2015), wine (Brice, 2014), meat (Henry, 2017), mushrooms (Tsing, 2015) and many others. Central to these studies is the insight that biological properties, especially the 'animacy' of living organisms, play a role in shaping economic institutions and markets.

Similarly, in response to the rise of market-based environmental governance including emissions trading and payment for ecosystem services, a robust literature examining the commodification processes when 'nature' encounters markets has developed (Bakker, 2005; Castree, 2003; Mansfield, 2004; Prudham, 2007; Robertson, 2012).

The approach used here puts the materiality of carbon at the centre of its analysis. This offers three key insights into the study of carbon markets. Firstly, the existing literature does not pay enough attention to the diverse modes of carbon accounting work. I especially draw from Cooper's (2015) 'critical metrology' approach to highlight the importance of carbon measurement, known as physical carbon accounting. I will demonstrate that, while many other scholars have looked into various commensuration work in carbon markets, carbon measurement – the most basic step – is overlooked and undertheorized.

Secondly, focusing on carbon measurement inevitably invites an investigation into carbon's materiality: how do the diverse physical properties of *carbon* matter in the making of a *carbon* market? To illustrate this, I present a case study on the carbon measurement standards at coal-fired power plants. My findings indicate that, even for one of the most 'cooperative' carbons, measurement uncertainties are significant. Even if carbon may be temporarily 'pacified' in local jurisdictions, mounting uncertainties – the 'overflows' in the Callonian sense – hint at the possibility that pacification might be called into question. I, therefore, suggest that we need to take carbon's diverse materialities seriously in the study of marketization processes. Some carbons are more cooperative than others and thus more conducive to market-based governance. This has significant implications for the future development of carbon markets.

The final insight concerns my empirical case. This paper is the first social scientific case study on coal-fired power plants. Measuring coal-based emissions is an 'extreme case' in many ways – coal is well-understood and relatively easy to measure; it is the most 'cooperative', and also the most prevalent emission source. This research can serve as an important benchmark case for thinking about the broader carbon marketization processes. From a practical aspect, the measurement standards in coal-fired power plants are rarely discussed even in the carbon policy world, and many practitioners do not realize that significant uncertainties exist in this area. This paper directs attention to the technical challenges of 'pacifying' carbon with the aim of laying the groundwork for further research in this area.

The following section describes how carbon markets depend on various carbon accounting practices to 'pacify' carbon into becoming a tradable object and reviews the current debate on how the materialities of different carbons play a role in the marketization process. I then describe my method and data. The empirical section looks into the two methods for measuring carbon in coal-fired plants. I detail how human actors try to cope with mounting uncertainties and how the contours of the market are ultimately constrained by carbon's materiality. This paper suggests that only by taking carbon seriously in its biophysical form, as well as the calculative devices, can we genuinely understand the marketization of greenhouse gases (GHG) and address problems in market design. I conclude by discussing how my project helps elucidate the promises and constraints of the carbon market and, broadly, other market-based approaches to environmental governance.

Pacifying carbon and critical metrology

Obviously, carbon is not emitted with a price tag already attached. To trade carbon, carbon as a physical entity has to 'sit still' as a commodity that is exchanged within such markets. To understand this process, I draw from Callon and his colleagues to view market exchanges as a never-ending process of 'framing' – choosing what to calculate and what to ignore (Çalışkan &

Callon, 2009, 2010; Callon, 1999). In their two-part agenda-setting papers, Çalışkan and Callon (2009, 2010) highlight 'pacifying goods' as one of the five types of basic 'framings' in the marketization process. For this approach, a scientific fact emerges only when scientists successfully pacify natural objects, reducing them from 'wild' unknowns to things with fixed qualities. The pacified status of things is the prerequisite for actors to 'form expectations, make plans, stabilize their preferences and undertake calculations' to initiate organized market exchanges (Çalışkan & Callon, 2010, p. 5).

In the case of carbon, Callon (2009) regards the carbon market as an ongoing experiment. The 'framing' of the carbon market is best understood as an incomplete, contested and rapidly changing process. He particularly underscores the pacification of carbon through commensuration, arguing that 'calculative equipment, whether it serves to establish equivalences between chemical entities … , or simply to measure emissions, is also the subject of stormy debates and lies at the heart of the structuring of carbon markets' (Callon, 2009, pp. 540–541). Echoing this point, MacKenzie (2009), in the same special issue of *Accounting, Organizations and Society*, calls for a research agenda to examine the 'politics of market design'. In his exemplary paper, MacKenzie demonstrates that 'making different gases the same' through the factor of global warming potential (GWP), and constructing a standard accounting treatment for 'emission rights', are both important steps in building carbon markets. He argues that the politics lie not only in the 'overall features of carbon markets, but the crucial "nuts and bolts" of their construction, [including] questions such as how different carbon sources and sinks are commensurated' (MacKenzie, 2009, p. 454).

It is worth noting that commensuration – more broadly speaking, calculation, classification, standardization and quantification – has long been a subject for sociological inquiries. Sociologists have demonstrated quite extensively that these processes are closely connected with other aspects of social organization – including laws, politics, culture and environmental knowledge (Busch, 2011; Espeland & Stevens, 1998, 2008; Fourcade, 2011; Timmermans & Epstein, 2010). These processes are particularly relevant to the 'sociology of valuation and evaluation' – a research agenda that has received growing attention in recent years (Lamont, 2012).

Regarding the carbon market, I use the term 'carbon accounting' to refer to a wide range of practices that includes efforts to classify, measure, commensurate, monitor, report, verify and communicate carbon emissions – all of which contribute to 'pacify' carbon into a stable commodity. There has been a proliferation of literature on carbon accounting work in the construction of the carbon market (Bumpus, 2011; Cooper, 2015; Friedberg, 2013, 2014; Gupta *et al.*, 2012; Gutiérrez, 2011; Lansing, 2011, 2012; Lohmann, 2011; Lövbrand & Stripple, 2011; MacKenzie, 2009; Nel, 2017; Ormond & Goodman, 2015), and many authors have demonstrated that carbon accounting is an uncertain and heavily contested process.

I argue, however, that the current literature does not adequately differentiate the multiple modes of carbon accounting. Carbon accounting, as I demonstrate below, should be conceptualized as a multi-stage and heterogeneous process. Imagine carbon emissions from a coal-fired power plant: carbon accounting can be the metrological equipment that companies are required to install; it can refer to measuring the CO_2 concentration in the flue gas; it can be the rules regarding third-party verification of emission data; it can be about commensurating CO_2 with other types of greenhouse gases; it can be about how the factory owner records the numbers in the company's annual report to the Carbon Disclosure Project; it can also be about how accountants classify emission allowances on their balance sheets. A wide range of actors, including scientists, engineers, regulators, environmental consultants, accountants and many others, as well as the necessary technical equipment, and finally, of course, the carbon molecules themselves have to participate in this sophisticated process.

To support my argument, I find it particularly useful to draw from Ascui and Lovell (2011), in which the two authors distinguished the general term 'carbon accounting' into five different areas: (i) physical (e.g. measurement in the biophysical environment); (ii) political (e.g. drawing boundaries for monitoring); (iii) market-enabling (e.g. calculation for offset projects); (iv) financial (e.g. accounting treatment of emission rights); and (v) social/environmental carbon accounting (e.g. carbon disclosure and footprinting). Based on Ascui and Lovell's paper, these modes are a series of connected and interacting steps:

> three of these [carbon accounting] – physical, political and market-enabling carbon accounting – are closely related to one another, developing in sequence and each relying on the earlier frame. The fourth, financial carbon accounting, also follows in roughly temporal sequence as a consequence of market-enabling carbon accounting, but has very different origins and objectives, and is largely blind to the earlier frames. By contrast, the fifth frame of social/environmental carbon accounting has a longer pedigree which runs alongside the other frames, sometimes interacting, but with its own specific origins and objectives. (Ascui & Lovell, 2011, pp. 982–983)

The distinction of these carbon accounting modes is crucial for two reasons. *Firstly*, some carbon accounting modes depend on one another, while other modes are more independent. Attending to the diverse practices allows us to appreciate the full picture of carbon marketization. In particular, physical carbon accounting serves as the fundamental principle of this market. The sole objective of the carbon market is to reduce carbon emissions. If carbon molecules do not participate – i.e. they are not adequately measured up – the whole purpose of pricing emissions is lost.

When reviewing the existing literature with these various carbon accounting modes in mind, I realized physical carbon accounting is rather overlooked. The majority of research in this area has focused on the 'downstream' aspects. For example, Freidberg (2013, 2014) looks into the carbon calculations in lifecycle assessment (LCA) in supply chains, and, somewhat similarly, Ormond and Goodman (2015) examine the carbon footprint of a pint of milk – both cases fall into the 'social/environmental carbon accounting' category, rather than tracing how measurement works. Lövbrand and Stripple (2011) focus on the different levels – national, project and personal – of accounting, not on materials. In addition, a steady stream of scholarship critically examines carbon accounting in offsets projects, in forestry (Gupta *et al.*, 2012; Gutiérrez, 2011; Lansing, 2011, 2012; Nel, 2017), in hydropower and cookstoves (Bumpus 2011) and from a more theoretical perspective (Lohmann, 2011). While this research agenda has provided some useful insights, carbon offset is an ancillary component, not the fundamental bedrock, of carbon markets. Among this literature, only MacKenzie (2009), in his discussion of global warming potential (GWP), touches upon physical carbon accounting in my aforementioned categorization. Much work still needs to be done.

On this note, this paper follows Cooper's (2015) recent call to adopt a 'critical metrology' approach, which draws attention to the 'social, political, and scientific condition under which measurement and commensuration occur as well as the consequences and effects of these processes' (Cooper, 2015, p. 1787). He contends that we should see measurement practices as inherently political due to their inevitable distributional effects. I will demonstrate how, as has been shown in other cases (Bailey & Maresh, 2009; Bridge, 2011; Kama, 2014), these metrological regimes are territorialized.

Secondly, it is important to differentiate modes of carbon accounting because they have various degrees of interaction with carbons. For physical carbon accounting, the biophysical qualities loom large; for financial carbon accounting, carbon's properties are tangentially relevant at best. Because the existing research focuses on 'downstream' carbon accounting, carbon's materiality has not been fully recognized in the marketization process.

Materiality is critical in how the market is constructed and functions. Scholars across different disciplines have documented how 'nature' and materials shape market rules. In the introduction, I have listed a group of agri-food scholars showing the importance of the generative power of biology. Materiality does not only matter in animate 'nature', but in inanimate 'things', too. For instance, geographer Karen Bakker (2005) coined the term 'uncooperative commodity' to describe water in her research on the privatization of water in England and Wales. She argues that water, due to its biophysical, spatial and sociocultural characteristics, is particularly resistant to commodification. Sociologist Kaup (2008) has shown that the materiality of natural gas shapes the structure of Bolivia's gas industry, both enabling and constraining the opportunities to accumulate. Economists Fisher-Vanden and Olmstead (2013) noted that 'non-uniform mixing of pollutants' and 'difficulties in measuring and monitoring nonpoint sources' limit the scope of water quality trading to significantly less than the theoretical ideal.

The above examples demonstrate that materials can bring a 'resistant materiality' to commodification. Such statements, however, are contentious. For example, Lansing (2012), through his study of a carbon offset project in

Costa Rica, notes that the performance of the market sometimes fails ' … not from the material qualities of the forest but, rather, through the self-reflexive stance of the actors charged with bringing this object into being as an object of exchange' (Lansing, 2012, p. 208). On the other hand, others have asserted that material qualities and technologies play crucial roles in shaping carbon's commodification. According to Bumpus (2011), some carbons allow a more cooperative commodification than others – all the carbon offset projects can be viewed on a spectrum of 'more' or 'less' uncooperative carbon. For example, in Bumpus's study, carbon from a hydroelectricity project is more cooperative than carbon from cookstove projects.

On this point, I follow Bakker and Bridge's (2006, p. 21) argument to address 'the analytical significance of concrete differences in the material world and the way these enable and constrain the social relations necessary for resource production'. In other words, I suggest we go beyond the cooperative versus uncooperative debate; instead, we can recast our question as 'how cooperative' the material is, and how materiality affects processes of marketization.

This theoretical discussion also challenges the economization research programme to engage more seriously with the materiality of nature literature. Although attending to the role of 'things', neither Callon nor MacKenzie directly addresses how the biophysical qualities of carbon might shape market rules. I argue that it is important to conceptualize 'pacification' as a dynamic process, as materials have varying capacities, mediated through our standards and technologies, to enrol in a market *agencement*.

For example, all carbon dioxide molecules are identical in their chemical structure; however, not all *carbon emissions* are created equal. The biophysical properties of carbon emissions vary significantly across sources. Emissions can come from 'point sources', such as smokestacks in energy and industrial sectors; they can also come from 'non-point sources', such as agriculture, mining and land use change, which spread across large geographic regions. The former is generally easier to measure and more regulated than the latter. Another example concerns natural gas versus coal – the two most common forms of fossil fuel. Coal appears as mixtures, relying on various 'grades' to determine its energy content; natural gas is much more homogeneous, mostly consists of methane and once it enters the pipeline it is standardized and always consistent within a tight range. These physical properties shape our interactions with these fuels, as well as our abilities to regulate them.

In sum, this paper brings carbon's materiality to the centre of the analysis of carbon markets. According to Bakker and Bridge (2006, p. 21), 'matter matters because it is through grounded research that we encounter differences that make a difference'. Materiality analysis requires careful empirical work. As Lovell (2014) suggests, focusing on standards offers a clear empirical avenue to shed light on complex market assemblage. I, therefore, turn to scrutinize the carbon measurement standards in coal-fired power plants. Carbon metrological equipment – the volumetric scales and the continuous emission monitoring system (CEMS) – are market devices critical to the construction of carbon markets. I highlight that the pacification processes are full of uncertainties and can become sites for political contestations. Furthermore, the difficulties in taming 'wild carbon' may further limit the development of carbon markets.

Research design and method

This paper is based on my global fieldwork during 2012 and 2013. The empirical data consist of 70 interviews conducted with people in the world of carbon markets, including regulators, policy-makers, carbon traders and brokers, scientists and activists. For the purpose of this paper, my interviews at the European Commission's Directorate General of Climate Action, the United Kingdom's National Physical Laboratory (NPL) and the National Institute of Standards and Technology (NIST) in the United States are especially valuable. I also draw insights from my participant observation at key events, such as the United Nations climate conferences, the Carbon Expo and public hearings held by governments.

I purposefully chose to investigate the carbon measurement practices in coal-fired power plants for a few reasons. Firstly, power generation is of unparalleled importance in addressing climate change. According to the estimation of the Intergovernmental Panel on Climate Change (IPCC), 26 per cent of global greenhouse gas emissions are from energy supply – more than from industry (19 per cent), forestry (17 per cent), agriculture (14 per cent) and transport (13 per cent). The ratio of power generation emissions is even higher in the European Union[2] (32 per cent), the United States[3] (32 per cent) and China (47 per cent). Secondly, power plants, as 'point source' emissions, can be measured with greater accuracy – and are, hence, more 'cooperative' – compared to 'non-point sources', such as agriculture, landfill and land use change. Finally, coal-fired power plants are one of the best-understood emission sources – with the existence of rather comprehensive knowledge of the operation of coal-fired power plants.

More specifically, this study compares the measurement of coal-fired power plant emissions in the United States and the European Union. To examine the technical standards, I review the EU emission trading system's (ETS's) Monitoring and Reporting Guidelines, the Greenhouse Gases Reporting Rules of the US Environmental Protection Agency (EPA), as well as a variety of regulations, technical documents and scientific reports on this subject.

In other words, this study could be understood as an 'extreme case' that examines the most understood emission sources from the countries/regions with the most advanced technological capacities. Carbon emissions from coal-fired power plants should be a more 'cooperative' form of carbon than other sources, yet uncertainties still prevail. As coal-fired power plants present one of the best scenarios for measuring carbon, we can obtain a meaningful reference point to think about the scale of this phenomenon regarding other emission sources.

I now turn to the case study of coal-fired power plants. The following section describes how people use various formulas and tools to pacify carbon and the difficulties in doing so. These technicalities are key to market design and, thus, the performance of the carbon markets.

Pacifying carbon in coal-fired power plants

Using coal to generate electricity is a straightforward process. Coal is primarily composed of carbon. When burning, coal releases heat that is converted to mechanical energy to operate an electricity generator. In combustion, carbon molecules in coal are oxidized to become carbon dioxide, which is subsequently discharged as flue gas into the atmosphere. To measure carbon emissions, one can use either (i) the calculation method or (ii) the direct measurement method (CEMS). In the following paragraphs, I will briefly introduce both methods and the uncertainties in carbon measurement.

The calculation method

The 'calculation method' infers carbon emissions from the material input. The amount of carbon emitted must be equal to the amount combusted – the law of conservation of mass. The method can be expressed by the following formula.

$$\text{Calculated emission} = \text{activitydata} * \text{emission factor} * (\text{oxidation factor})$$

The 'activity data' is the amount of fuel or material consumed by the combustion process. To obtain activity data, coal-fired power plants usually use a conveyor belt weighing system that constantly records the material inputs that feed into the plant.

To convert the input into CO_2 emissions, the activity data is then multiplied by an 'emission factor', which denotes the carbon content in coal. The emission factor varies by coal type. For example, anthracite coal, with an emission factor of 2,602 (kg CO_2/short ton) is the most carbon-dense coal, while lignite 1,389 (kg CO_2/short ton) has the least carbon per unit of coal.[4] Finally, the oxidation factor describes whether combustion is complete. For complete combustion, the oxidation factor equals one; for incomplete combustion, it is a fraction.

The direct measurement method (CEMS)

Carbon emissions can also be derived from the direct measurement method, which is commonly known as the continuous emission monitoring system (CEMS).[5] In contrast to the calculation method, which is an 'input' method, direct measurement is an 'output' method. CEMS directly gauges the CO_2

concentration in smokestacks and multiplies the total gas volume leaving the stack. The formula is as follows:

$$\text{Measured Emissions} = \text{Hourly average } CO_2\text{concentration} \\ *\text{Hourly average volumetric flow rate}*\text{Operation time}$$

The CEMS has probes, sample lines and vacuum pumps that continuously withdraw samples of the effluent gas from the stack, and the samples are subsequently sent to a diluent analyser. The diluent analyser yields readings of the CO_2 concentration via various chemical techniques. To measure the gas flow rate, the CEMS also includes a volumetric flowmeter.

According to EPA regulations, the system should sample, analyse and record data at least every 15 minutes. All emissions and flow data are reduced to hourly averages for further calculation. Finally, CEMS contains a data acquisition and handling system (DAHS) for data storage and calculations, which is linked with the EPA's Emissions & Generation Resource Integrated Database (eGRID).

Carbon can be uncooperative

Intuitively, we would want to know how the two methods compare with each other. In theory, coal goes in as fuel and goes out as carbon emissions – input should equal to output. The two methods should yield identical numbers for any given facility. In reality, it is surprisingly difficult to verify these carbon emission numbers.

'We simply have no way to compare!', an EU ETS official said frankly during my interview. He laments that there is little research that compares different carbon measurement methodologies; thus, emission numbers cannot be cross-checked using a reference method.

For a long time, the only existing data source that illuminates emission data uncertainties in coal-burning power plants comes from the unique reporting rules in the United States: all coal-burning power plants report to both the Environmental Protection Agency (EPA) and the Energy Information Administration (EIA) at the same time. For the EPA, companies have to use CEMS to report their carbon emissions; for the EIA, they need to report a different set of energy statistics, as mandated by the Energy Policy Act of 1992. Academics can thus calculate carbon emissions from the EIA's fuel consumption data sets. Putting the two data sets side by side, we can then obtain two emission numbers for the same facility.

Using this comparison, a few research teams have looked at the differences between the calculation method and CEMS. Based on the 2004 version of the two data sets, scientists found that, despite numerical similarities when aggregating data across plants, the emissions varied widely at individual plants. The average difference was around 17 per cent between the numbers derived from the two methods (Ackerman & Sundquist, 2008). Other scientists also applied this method to data sets from different years and aggregate levels, and all arrived at similar conclusions (Huang & Gurney, 2011; Quick, 2010, 2014). In other case studies, the two numbers differed by as much as 50 per cent (Borthwick *et al.*, 2011) or 70 per cent (Evans *et al.*, 2009).

Outside of the United States, a group of South Korean scientists compared the two methods in a coal-based heat production plant (Lee *et al.*, 2014). The results show that CO_2 emissions are 12–19 per cent less using the calculation method than CEMS, while N_2O and CH_4 – two stronger greenhouse gases – have larger margins of difference at two orders of magnitude and 60 per cent, respectively. The generalizability is limited, as their experiment only examines one plant. Nevertheless, it shows the scale of the uncertainties.

Based on current research, it is exceedingly difficult, if not impossible, to adjudicate the accuracy of the two methods.[6] Each method has its own weaknesses. Biases might result from the calculation method due to the inadequate calibration and poor quality assurance of the belt scales that continuously take the weight of coal inputs. In addition, the default emission factors may also lead to errors, as significant content variations exist within coal rank classes (Liu *et al.*, 2015). The accuracy of the direct measurement method, which depends on flow rate measurement, is called into question when non-uniform flows exist in the stack (Dimopoulos, 2015).

Scientists are aware of the challenges in measuring carbon emissions. In the Greenhouse Gas Quantification Workshop hosted by the National Institute of Standards and Technology (NIST) in 2010, participants recognized that there is no good comparison of direct measurements (CEMS) and indirect calculation based on fuel value for combustion emissions. The workshop's final report concluded that:

> The accuracy and resolution of instruments used to measure GHG gases and offsets are currently inadequate to support future climate efforts. (National Institute of Standards and Technology, 2011, p. 8)
>
> A comparison of these [calculation and CEMS] estimation method application areas is currently lacking for combustion emissions, which comprise the largest portion of GHG emissions from the industrial sector. (National Institute of Standards and Technology, 2011, pp. 12–13)

During my fieldwork, I spoke to scientists in a national laboratory. When I brought up the measurement gap between the two methods, one of my respondents greeted me with nods and smiles, saying that: 'so, you know the *problem*'. His colleague, also a metrological expert, attested to the difficulties involved in the measurement carbon, saying:

> For coal-fired power plants, the property of coal varies, they are not homogeneous, and the carbon value is constantly changing. Furnace temperature varies. You have to do some really smart averaging to get the numbers. It is not a trivial thing to do! It is a good job if the uncertainty is within 20 per cent! (Interviewee #47)

To summarize, for coal-fired power plants, we cannot even tell the best method to obtain the data, and the uncertainties are significant enough to potentially endanger market formation. Putting this into perspective, coal is a 'reference case' – the most understood and arguably the most 'cooperative' carbon. If we have trouble measuring coal combustion, we would expect the problem to amplify by many orders of magnitude for other emission sources. The carbon market architects require much difficult work to pacify the seemingly 'uncooperative' carbons to make markets work. On this note, I now turn to how actors cope with the measurement uncertainties in order to pacify carbon.

Coping with uncertainties

Knowing carbon's potential uncooperativeness, a critical question involves how carbon regulators and marketers have managed to contain such uncertainties to build markets. Within Çalışkan and Callon's economization programme actors contain 'overflows' which stabilize particular framings. To answer this question, I found a number of factors that shape carbon measurement in practice, including: (i) economics of carbon measurement; (ii) regulatory path dependency; and (iii) depoliticization.

Firstly, the economics of carbon measurement is a major concern for both regulators and the regulated. In terms of cost, the calculation method remains the cheaper option. As most companies already need to report their fuel statistics, the calculation method does not require new infrastructure and can readily be implemented. CEMS, meanwhile, involves substantial capital investment. According to the US EPA's calculation, it costs more than a quarter of a million dollars to install a new CEMS and operate it for one year;[7] in the European Union, it is estimated that purchase and installation will cost 30,000 to 90,000 euros (Dimopoulos, 2015). Both estimates represent a significant cost for smaller operators.

The economics of carbon measurement matters especially in newly established carbon markets in the developing world. When I visited one of China's new 'environmental exchanges' that runs a pilot carbon market, I asked its carbon accounting expert, 'L', why the exchange chose the calculation method over direct measurement. She responded:[8]

> L: At this stage, there is no way to know whether calculation or direct measurement is the better approach for quantifying carbon emissions … We have also consulted some EU experts but received no definite answer … currently, we follow the calculation approach as it does not entail extra costs.

Even if one considers that CEMS may provide better data, the trade-off between accuracy and financial cost is still a major concern. L also asked me, 'how accurate is enough?' – a question that preoccupied many practitioners in this field.

Secondly, carbon accounting practices often follow existing social institutions. As nation-states remain the central actors in addressing climate change, carbon is often 'pacified' within national boundaries by specific standards, rules and cultures. This is not a new point. Geographers have identified that similar 'territorial logic' often influences design in climate governance (Bailey & Maresh, 2009; Bridge, 2011; Kama, 2014). In the case I examined, there is a cross-Atlantic divide in the choice of calculation or direct measurement methods. During my interviews with regulators on both sides of the Atlantic, regulators often spoke rather defensively about the methods they chose to apply.

In the EU ETS, the world's largest carbon market, most operators derive their emission data from the calculation method. In the EU ETS's Monitoring and Reporting Guidelines (MRG), which regulated how carbon should be accounted before 2012, the calculation method was the preferred approach. Operators shoulder the burden to prove that the data from direct measurement are at least as accurate as the calculation approach. Since 2012, the new Monitoring and Reporting Regulation (MRR) has given an equal footing to the measurement method as to the calculation method. In practice, though, very few companies choose to apply the direct measurement method under EU ETS.[9]

The European Union's adoption of the calculation method is expected. The calculation method is the default approach in the world of carbon measurement. The Intergovernmental Panel on Climate Change (IPCC) suggests countries apply this method to prepare for their national emission inventories. One of my interviewees, an IPCC carbon measurement expert, had never even heard of the direct measurement method for CO_2, having used only the calculation method. 'Why would anyone do otherwise?', he asked me incredulously during the interview.

On the other hand, most US-based coal-fired power plants report their emissions through direct measurement. In 2009, the EPA issued the Mandatory Greenhouse Gases Reporting Rule (40 CFR Part 98), with the expectation that the data would serve as the basis for subsequent nationwide climate action. The reporting rule mandates that all solid-fuel fire units, i.e. coal or biomass, are required to adopt CEMS. This rule also creates a 'tier' system that dictates the data requirement: the bigger the facility, the higher the tier, the more accuracy required on the emission numbers. More importantly, the tier system also prescribes the measurement methodology. For lower tiers (1, 2 and 3), facilities can use calculation methods; for tier 4, the highest tier, there is a mandate to use the continuous emission monitoring system (CEMS). As a result, CEMS has been adopted in about 30 per cent of the stationary fuel combustion sources, approximately 80 per cent of the total emissions in this category.

The United States and the European Union follow territorialized regulatory logics and path dependency to measure carbon. The United States' adoption of the CEMS followed in the footsteps of the US EPA's acid rain programme, where the CEMS was mandated to monitor SO_2 emissions. Most US-based power plants, then, already had CEMS in place when the Reporting Rule was implemented. They only needed to install an extra CO_2 sensor in the existing system. As the acid rain programme has generally been considered a success, CEMS, the EPA's brainchild, also became highly regarded in the administration. On the EPA's website, the CEMS data are described as 'the gold standard to back up the paper currency of emissions allowances', and the requirement will 'instill confidence in the market-based approach by verifying the existence and value of the traded allowance'.[10]

Europeans, however, do not share similar confidence in CEMS. During an interview, a European carbon expert 'P' complained to me:

> P: Those Americans do not want to hear anything other than their CEMS … it is invented by the EPA, so they have a lot of pride in it.

Additionally, the distinct culture of 'verification' might be another factor that shapes the carbon measurement practices on both sides of the Atlantic. In the EU ETS, all emissions data have to be verified by an accredited third-party verifier.[11] In the US EPA, the CEMS data are directly transmitted to the EPA's Emissions & Generation Resource Integrated Database (eGRID), which automatically detects data anomalies. For CEMS, no third-party verification is required. While it is beyond the scope of this paper to trace the development of carbon measurement standards in greater detail, it is possible that the regulatory cultures may lead to a distinct political economy that dictates how carbon gets measured. In my discussion with one industrial representative, 'D', based in Washington DC, about emission data verification, he took issue with the concept of equating verification with transparency, saying:

> D: CEMS is considered the gold standard. With the strict data quality, asking for third-party verification does not really make sense. Although they said, you are [a] million dollar industry, you should be able to afford it, but \$5,000–\$10,000 annually is still money … they [the third-party verifiers] sometimes become a strong interest in how you design the monitoring and reporting system.
>
> Author: How do you make sure [of] the quality of CEMS data then?
>
> D: The data is of the highest quality. It is protected by both civil and criminal law. Do you know that falsification of emission data is a felony? A few years ago, one inspector was charged because he messed up with the data …

Thirdly, to resolve issues of data uncertainty, another coping strategy is to 'depoliticize' the problem and simply confine the discussion to the scientific community. Beyond the scientific endeavour to improve measurement practices, it is often in no one's interest to touch upon the 'uncooperative' character of carbon. During an interview, a former EU official and technical expert expressed to me his frustration that no one seemed to care about this data problem. He said:

> The discrepancy between input method (calculation) and output method (direct measurement) can be as large as 30 per cent! But people do not want to talk about this. EU ETS folks fear that it might damage the credibility of their system … companies have no incentive to deal with this, as long as they are able to comply … I really hope someone can highlight this issue. (Interviewee #19)

Another scientist communicated his frustration regarding his interactions with the policy community. He noted that policy-makers would call on scientists when they needed them, but that the policy world had a very shallow understanding of the scientific matters. While I only touched upon the surface of complicated technopolitics of carbon measurement, my fieldwork has given me the sense that regulators, scientists and consultants all work according to their specific logic and understanding of carbon accounting. The discussion of carbon measurement typically occurs within the scientific community alone and does not often plug back into the policy arena. On the other hand, it is worth noting that my case is relatively 'cool' in Callon's term, compared to the politicized process – the 'hot' condition – described by Ormond and Goodman (2015). This is because measurement infrastructure in coal-fired power plants has been established for a long time, while cases such as theirs only recently emerged with the new carbon economy. That said, with the significant uncertainties and growing attention in this area, its 'cool' status can easily be contested.

Carbon's materiality shapes market rules

As I have argued, carbon is a participant in the market-making process, and its materiality often shapes rules or creates ruptures in existing systems. Carbon's 'cooperation' should not be taken for granted. As the carbon market continues to flourish in different parts of the world, there is no better time for us to take a step back and acknowledge that there are significant unknowns in the making of this market.

Some carbon market professionals recognize that the carbon market is built upon a very shaky material foundation. During one interview, the managing director, 'S', of a leading carbon consulting company said to me:

> S: The carbon market has enjoyed a good run like the railroad boom. The early market pioneers have succeeded in many ways, but they did not have too much concern on the accounting standards … the market is very often based on imperfect sciences, and the foundation is quite fragile.

Although his company claimed to provide 'high quality carbon offsets' on its website, as we discussed the measurement challenges in the forestry sector (REDD+), he said, frankly, that: 'I just don't know how you measure!'

He went on to describe how data uncertainties are central to international negotiations. To explain the collapse in Copenhagen, he said:

> S: The US has the right concern that nobody has the correct data. It is fascinating to follow the REDD+ discussion that people are just not confident about the numbers. Before the Copenhagen meeting, if everything is measured up, I really think that they [the United States] would come in. When everyone was saying that equity was the issue on the table, the carbon measurement was often overlooked.

My interviewee's point is corroborated by NIST's scientific report on GHG quantification:

> A lack of accurate and appropriate measurement and quantification technologies for agriculture, forestry, and land use change was identified as a significant measurement challenge. Some key issues were accounting for impermanence, inconsistency of measurement technologies and models, and lack of data on carbon stored by species, age, geography, and other criteria. These issues hamper the integrity and public acceptance of GHG markets that trade carbon offsets. (National Institute of Standards and Technology, 2010, p. 48)

This insight reaffirms this paper's key argument: carbon measurement – the most fundamental step in carbon commensuration – is often overlooked. This focus does not downplay the importance of the political challenges and social inequalities that dominate the conversation in climate negotiation. Those concerns are indeed real and significant. Nonetheless, we can only fully understand the problem of economizing carbon by considering its material dimensions. I will now give a few practical examples of how carbon's materiality is a factor in shaping the market.

First, let us consider the case of 'linking' different carbon markets – an important policy agenda for carbon market pioneers. In the 'linking' discussion, a key issue is to ensure every ton of carbon is commensurable in different markets. In a discussion on linking carbon markets during UNFCCC's COP19 in Warsaw, where I was an observer in the room, a speaker from a large European utility company stressed the significance of carbon accounting:

> A ton needs to be a ton. It is achievable, and there are different levels of uncertainties in EU ETS. Uncertainties translate into money, so accounting is key … linking also requires comparable compliance practices, including how credible, how thorough, and the level of penalty.

In practice, there are few reasons to be optimistic about future market links. As I have shown, carbon measurement practices are territorialized within national borders. In a way, carbon credits resemble different currencies, and linking two carbon markets is akin to establishing a currency union. Carbon credits are ultimately 'political commodities' that denote who bears the moral responsibilities required to address climate change. How to define the scope of such responsibility is a perennially contentious topic in climate negotiation.

The politics is not only about who should pay for mitigation, however. The politics is also about how different countries account for their carbon emissions, as also reflected in the discussion on ‘transparency and accountability’ at the Paris climate summit. Linking carbon markets becomes particularly difficult between the global North and the global South, as countries have vastly unequal capacities and resources to measure their carbon emissions. First, national sovereignty is an important concern. Many developing countries are wary of developed countries trying to audit their emission data and then interfere in their governance. More importantly, the data reliability in many countries is just not conducive to market exchanges. For example, in the UNFCCC process, countries need to provide emission inventories as the basis for international negotiations. A recent paper notes that China’s emission numbers have at least 20 per cent uncertainty, as a research team found a 20 per cent difference in China’s national data and its aggregated provincial data (Guan *et al.*, 2012); other research shows that China’s official fossil fuel emissions number is overestimated by 14 per cent based on a set of corrected emission factors (Liu *et al.*, 2015). In the case of Indonesia, research shows that the country can have either a net increase or a net decrease in emission intensity trends depending on the data sources used (Macknick, 2011). In the context of the mounting data uncertainties, carbon’s materiality is likely to impose an extra barrier to linking carbon markets.

Besides ‘linking’, carbon’s materiality also explains why some carbons are included in the market, while others are not. In point sources, emissions come from input–output processes through pipelines and smokestacks. Measurement is relatively easy. In contrast, for non-point sources, such as transportation and landfills, or biogenic emissions like agriculture, land use change and forestry, carbon measurement can be extremely challenging, as noted in the NIST report. Pacifying carbon is likely to be nearly impossible in some instances. A quick survey of carbon markets around the world reveals that most schemes include power and industrial sectors (point sources), while other sectors, like agriculture and forestry, are only included in rare cases.

Coal combustion can be seen as a reference case for emissions measurement; uncertainties of even greater magnitudes exist for other carbon emission sources. Methane, a greenhouse gas 28 times more potent than CO_2,[12] can be more uncooperative. Through a comparison of top-down versus bottom-up measurement, a recent *Proceedings of the National Academy of Sciences* paper finds that the ‘government estimates for total US methane emissions may be biased by 50 per cent, and estimates of individual source sectors are even more uncertain’ (Miller *et al.*, 2013, p. 20018). Another recent study in Pennsylvania has shown that methane leakage during fracking processes range from 2.8 per cent to 17.3 per cent. With the potency of methane, this is a much more serious situation than the case of coal-fired power plants (Caulton *et al.*, 2014). Researchers have coined a very illustrative term – ‘fugitive gas’ – for such leaks, which are, as a result, extremely difficult to include in market-based regulations.

Conclusion

To build a carbon market, carbon needs to show desirable qualities as a stable object for trading – it must be pacified. While many scholars point to commensuration as an important process in constructing markets, few pay serious attention to the material dimensions of carbon and carbon accounting. In this paper, I argue that we need to carefully differentiate various modes of carbon accounting, as it is a diverse, multi-stage and interdependent process. Regarding these modes, I highlight that physical carbon accounting, or carbon measurement, is a fundamental step, yet often overlooked in the literature. Carbon measurement is the focal process through which human actors interact with carbon's materiality. Measurement is never easy. I have shown that two carbon measurement methods, calculation and direct measurement, do not attest to the findings of the other in the case of coal-fired power plants – arguably one of the most 'cooperative' cases of carbon emissions. This necessarily means that our ability to measure, and thus pacify, carbon is quite constrained.

To be sure, materiality is never the only factor in pacification. A critical metrology approach reminds us that interests are always involved and regulations often follow territorial borders. To this point, countries have to establish regulatory agencies, define default values and develop calculative devices and accounting standards to render carbon emissions intelligible to the desires of market actors. One of my informants even told me that 'we don't need the best standard; we only need one that everybody can agree upon'. According to this view, measurement uncertainties can be 'papered over' with a common standard and thus resolved socially (Newell & Vos, 2011).

Materiality, however, shapes the conditions within which agreement on standards occurs. As Bakker and Bridge (2006) argue, materiality has analytical significance in enabling or constraining our social relations. In the case of carbon, the greater the uncertainty, the greater the likelihood that the social process of pacification will be unsuccessful. Some types of carbon, such as fugitive gases, may refuse to work with marketization as intended by social actors. This paper suggests that we should conceptualize 'pacification' as dynamic processes and focus on how 'cooperative' the material is. On the other hand, the carbon market does not exist for the sake of being a market. It is a means to the end of reducing greenhouse gas emissions. If we do not have robust standards to ensure emission reductions are real, the very goal of carbon market construction will be moot. In other words, if carbons do not participate in the market *agencement* – i.e. they are not calculated properly – the whole market is in vain and will be endangered.

With these insights, I want to challenge the dominant market narrative that takes carbon's pacified status for granted. For carbon market supporters, it is often a question of whether policy-makers have the will to take action; for critics, carbon markets are often seen as a sweeping neoliberal agenda with little contestation. Both perspectives treat carbon emissions as if they were ready for sale. Such optimism is unwarranted. This blind spot hinders us in analysing the real dynamics in the market-making process and their consequences. We, therefore, should adopt the critical metrology approach to examine how carbon emissions are measured and the contestations that arise during these processes.

This paper does not seek to discredit the carbon market as a part of our policy portfolio to reduce greenhouse gas emissions. My goal, rather, is to find the proper place for it. First, scholars and practitioners need to recognize that carbon's biophysical properties have limited, and will continue to limit, the potential of market governance. Too often, the accounting problem is treated as an unimportant technical issue to be figured out by scientists. We have to seriously consider that many carbon emissions are uncooperative commodities. Contrary to the conventional adage 'you can manage what you can measure', the key issue, in my opinion, is to build creative social organizations to 'manage what we cannot precisely measure'. Even when we decide to build markets, we must do so with extreme care. It is in carbon market architects' best interests to confront the issues around emission uncertainties. This issue can potentially undermine the public's trust in emission trading as a policy tool. Only if we are honest about the 'quality' of carbon credits can the carbon market sustain its public support and serve its environmental purposes.

To this end, I wish to invite more research on the fundamentals – fossil fuel, combustion, emission factors – in the making of the carbon market. These variables are not as trendy as topics such as offsets or finances, but they are the principal causes of climate change and the keys to its governance. The environmental social sciences can and should make distinctive and important contributions that shed light on the material foundation of market-based governance.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This research is supported by the Social Science Research Council (SSRC) through the International Dissertation Research Fellowship (IDRF), as well as the Vilas Research Travel Award, EU Center of Excellence Research Travel Grant, and the Crowe Scholarship from the University of Wisconsin-Madison.

Notes

1 This paper uses the term 'carbon' loosely. By 'carbon' or 'carbon emission', I refer to the six greenhouse gases covered by the United Nations Framework Convention on Climate Change (UNFCCC): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). I use carbon emissions and greenhouse gas (GHG) emissions interchangeably for convenience.

2 Energy industries account for 31.9 per cent of greenhouse gas emissions in EU member states in 2010 (http://ec.europa.eu/energy/publications/doc/statistics/ext_greenhouse_gas_emissions_by_sector.pdf).

3 Electricity accounts for 32 per cent of the US greenhouse gas emissions in 2012 (http://www.epa.gov/climatechange/ghgemissions/sources/industry.html).
4 Data from US EPA's 'Emission Factors for Greenhouse Gas Inventories' (http://www.epa.gov/climateleadership/documents/emission-factors.pdf).
5 For an introduction to the continuous emission monitoring system (CEMS), please refer to the 'Plain English Guide to the Part 75 Rule' published by US EPA (Note: Part 75 is the Acid Rain Program).
6 For an informative discussion on the two methods, see two rounds of comment and author's response to Quick's 2014 paper 'Carbon dioxide emission tallies for 210 US coal-fired power plants: A comparison of two accounting methods' in the *Journal of the Air & Waste Management Association*. Dimopoulos also offers a good comparison table of the two methods in his chapter in *Accounting for Carbon* (Dimopoulos, 2015).
7 Please refer to the EPA's calculation (http://www.epa.gov/ttncatc1/dir1/cs2ch4.pdf).
8 The interview was conducted in Chinese and then translated by the author.
9 For an accessible outline of EU ETS's monitoring, reporting and verification system, see Chapter 5 'Trendsetter for companies and industrial sites: The EU Emissions Trading Scheme' by Guillaume Jacquier and Valentin Bellassen in *Accounting for carbon*; for an up-to-date review on direct measurement method in EU ETS, see Chapter 10 'Direct measurement in the EU ETS' by Chris Dimopoulos (2015), in the same publication; to access the original regulation, see EU Commission Decision of 18 July 2007 No. 2007/589/EC for the Monitoring and Reporting Guidelines (MRG) (http://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:32007D0589); and EU Commission Regulation (EU) No 600/2012 for Monitoring and Reporting Regulation (MRR) (http://ec.europa.eu/clima/policies/ets/monitoring/docs/gd1_guidance_installations_en.pdf).
10 See EPA's 'Continuous Emissions Monitoring Fact Sheet' (http://www.epa.gov/airmarkets/emissions/continuous-factsheet.html).
11 For details on verification and accreditation requirement in the EU ETS, see Commission Regulation (EU) No 600/2012. (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:181:0001:0029:EN:PDF).
12 According to the IPCC's Fifth Assessment Report published 2014, methane's global warming potential (100 year) is 28. This number has been adjusted multiple times to reflect updated scientific understanding. The IPCC's Second Assessment Report in 1995 calculated the global warming potential (100 year) for methane to be 21, and this is the value used in the Kyoto Protocol and its market mechanisms. The Third Assessment Report in 2001 and Fourth Assessment Report updated the figure to 23 and 25, respectively.

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