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# Climate mitigation policy as a system solution: addressing the risk cost of carbon

Delton B. Chen [a], Joel van der Beek [b] and Jonathan Cloud[a]

[a]Center for Regenerative Community Solutions 501(c)(3), Basking Ridge, USA; [b]EconoVision – Economic Research and Consultancy, Doorn, The Netherlands

**ABSTRACT**

*Global 4C* is a new international climate mitigation policy that adopts a risk management framework. Global 4C offers a financial reward for mitigation and aims to internalise a *Risk Cost of Carbon* (RCC) into the economy. Carbon taxes (i.e. carbon prices) are essential for internalising the Social Cost of Carbon (SCC), however a SCC-RCC duality is inferred with an epistemological method and is supported with a new hypothesis, called the *Holistic Market Hypothesis*. Based on the inferred SCC-RCC duality, a system of complementary market pricing is proposed as an effective response to emerging climate systemic risk and fat-tailed probability distributions for the Earth's climate sensitivity.

The recommended policy instrument is a currency, called *Complementary Currencies for Climate Change* (4C). 4C should be priced in foreign exchange currency markets (Forex) to mirror the RCC and to incentivise a spectrum of mitigation services, including clean renewable energy and carbon sequestration. A public broadcast message for climate systemic risk should be made each year, in the form of a '100-year advance 4C price alert', which is an assurance of reward prices for carbon mitigation (i.e. the 4C exchange rate) under a *Carbon Exchange Standard* (CES). The CES is a macro-prudential protocol for central banks to provide collective insurability against climate catastrophe and incentives for socio-ecological co-benefits.

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## 1. Introduction

Climate change poses deep risks to human welfare and ecosystems, and it has been described as a wicked problem (Sun and Yang 2016) for reasons relating to its complex relationships, fragmentation of social responses, and an apparent absence of a policy toolkit for decarbonising the economy to a specific carbon quota (Anderson and Bows 2011; Knutti and Rogelj 2015; Nordhaus 2016; Rogelj et al. 2016). In response to the various challenges of the wicked problem, this exposition confronts the central question of how climate finance could be most effectively mobilised to respond to the 1.5–2°C ambition of maximum global warming as agreed at the 21st Conference of the Parties (COP21) in Paris (UNFCCC 2015).

**CONTACT** Delton B. Chen deltonchen@crcsolutions.org Center for Regenerative Community Solutions 501(c)(3), 8 Revere Drive, Basking Ridge, NJ 07920, USA

This paper presents a claim that the existing policy space is missing a global price signal that can allow market actors to perceive the systemic risk of unacceptably dangerous global warming, and then act on the signal to reduce the risk. The claim is addressed with a fundamentally new market policy for climate mitigation that is derived with deductive reasoning and scientific and economic principles. The new policy involves a global reward for mitigation services, and a price signal based on risk assessments. The policy presents a new roadmap that might overcome structural barriers to deep decarbonisation, and the approach is complementary to the carbon tax which is based on the Social Cost of Carbon (SCC). The SCC is the net present value of marginal damages to society resulting from one additional metric tonne of $CO_2$-e pollution in a given year (IAWG 2013).

A cost metric is deduced to address the missing price signal, and it is called the *Risk Cost of Carbon* (RCC). The RCC is a systems reliability metric and a measure of the probability of a systemic mitigation 'failure', and it would be estimated in relation to a specific risk management objective. The internalisation of the RCC would involve a new pricing mechanism that is responsive to the global carbon budget, thus strengthening the 2015 Paris Agreement (COP21).

The RCC is theorised, with an epistemological method, to be the (missing) complement to the SCC, and a hypothesis for the RCC is posited as the *Holistic Market Hypothesis* (HMH). The RCC should be internalised into the economy with a *reward* per tonne of additional $CO_2$-e mitigation service and the reward price should be periodically estimated by risk-cost-effectiveness analysis. Risk-cost-effectiveness is defined here as a combination of two existing economic concepts, namely (a) risk-cost, and (b) cost-effectiveness. Risk-cost was originally defined in the insurance industry (Zhang 2009), and it is adopted here as the expense of managing risk but disregarding losses and compensation. Cost-effectiveness is a method of comparing options based on their costs and non-monetary effectiveness, and it is commonly used in the medical industry for selecting treatments (e.g. Edejer et al. 2002) and it is an option for formulating climate policy (e.g. Koomey 2013; IPCC 2014b). The risk-cost-effectiveness analysis that is proposed here, aims to establish the RCC as a reward price for climate mitigation services that can reduce systemic risk to a normatively agreed level. The RCC differs significantly from the SCC, with the later being used to estimate an optimal carbon tax using a cost-benefit analysis (e.g. Nordhaus 2016).

The SCC has been the compass for navigating through climate policy, and it is the basis for imposing a variety of carbon taxes and permits for improving economic efficiency. Nordhaus (2017) described the SCC as 'The most important single economic concept in the economics of climate change … '. This proposal for the RCC presents an opportunity to reflect on the limitations of the SCC paradigm, and to consider a new paradigm in which the SCC and RCC co-exist in a genuine cost *duality*.

A distinctive feature of the RCC is that a parallel currency is identified (epistemologically) as the appropriate tool for internalising the RCC into the economy. The currency should be used to create a global reward price for carbon in world markets. The currency should have an outright asset value under monetary policy so that it is tradable as a currency but *not* tradable as a carbon offset. One consequence is that the currency will place upward pressure on carbon prices in established carbon markets.

The currency instrument offers a channel for macro-prudential governance, accountability, and control by imbedding a physical *unit-of-account* (i.e. 100 kg of $CO_2$-e mitigation service) directly into global finance and measures of Gross Domestic Product (GDP) and Global World Product (GWP). The currency also enables micro-financial management for sustainable development. It is suggested, by inference, that a parallel currency priced to the RCC could have a transformative social effect by guiding markets towards deep decarbonisation. These topics are discussed in the following six sections:

(1) The first section introduces the topic of climate change in terms of emerging risk, the 2015 Paris Agreement, and climate systemic risk.
(2) The second section is an introduction to the new policy, the economic instrument, and the policy aims and operational objectives.
(3) The third section introduces two new theories in market-based environmental policy, including an epistemology for complementary relationships and a hypothesis for the (total) cost of carbon pollution.
(4) The fourth section describes the policy architecture, financial mechanism, currency instrument, market policy and monetary policy.
(5) The fifth section provides some normative justifications for the policy with a synthesis of social and economic concepts.
(6) Finally, the sixth section comments on the most salient issues, including the new hypothesis, the currency proposal, and a roadmap for policy adoption.

### 1.1. Emerging risk of dangerous climate change

Anthropogenic greenhouse gas (GHG) emissions are resulting in the warming of the climate system with widespread impacts (IPCC 2013, 2014a) that include more frequent weather extremes (e.g. Herring et al. 2016). Various studies have projected that global warming greater than 2°C above a pre-industrial baseline could produce significant, dangerous and irreversible damages (World Bank 2012). It also appears from various studies that global warming has a tendency to become more risky at higher temperatures due to amplifying climate feedbacks (e.g. Hansen et al. 2013; Park et al. 2015; Friedrich et al. 2016). Evidence of climate change is profound in the Arctic, where as many as 19 regime-shifts have been identified by the Arctic Council (2016), including a transition to sea-ice free summers, a collapse of some fisheries and a transformation of landscapes.

The changing risk profile for climate change is partly related to our imperfect knowledge of the climate system. For example, a recent study by Crowther et al. (2016) shows that soil biological activity could release significantly more carbon to the atmosphere than previously anticipated. Over time, the science is providing a more detailed understanding of climate change and its impacts, and this has so far revealed a worsening risk profile. Example findings include: large-scale coral reef mortality with additional ocean warming (Hoegh-Guldberg 1999); carbon cycle feedbacks via plant responses to atmospheric $CO_2$ and a changing climate (Seppälä, Buck, and Katila 2009; Brienen et al. 2015); 'relatively severe future warming' due to the effects of atmospheric convection on clouds (Sherwood, Bony, and Dufresne 2014); and a potential for significant ice sheet disintegration, sea level rise and storminess (Hansen et al. 2016).

Gradual and abrupt changes in the climate system are already underway (NRC 2013) and other changes appear plausible (e.g. Wadhams 2016; Friedrich et al. 2016). Abrupt climate impacts have also been observed (NRC 2013), such as an elevated rate of species extinction (e.g. Şengör, Atayman, and Özeren 2008; RockstrÖm et al., 2009; Steffen et al. 2015; Ceballos et al. 2015). Global warming might also produce a domino effect that could interact with military and nuclear risks (Scheffran 2011).

### 1.2. The Paris Agreement

The 2015 Paris Agreement, which was negotiated at COP21 under the United Nations Framework Convention on Climate Change (UNFCCC), defined the level of ambition for international climate change mitigation. This ambition is to remain below 1.5–2°C of global warming relative to the pre-industrial baseline (UNFCCC 2015). In support of this agreement, countries have defined their post-2020 climate pledges, called Intended Nationally Determined Contributions (INDCs). An assessment of these INDCs by Rogelj et al. (2016) indicates that international commitments currently fall short of the ambition of the Paris Agreement and could result in a median of 2.6–3.1°C of global warming by 2100. The main goals of the Paris Agreement are ultimately dependent on five-year pledging cycles and peer reviews that can focus on and deliver a 1.5–2°C carbon quota (van Vuuren, Stehfest, and den Elzen 2011; Hansen et al. 2013; Friedlingstein et al. 2014; Rogelj et al. 2016).

The political and diplomatic integrity of the Paris Agreement also remains vulnerable to a protracted *status quo* or defections (Herz 2017). This vulnerability was exposed when the Trump administration recently announced its plans to reverse U.S. domestic policy on cleaner energy (UCS 2017). Beyond the Agreement itself, the international carbon price is also an iconic metric for progress on climate change, but complexity within Emissions Trading Schemes (ETSs) might dampen the carbon price and slow mitigation in the E.U., China and elsewhere (e.g. Green 2017). The total adverse effect of all of such uncertainties on climate change (incl. political, social, financial and physical uncertainties) is considered in this policy exposition in terms of one overarching concept called the 'climate systemic risk', as explained below.

### 1.3. Climate systemic risk

Risk has been defined as the 'effect of uncertainty on objectives' (ISO 2009b), and so risk is involved in virtually every human endeavour. According to Higgins (2014), risk management in response to climate change can be categorised by the following concerns: (i) mitigation, (ii) adaptation, (iii) geo-engineering and (iv) knowledge expansion. This policy exposition is focused on mitigation, because it is the only reliable option for preventing irreversible climate change (e.g. Anderson and Bows 2011).

A 'systemic risk' exists if a system, such as a financial system, could become dysfunctional or collapse due to a knowable cause or event. An example of a financial systemic risk was the pre-2007 subprime mortgage trading and risky investing that resulted in the U.S. banking crisis, bailouts, mergers, liquidations and 2007–8 global financial crisis. Shortly after the crisis, the U.S. government responded with the Dodd-Frank Act (H.R. 4173) and regulations for monitoring systemically important financial institutions.

Aglietta and Espagne (2016) introduced the term 'climate systemic risk' with a view that GHG emissions are also a systemic social and financial risk, and that a 'collective insurance approach' to climate mitigation has merit. Based on the ISO Guide 73:2009 (ISO 2009b), this systemic risk problem can be defined by (i) an unwanted systemic failure, (ii) an objective of avoiding this failure, and (iii) an uncertainty of meeting the objective. For example, 4°C of global warming by 2100 could be used to define a climate systemic risk. Given that a '… 4°C warmer world must be avoided' (World Bank 2012), it appears rational that an upper probability limit (%) to GHG emissions should be politically negotiated as a global safeguard against 4°C of warming. Such a limit could establish a maximum GHG emissions trajectory and corresponding market mechanisms and regulations that are appropriate.

The UNFCCC appears committed to addressing climate risks with adaptive management, including with insurance (e.g. UNFCCC 2009) and loss and damages (e.g. UNFCCC 2013). But does the 2015 Paris Agreement (COP21) qualify as a *systemic climate risk management plan* based on mitigation? It appears not to qualify, because the Intended Nationally Determined Contributions (INDCs) of parties to the Agreement currently fall short of the 1.5°C–2°C ambition (Rogelj et al. 2016), and moreover, the Agreement does not define upper limits to cumulative GHG emissions with a mechanism of pricing or enforcement. Although the Paris Agreement was successful politically, the negotiation roadmap was a bottom-up approach that only requires each member country to '… pursue domestic mitigation measures … ' (Article 4.2 in UNFCCC 2015).

Since the Stern Report (2007) the topic of climate risk has attracted more attention (e.g. Stern 2013; Nordhaus 2013) and especially now that climate change is a leading cause of global risk (WEF 2016). The science community acknowledges that there is uncertainty in the Equilibrium Climate Sensitivity (ECS), and in the ECS probability distribution function (e.g. Kunreuther et al. 2013). For example, a recent analysis of paleo-data by Friedrich et al. (2016) suggests that the ECS might increase with rising average surface temperatures. These uncertainties, in combination with rising GHG emissions (IPCC 2014a) and the absence of binding limits on cumulative emissions (Knutti and Rogelj 2015; UNFCCC 2015; Rogelj et al. 2016), are evidence that climate systemic risk is difficult to manage with conventional policies.

## 2. Global 4C Risk Mitigation policy

### 2.1. Policy name and introduction

The new climate mitigation policy is called *Global 4C Risk Mitigation*, and it is abbreviated as *Global 4C* for the remainder of this exposition. Development of Global 4C began in 2013 as a collaborative project at the Center for Regenerative Community Solutions (U.S. non-profit). Global 4C is based on the work of Chen, Cloud, and van der Beek (2015a) and Chen et al. (2015b), which includes an epistemological method for classifying market policies. The Global 4C policy presented here is a major advance on previous policy versions, by including the new risk management framework and the Risk Cost of Carbon (RCC) metric.

### 2.2. Policy background

The mandates of central banks do not specifically address the problem of climate change (Campiglio 2014; UNEP 2015) and this issue is 'largely unexplored', according to the Bank

**Table 1.** Overview of the climate policy landscape: conventional separation of (A) central bank responsibilities and (B) carbon markets; and the proposed (C) linking of monetary policy with international 4C currency/rewards for climate mitigation.

| (A) Monetary policy of a nation or union | (B) Market policy of a nation or union |
|---|---|
| Central Banks (National Fiat) | Agents & Regulators (Carbon Pricing) |
| Operational objectives | |
| • Stable prices | • Tax or cap on carbon pollution |
| • Steady growth | • Internalise the SCC |
| Long-term aims | |
| • Financial stability and regulation | • Economic efficiency |
| Systemic challenges | |
| • Financial systemic risk | • Political delay over cost sharing |
| Common policy terms | |
| • Interest Rates | • Social Cost of Carbon (SCC) |
| • Currency Supply | • Carbon Price |
| • Minimum Reserves | • Carbon Tax |
| • Quantitative Easing (QE) | • Carbon Offset |
| (C) Monetary-and-market policy linked internationally | |
| Central Banks (4C Currency) | Agents & Regulators (4C Rewards) |
| Operational objectives | |
| • Risk-cost-effectiveness analysis | • Issue 4C rewards for mitigation |
| • Underwrite 4C prices in the Forex | • Internalise the RCC |
| Long-term aims | |
| • Macro-prudential climate governance | • Maintaining service standards |
| Systemic challenges | |
| • Climate systemic risk | • Maintaining a carbon budget |
| New policy terms | |
| • 100-Year Advance 4C Price Alert | Figure 1 |
| • Carbon Exchange Standard (CES) | Section 4.2, Figure 5 |
| • Carbon Quantitative Easing (CQE) | Section 5.5 |
| • Complementary Currencies for Climate Change (4C) | Section 2.3, Figure 1 |
| • Collective and Systemic Risk Insurability (CASRI) | Section 5.2 |
| • Global 4C Risk Mitigation Policy (Global 4C) | Section 2, Figures 4 and 5 |
| • Risk Cost of Carbon (RCC) | Section 3.13, Table 3, Appx. A |
| • Systemic Risk Abatement Cost Curve (SRACC) | Section 3.13, Figure 3 |
| • Systemic Risk of a Climate Mitigation Failure (SRCMF) | Section 3.12, Appx. A |
| • Total Cost of Carbon (TCC) | Section 3.14, Figure 7, Appx. A |

References: (A) Goodhart (2011) & Bank of England (2016); (B) World Bank (2016) & Nordhaus (2017).

of England (BoE 2016). The background to Global 4C is that monetary policy and climate policy are currently unrelated, with few initiatives to investigate the benefits of their structural integration (refer Table 1, A & B). Global 4C defines a channel for Central Banks to manage the 'climate systemic risk' that was described by Aglietta and Espagne (2016), and the medium of this channel is a parallel world currency (refer Table 1, C). The currency would be issued as seigniorage income for mitigation (i.e. a reward), and it would also link central banks with mitigation markets via foreign exchange currency markets (Forex). The new currency is not just for generating new climate finance. The currency is to enable global good governance and to avoid a climate mitigation failure. The currency pricing mechanism is termed the *Carbon Exchange Standard* (CES) (Chen, Cloud, and van der Beek 2015a).

At least two other versions of a CES have been proposed, but these are substantially different to Global 4C. Cato (2009) proposed that a CES could be used to monetise a globalised per capita allocation of GHG pollution in a pollution convergence scheme. Verhagen (2012) proposed a CES for a world currency, called the Tierra, and a Tierra Fee and Dividend System, which would require nations to pay allocations into carbon accounts under the authority of a new world institution. These other proposals have virtue, but Global 4C is recommended because it offers a market mechanism for limiting climate systemic risk.

Risk management is already an established practice in industry (e.g. ESRB 2015; British Standard 2016). What is theoretically unique about Global 4C is the way that the Risk Cost of Carbon (RCC) is hypothesised and adopted as the complement to the Social Cost of Carbon (SCC) in a duality of costs. A question that is raised by the approach is whether the existing SCC paradigm is complete and adequate for addressing Article 2 of the Paris Agreement, or whether internalising the RCC with a global reward is also needed. If the theory for the RCC is cogent, then Global 4C should be examined as a policy for addressing climate systemic risk and a potential new pathway for revitalising Article 2 with limits on cumulative GHG emissions.

The Global 4C approach does not rely on new direct taxes or regulations. The approach is to politically establish a risk tolerance (based on scientific advice) and to create a rising reward price for managing systemic risk with mitigation. This approach is intended to be globally effective, but it would also bolster and reinforce existing market policies that seek a '… rising price on carbon emissions', as Hansen et al. (2013) and others have called for.

### 2.3. 4C currency instrument

Global 4C is a policy that will employ currencies that are termed *Complementary Currencies for Climate Change* and abbreviated '4C' (not to be confused with 4°C). 4C will be an international currency that can be conveniently traded over the Internet, mobile phones and banking networks, and it will be used for much the same reasons that people trade with national fiat. What makes 4C unique is that it will only be created/issued as a reward for carbon abatement and carbon sequestration services.

4C is a generic term, and 4C may comprise a number of currencies, each of which should be officially recognised and registered in ISO 4217. 4C may exist as a single parallel world currency managed by one coalition of the world's nations, or as several parallel world currencies managed by several clubs of nations. A policy precondition is that all 4C currencies will be traded in one global market with common rules so that 4C prices will converge under the Law of One Price. The option of deploying several 4C currencies may be preferred to enable multilateral policy negotiations, but for reasons of brevity it is henceforth assumed that just one 4C currency is sufficient.

4C is intended as a technology link for spanning geographic, social and financial divides, and for radically scaling-up carbon markets. Digital technologies such as the blockchain (e.g. Nakamoto 2009; Buterin 2014) will be of special utility because they can be used to administer, track and micro-manage every 4C mitigation assessment and 4C contract. The plan is to account for all transactions in a public ledger that can engender transparency and public trust. The 4C network topology for administrative services need not follow a traditional model, and it could adopt decentralised and centralised topologies for reliability, flexibility and rapid scaling.

4C is to be issued as a financial reward for verifiable GHG mitigation, such that 4C has some similarity with carbon offsets. Unlike carbon offsets, 4C will be valued as an *asset* under monetary policy and not as a *liability* in a carbon tax or a permitting scheme, such as those which give Certified Emission Reductions (CERs) their value under the Clean Development Mechanism (CDM) of the U.N. The 4C price would be macro-managed by monetary policy under a Carbon Exchange Standard (CES). The Global 4C policy therefore makes a sweeping claim that it will be possible, with 4C, to macro-manage a global reward price and simultaneously micro-manage its issuance.

4C will have a unit-of-account of *100 kg of $CO_2$-e mitigation under service agreements of up to 100 years duration*, with each agreement being made between a private market actor and an administrative agent (agents will act on behalf of an authority). 4C will be denominated in 100 kg lots of $CO_2$-e mitigation, rather than 1000 kg lots, so that the 4C exchange rate and its smallest divisible unit are convenient for trading. Certified auditors/assessors will be contracted to carry out audits/assessments, and will be paid with 4C commissions.

Service agreements lasting up to 100 years duration are to ensure that $CO_2$-e mitigation projects are awarded for their long-term cumulative greenhouse effect, and to minimise rent-seeking and perverse rewards. It is also needed to ensure that service responsibilities are transferred with ownership of assets. Continuity of service with novation contracts is a practical consideration, because the life span of companies is generally limited. For example, in the 1920's the average life span of companies listed on the first S&P index was about 65 years, whereas by 1998 the average life span of companies on the S&P 500 was only 10 years (Foster and Kaplan 2001).

### *2.4. Policy aims*

The main aim of Global 4C is to inject major new liquidity into the global mitigation market to limit the overall probability of a systemic mitigation failure and to avoid a climate catastrophe. For example, achieving <5% chance of exceeding 4°C of warming by 2100 is a plausible example of the policy's main aim. This will include, by default, new scope to reinforce Article 2 of the 2015 Paris Agreement.

The policy instrument is the 4C currency, which will be issued as a global reward (ex-post) for greenhouse mitigation. To achieve the policy's main aim, it will be necessary to publically broadcast a quantitative assessment of the climate systemic risk. This will take the form of a *100-year advance 4C price alert* (see Figure 1). This 100-year 4C price alert is also a 100-year price guarantee provided by central banks. The 100-year advance 4C price alert will be revised annually based on a risk-cost-effectiveness mechanism for assessing risk, pricing risk, and reducing risk (see Table 2).

This 4C currency will be a new type of international equity/security, with a yield that can be readily calculated from the 100-year advance 4C price alert (refer C to E in Figure 1). By revising the price alert on an annual basis, a feedback loop will be established between risk perceptions and the 4C price and yield, thus establishing institutional 'reflexivity' (refer Dryzek 2014) and dynamic market responses to the risk. The 100-year advance 4C price alert will attract voluntary market participation based on the 4C price and yield.

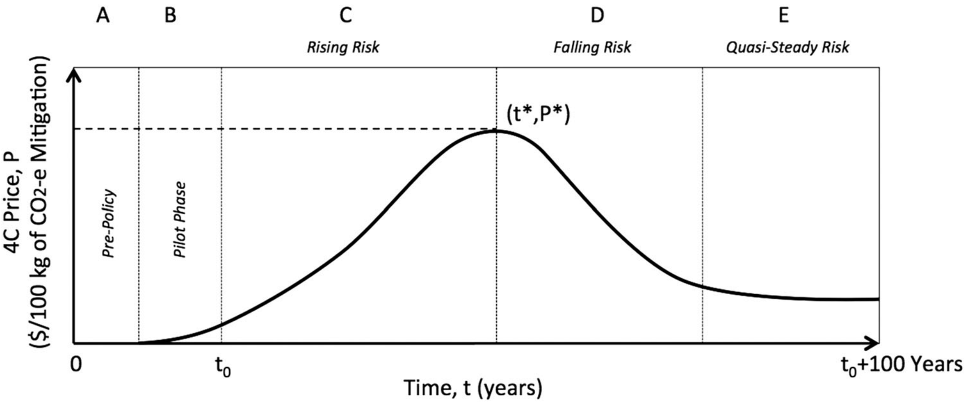


**Figure 1.** Hypothetical 4C currency/reward prices, including (A) a pre-policy period, (B) a pilot phase, followed by the '100-year advance 4C price alert' which should be communicated as a public broadcast message and could have three major phases, including (C) rising risk and a positive 4C yield, (D) falling risk and a negative 4C yield, and (E) quasi-steady risk and near-zero 4C yield.

Enterprises that need to borrow money from commercial banks to cover their expenses of mitigation, may report 4C in their future earnings forecasts when applying for loans. The 100-year advance 4C price alert will improve certainty for commercial banks when lending to low-carbon projects, as recommended by Campiglio (2014). The 100-year advance 4C price alert will also improve market intelligence in the pricing/indexing of various debt securities (e.g. green bonds and climate bonds) and private equities (e.g. shares) that are used to finance low-carbon projects. 4C will also attract new investors to these securities based on higher profit margins.

The risk-cost-effectiveness mechanism (see Table 2) will require (i) a systems reliability metric and a measure of the probability of a climate mitigation failure; and (ii) an internationally agreed maximum probability of failure (i.e. a risk limit). For this purpose, the *Systemic Risk of a Climate Mitigation Failure* (SRCMF) metric is introduced as the probability of failing to prevent a systemic climate catastrophe. Article 2 of the Paris Agreement may be assigned an SRCMF limit by agreement, if exceeding 2°C is considered a systemic failure. Two hypothetical examples of SRCMF limits are: (i) remaining below 2°C of

**Table 2.** Main aims of the Global 4C policy for managing climate systemic risk.

| Main aims |
|---|
| **1. Foresee Risk:** To define acceptable levels of systemic risk for climate mitigation goals under existing or new political agreements. This will include setting limits for a Systemic Risk of a Climate Mitigation Failure, SRCMF{ΔT,Y}. For example, staying below 4°C of global warming by 2100 with <5% chance of failure (e.g. SRCMF{4°C,2100} limit = 5%). This will also require the design and development of a globally networked administrative system for assessing mitigation and issuing 4C currency as a reward for GHG mitigation services. |
| **2. Assess Risk:** To periodically estimate the current SRCMF{ΔT,Y} probabilities in a top-down risk assessment that estimates current GHG mitigation trends and required rates of additional mitigation, ΔQ{t}, for achieving the SCRMF limits. |
| **3. Price Risk:** To translate required rates of additional GHG mitigation, ΔQ{t}, into price targets for the 4C currency/reward based on a risk-cost-effectiveness analysis. To coordinate central banks with protocols that executes a *Carbon Exchange Standard* (CES) for 4C price setting in currency markets. To advertise a 100-year advance 4C price alert, and to offer 4C rewards via the 4C administrative system. |
| **4. Reduce Risk:** To issue 4C currency/rewards for assessed climate mitigation across the 'four corners' of the world. To collect and globally share mitigation data. To engender a global digital network with 'networked intelligence' and to rapidly scale useful innovations and coordinate people and resources. |

warming by 2100 with 50% chance of failure (i.e. SRCMF{2°C, 2100}=50%), and (ii) remaining below 4°C of warming by 2100 with 5% chance of failure (i.e. SRCMF{4°C, 2100}=5%). Multiple concurrent SRCMFs can be defined and addressed, and the SRCMF is explained below and in a hypothetical storyline in Appendix A.

Clarification is warranted regarding the policy of using financial rewards and not taxes (or some other modality) for communicating and managing risk. The current option of using rewards was interpreted epistemologically (refer Market Policy Dualism), but it is also consistent with Williams and Perera's (2005) advice to NASA's space exploration programme. They state, in their unpublished presentation, that '1st Principle: You can't count on people to communicate risks unless that communication benefits them in some way, personally and immediately.' If the principle is reliable, then taxes are a poor option for communicating risk because taxes do not provide immediate financial benefits to recipients. A revenue neutral tax might provide some relief, but such price signals lack the immediacy of a reward. Financial rewards are consistent with the current policy for risk management because rewards have the advantage of providing resources that can be used to undertake climate mitigation work.

The policy does not aim to meet social preferences for culpability or forgiveness over past or future pollution. The policy aim is to implement a global price signal that can positively interact with existing carbon prices and regulations wherever these happen to exist. Global 4C therefore does not impose any preconditions on market actors in terms of their historical externalised costs, pollution taxes or profitability.

## 2.5. Policy operational objectives

### 2.5.1. Agents and regulators

Operational objectives of Global 4C will focus on issuing 4C to enterprises on a private contractual basis, and as a proportional ex-post reward for their $CO_2$-e abatement and sequestration amounts. Those enterprises that wish to earn 4C will need to enter into a contract that permits the sharing of key data in a public 4C database (with exceptions for confidential data and intellectual property). This sharing will enable 'instantaneous market knowledge' for the rapid scaling of cost-effective technologies. 4C will be issued to enterprises as a debt-free currency/reward for each 100 kg of $CO_2$-e mitigated and with contractual conditions on service performance. The reward price per 100 kg of $CO_2$-e mitigated is defined by the 4C exchange rate (i.e. the 4C price). The units (100 kg of $CO_2$-e) only refer to greenhouse gases, and so solar radiation management and other geo-engineering methods are not covered by the policy.

The policy will handle mitigation claims as either discrete physical projects (e.g. a solar power plant) or as enterprise-wide claims (e.g. a national food producer and retailer) depending on which rule provides the most reliable assessment. Draft rules for cleaner energy and industry are presented in a later section, but other rules are not discussed for reasons of brevity. A complete set of draft rules may be proposed in the future if/when the Global 4C policy receives support. The policy is to develop an administrative system that can detect and deter free riders and colluders who may wish to game the policy; and the policy will only reward mitigation that is legal and has passed a common standard of ethical behaviour.

Enterprises may be identified as communities, businesses, corporations, villages, cities or nation states. Claimants will need to demonstrate that their mitigation results are statistically significant and exclusive to the policy, as defined by a suitable baseline and assessment rule. Each major practice, technology or behaviour that can abate or sequester $CO_2$-e will require a matching fit-for-purpose 4C assessment methodology.

A secondary operational objective is to skew the 4C rewards to incentivise co-benefits based on the results of a weighted decision matrix (e.g. Ingwersen et al. 2014). The weighting will have a spatial context (e.g. bio-regional and cultural) and will be used to leverage the market for sustainable agriculture, bio-diversity protection, job creation, wealth equality and social cohesion. The policy is to increase the mitigation rate and the innovation rate, whilst also nurturing co-benefits and reducing externalities.

#### *2.5.2. Central banks*

A monetary policy will set the 4C floor price to mirror the Risk Cost of Carbon (RCC) while 4C is openly traded in international currency markets. The policy is to give the central banks the job of being the 4C price setters (refer the Carbon Exchange Standard). They will set 4C prices by undertaking currency interventions. As this trading occurs, private actors may trade 4C to capitalise on the rising 4C trend-line (see C in Figure 1); and this is a strategically important social feedback for risk communication, group learning and attracting private finance into climate mitigation.

Mitigation costs of the policy will be discharged as a combination of real inflation and monetary inflation. The real inflation will correspond to the $CO_2$-e mitigation services that are financed by the policy; and the monetary inflation will correspond to the expansion of the fiat money supply as central banks support 4C with strategic currency interventions. This fiat expansion will be deflationary for 4C holders, and it will be inflationary for fiat holders. The monetary component of the total inflation will be the least visible because it will be spread globally. Central banks may continue with their usual operations as defined by their other policies (refer Table 1, A).

The operational financial objective includes issuing enough 4C to create a low-carbon energy revolution, possibly costing USD $40 trillion[1] by 2050, as advised by the IEA (2015). The financial objective includes leveraging all significant approaches to $CO_2$-e mitigation with the overall aim of reducing the SRCMFs until they fall below the SRCMF limits. If, for example, $CO_2$-e emissions cause an overshoot of a SRCMF limit and its associated carbon budget, then 4C prices will reflexively increase until Negative Emissions Technologies (NETs) capture and store sufficient atmospheric $CO_2$-e to reduce the SRCMFs to below their limits.

## 3. New theories in market-based environmental policy

Two new theories were developed with the Global 4C policy, namely: (a) a principle of *Market Policy Dualism* (MPD) that was identified through an epistemology of defining complementary economic relationships; and (b) a hypothesis that justifies the application of MPD, called the *Holistic Market Hypothesis* (HMH). These theories comprise the conceptual background to Global 4C, and they also determined the policy's architecture, as described in the following sections.

### *3.1. Market policy dualism (MPD)*

Lietaer et al. (2010, 2012) advise that economies, like ecosystems, require a balance of efficiency, diversity, and interconnectivity to avoid system fragility. Anthropogenic global warming has been described as 'the greatest market failure the world has ever seen' (Stern 2007) and this failure is suggestive of long-term economic fragility. Chen, Cloud, and van der Beek (2015a) propose that a new market–based policy for climate mitigation can be derived with a principle that they term *Market Policy Dualism* (MPD). MPD is a principle that pairs of market policies for environmental mitigation are available based on relationships that are complementary-and-opposite. MPD also includes an implicit assumption that a complementary pair of market-based policies offers benefits, such as rebalancing of social relationships for social feedbacks (e.g. new group dynamics) and policy synergies (e.g. aggregation of price signals). Chen, Cloud, and van der Beek (2015a) show that a simple carbon tax and the Global 4C policy form a unique policy pair under MPD (see Table 3). It is speculated here that Global 4C may be vulnerable to multiple cognitive biases, including a 'framing effect' (e.g. Tversky and Kahneman 1985) in narratives that favour taxes on pollution over rewards for mitigation; and a confirmation bias that reinforces orthodox theory on carbon pricing even if that theory may be incomplete.

### 3.2. Complementary pairs

The application of MPD begins with the epistemology of defining *complementary pairs* as two socio-economic relationships that have opposite characteristics and a capacity to aggregate price signals (Chen, Cloud, and van der Beek 2015a). Complementary pairs can be found in policies, instruments, relationships and objectives. Important examples of complementary relationships are: (i) mitigating and polluting, (ii) rewarding and penalising, (iii) decentralising and centralising, (iv) innovating and streamlining, and (v) cooperating and competing.

### 3.3. Complementary instruments

Chen, Cloud, and van der Beek (2015a) showed that the first step in applying Market Policy Dualism (MPD) to the mitigation of pollution is to identify the primary pair of complementary instruments that can create independent prices for pollution and mitigation (refer Table 3). The unit-of-account of each instrument should be selected for scientific rigour and convenience, and the pair recommended for climate mitigation is: (a) a carbon tax/permit as a levy per 1000 kg of $CO_2$-e pollution, and (b) a currency as a global reward per 100 kg of $CO_2$-e mitigation with historical baseline determinations and service agreements for up to 100 years duration.

The currency/reward instrument is neither a commodity currency nor a fiat currency (refer Ferguson 2008), and it is formally termed a 'service currency' (Chen et al. 2015c). The issuance of this currency will require an assessment of historical pollution baselines and rolling service agreements (for up to 100 years duration) because the effectiveness of mitigation is a function of past and future events.

### 3.4. Complementary socioeconomic networks

Market Policy Dualism (MPD) recognises that socioeconomic networks that emerge from complementary market policies and instruments (e.g. tax liabilities and currency/rewards) will have different functionality and interconnectivity. Network topology is related to the

**Table 3.** Market policy dualism (MPD) identifies complementary market policies for climate change mitigation and achieving global climate ambitions.

| Focus | Market Policy |
|---|---|
| Type I. Social Cost Focus → Improving Efficiency | **Carbon Tax ('Sticks')**<br>**Unit-of-Account:** 1000 kg of $CO_2$-e pollution.<br>**Focus:** Society and economic efficiency.<br>**Market Policy:** The response to GHG pollution is to estimate the *Social Cost of Carbon* (SCC), and to internalise the SCC into the economy with tax liabilities or caps on carbon pollution. Social justification for the tax is provided with cost-benefit analysis and the *Polluter Pays Principle* (PPP).<br>**Objective:** Internalise the SCC and improve economic efficiency. |
| Type II. Systemic Risk Focus → Improving Certainty | **Global 4C Risk Mitigation ('Carrots')**<br>**Unit-of-Account:** 100 kg of CO2-e mitigation with baseline determinations and service agreements lasting up to 100 years.<br>**Focus:** System and economic certainty.<br>**Market Policy:** The response to GHG pollution is to estimate the *Systemic Risk of a Climate Mitigation Failure* (SRCMF) and the *Risk Cost of Carbon* (RCC), and to internalise the RCC into the economy with currency/rewards for carbon mitigation. Private trading of the currency and information sharing are undertaken with digital networks under the *Networked Intelligence Principle* (NIP). A uniform inflation levy finances the policy, and social justification is provided with risk-cost-effectiveness analysis and the *Beneficiary Pays Principle* (BPP).<br>**Objective:** Internalise the RCC to limit climate systemic risk and improve economic certainty. |

global pattern of value and information transfer between payers and payees in the system (see Figure 2). Policies for tax-liabilities can produce centralised networks with 'star' topologies, and this is to streamline the revenue collection for efficiency (see Figure 2a). Policies for scalable rewards, on the other hand, can favour decentralised networks with a 'tree' topology because improved collaboration and innovation amongst payees can increase their rewards (see Figure 2b). Policies for peer-to-peer (P2P) currencies benefit from networks that have a 'fully-connected' topology, because this improves privacy and efficiency in trade (see Figure 2c). MPD specifically acknowledges that a fully connected tree network of a currency/reward is the fullest complement to the star network of a tax-liability. Numerous policy leverage-points are available with currency/rewards because of this network topology, including the option to use monetary policy for micro-financial and macro-economic control.

### 3.5. Complementary policies

By carefully applying MPD, a pair of complementary market policies for climate mitigation was derived as shown in Table 3. These policies are termed 'carrots and sticks' because they include the simple carbon tax ('sticks') and the 4C reward ('carrots'). There are many different kinds of market-based policy for climate mitigation, however the Global 4C policy is unique. The 4C is similar to a carbon offset, but key differences are that 4C is a currency and is free of liabilities. The main implication is that monetary policy can be used to set 4C prices and to leverage mitigation rates while providing new carbon accounting and tracking systems.

### 3.6. Complementary objectives

A major test for MPD is the ability to define the policy objectives that correspond to the complementary 'carrot' and 'stick' policies (Table 3) that were originally described by

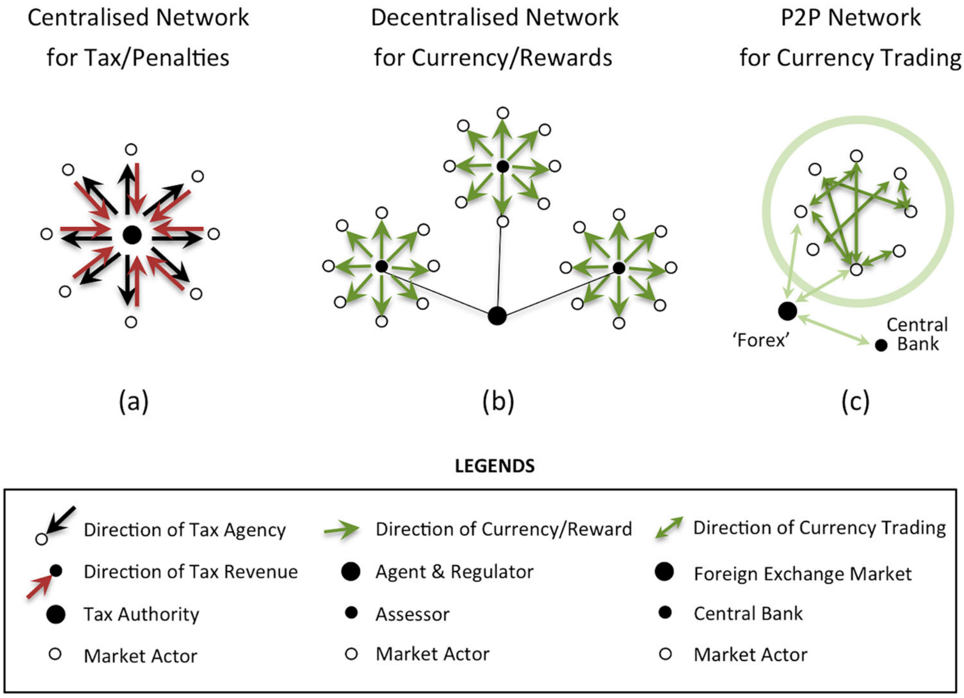


**Figure 2.** Market Policy Dualism (MPD) identifies complementary social networks with characteristic topologies, namely: (a) tax incentives with centralising social networks for streamlining information and reducing costs; (b) reward incentives with decentralising social networks for sharing information and increasing innovation; and (c) currency trading with peer-to-peer (P2P) networks for privacy and efficiency.

Chen, Cloud, and van der Beek (2015a). Whilst the (Type I) 'sticks' were known to have the objective of improving economic efficiency, the (Type II) 'carrots' were found to have the objective of improving system certainty. The MPD analysis of the Type II policy objective had several lines of investigation, but the most concise elucidation is that complementary objectives are established when the Type II objective is the reverse of the dominant Type I micro-foundational relationship; and when the dominant Type II micro-foundational relationship is the reverse of the Type I objective (i.e. these are the complementary policy relationships under MPD).

The dominant Type I micro-foundational relationship is the risk-reward trade-off principle, which implies that individual agents will *take risks for perceived rewards* during the process of improving economic efficiency. Consequently, the Type II objective is to improve systemic certainty by *offering rewards for reducing risk*. The Type I objective is *efficiency*, and so the dominant Type II micro-foundational relationship is that individual agents will become more *inefficient* (i.e. less efficient) when they invest more time and resources in reducing systemic risk. The above MPD result guides the architecture of Global 4C and it addresses the Tinbergen Rule[2] in terms of matching policy objectives with instruments.

The Type II micro-foundational relationship, which may be called an inefficiency-reward trade-off, may be counter-intuitive if a popular or normative view is that agents should always try to increase their efficiency. This private *inefficiency* relationship is justified at the system level (i.e. thermodynamically) if there is a need to counteract elastic demand. An elastic rebound in demand is known as the Jevons effect/paradox, and it occurs when rising energy efficiency stimulates more energy demand and material throughputs over the long run (e.g. Garrett 2012). A hypothesis is proposed that justifies the Type I and II objectives based on their associated instruments and foundational relationships. This hypothesis is named the *Holistic Market Hypothesis* (HMH) (see below).

The Type I and II objectives can be illustrated with an idealised aeroplane metaphor in which (Type I) fuel consumption is an economic efficiency issue for the airline and is reflected in the price of airline tickets; and in which (Type II) flight safety is a system certainty issue for the pilot. If the aeroplane develops a fragile structural defect during its flight, with a probability of a catastrophic failure, then the pilot will address this fragility with a course of action that is independent of the Type I objective.

### 3.7. Holistic market hypothesis (HMH)

The epistemology of complementary relationships explains *how* the Global 4C policy was derived, but a justification for deploying Global 4C may also require a falsifiable theory that explains *why* the policy can address the Tinbergen Rule, and *why* it is a reasonable approach for addressing climate systemic risk caused by anthropogenic GHG emissions. A theory, termed the *Holistic Market Hypothesis* (HMH), is thus presented to address two key questions:

(Q.1) Why does GHG pollution create two types of externalised cost in the economy?
(Q.2) Why is a complementary pair of market policies needed to internalise the two cost types into the economy?

The HMH is only presented conceptually, and the possibility of developing a complete set of descriptive analytics and a falsifiable test for the hypothesis is open to discussion and collaboration. The conceptual HMH is based on the following description of (a) a marginal social cost and a systemic risk-cost of pollution; (b) a system frame of reference; (c) system networked intelligence, and (d) system thermodynamics. The HMH conceptual model is illustrated with a hypothetical policy storyline in Appendix A.

### 3.8. Social cost of carbon (SCC)

A standard market theory is that carbon taxes/permits are needed to internalise the *Social Cost of Carbon* (SSC) and improve market efficiency (Stern 2007). The SCC is denoted here as a Type I cost and is conventionally defined as the net present value of the economic loss or damage of adding one additional metric tonne of $CO_2$-e pollution to the atmosphere in a given year (IAWG 2013). The SCC is influenced by many factors, including the chosen discount rate and uncertainty in climate sensitivity (Tol 2009; Nordhaus 2017). Other factors that influence carbon pricing are costs vs. benefits, Marginal Abatement Cost Curves (MACCs), and the political process. Carbon taxes may be justified with the Polluter Pays Principle (PPP).

### 3.9. Systemic risk as a cost

Most discussions of systemic risk for the climate and environment are concerned with assessing consequences and financial contingencies (e.g. Johnson 2013; PwC 2014). Aglietta and Espagne (2016) discuss *climate systemic risk* as an occasion for collective insurance *against* dangerous climate change that is '..equivalent of a value that society attributes to mitigation activities'. The current policy expands on this 'climate systemic risk' concept by giving it a scientific definition and a specific price signal. It is defined here as the subjective probability of failing to avoid system dysfunction or collapse because of anthropogenic interference with the climate.

When the climate systemic risk is estimated and monetised, the result is termed the *climate systemic risk-cost* or the Risk Cost of Carbon (RCC), as explained in more detail below. The RCC is the Type II cost, and it is monetised by estimating the market price for mitigation services that can reduce the probability of systemic failure to a tolerable level (based on statistical analysis and weighted decisions). With this definition, the RCC is both (a) a metric for actively communicating climate systemic risk as it is perceived, and (b) a price signal to reduce and manage the climate systemic risk.

### 3.10. System frame of reference

The SCC is a Type I cost, and the frame of reference for Type I costs are the individuals who make up society. The HMH introduces a new frame of reference for the (Type II) RCC, and this is a system frame of reference that is socially constructed and has its own identity, awareness, objectives and responsibilities that are inter-generational and not time discounted. The Type II system is the world economy and its interconnections with people and the environment. Legally recognised systems are common, and two notable examples are (a) legal personhood attributed to corporations, and (b) the *Law of the Rights of Mother Earth* under Bolivian law (Morales 2010). Based on these precedents, it is plausible that the world economy can be given an identity and may even be given legal personhood.

Based on MPD analysis, it is inferred that the world economy (system) should be given responsibility for the Type II cost and a social justification is the Beneficiary Pays Principle (BPP). In this frame of reference, the world economy is the beneficiary because it has an awareness of climate systemic risk and an aversion to this risk. To avoid a conflict of interest, the Type II cost should be internalised into the economy with rewards and a uniform inflation levy. The inflation levy will avoid the need to directly tax individual citizens and firms who are represented in the Type I frame of reference.

### 3.11. System certainty as an objective

When the (Type I) SCC is internalised with carbon prices, the objective is to marginally improve economic *efficiency*. As theorised above, carbon pollution also creates a climate systemic risk, thus resulting in the (Type II) RCC. When climate systemic risk is internalised with a market policy and a price signal, the objective is to create a safeguard that improves the *certainty* that enough mitigation will occur to avoid a systemic failure. This safeguard can have physical, social, political and financial aspects. A world economy (i.e. system) with the certainty of a safeguard is conceptually analogous to an aeroplane with autopilot systems for landing, or an ecosystem that can survive through its ability to create homeostasis.

### 3.12. Systemic risk of a climate mitigation failure (SRCMF)

To define the RCC as a systems reliability metric, an account of (a) uncertainty and (b) objectives is required. This is because risk is the 'effect of uncertainty on objectives' (ISO 2009b). A plausible climate systemic risk objective could be to avoid a temperature greater than 2°C of global warming (refer Article 2 of the Paris Agreement) based on a politically selected *probability of failure*. For this purpose a *Systemic Risk of a Climate Mitigation Failure* (SRCMF) metric is introduced. The SRCMF{ΔT,Y} is the probability of failing to avoid an average global warming of ΔT by year Y, due to structural barriers to mitigation and climate system dynamics. A hypothetical SRCMF{ΔT = 4°C, Y = 2100} of 5% would imply that a climate mitigation failure of 4°C warming by the year 2100 would have a 5 in 100 chance of occurring. Probability of failure is not a new concept and is commonly used in the design and maintenance of industrial processes, civil structures, and financial institutions (e.g. Santomero and Vinso 1977).

A bottom-up reductionist approach to SRCMF assessment would likely be impractical. A top-down approach to SRCMF assessment is to extrapolate the additional mass of GHGs that should be mitigated, ΔQ{t}, above that which is forecast to be mitigated without the Global 4C policy. The ΔQ{t} is therefore the additional rate of $CO_2$-e mitigation that is required to reduce the SRCMF to its limit and to achieve the policy objective (refer Figure 3). The ΔQ{t} is a dynamic policy target, and it will correspond to SRCMF limits that are politically agreed.

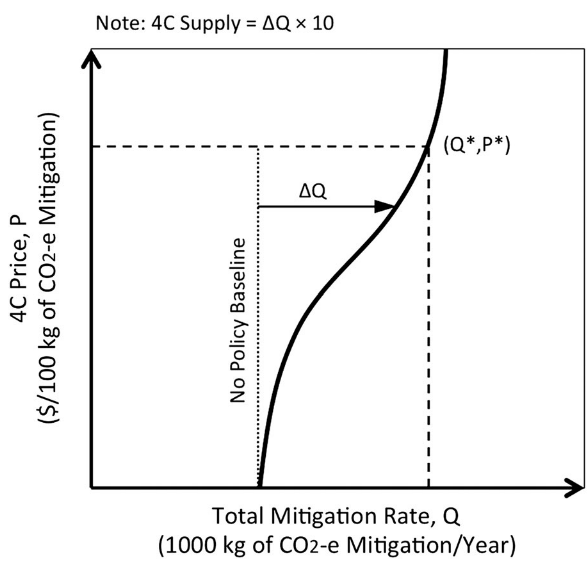


**Figure 3.** Hypothetical Systemic Risk Abatement Cost Curve (SRACC) at a point in time (t*). This is the price-quantity relationship (P vs. Q) for incentivising additional mitigation (ΔQ) with 4C rewards (refer Figure 1 for P vs. time).

Current GHG emissions are so large that they have not been exceeded for about 66 million years, according to Zeebe, Ridgwell and Zachos (2016), and hence there could be deep uncertainty in ΔQ{t} values. To improve the available ΔQ{t} estimates, ΔQ{t} should be reassessed every year using a combination of statistical methods and weighting factors that account for (a) the probability distribution function of the Equilibrium Climate Sensitivity (Kunreuther *et al.* 2013); (b) the advice of an expert panel; and (c) other relevant data. A procedure for estimating ΔQ{t} may be guided by a risk assessment panel and ISO 31000:2009 principles and guidelines for risk management (ISO 2009a).

### 3.13. Risk cost of carbon (RCC)

The (Type II) Risk Cost of Carbon (RCC) accounts for latent costs of mitigation caused by structural barriers or inhibitors to decarbonisation that are unable to be dealt with via other policies. The RCC is the cost of limiting the probability that a systemic failure will occur. The RCC requires no estimate of damages because it is based on a risk-cost-effectiveness analysis. The RCC is the monetisation of ΔQ{t}, which is the mitigation shortfall to meet the risk management objective (refer above). The monetisation of ΔQ {t} will require a price-quantity relationship for global mitigation, which is given the name: *Systemic Risk Abatement Cost Curve* (SRACC, SRAC curve) (see Figure 3). The SRACC will be similar to a global Marginal Abatement Cost (MAC) curve (e.g. Enkvist, Dinkel, and Lin 2010; Iyer et al. 2015) but will be tailored to reflect costs of implementation, monitoring and hidden costs (Kesicki and Ekins 2012). The assessment of rewards based on emissions baselines, social and environmental interactions, and trade-offs are important, but these issues should be assessed separately to the SRACC, and using science-based rules and weighted decision matrices.

After the ΔQ{t} is converted into a preliminary RCC{t} value with the SRACC (refer Figure 3), the final RCC{t} will be adjusted for utilising market sentiment and for contingencies against social, political and financial uncertainty. Contingencies may be required if, for example, there is uncertainty over other key policies or agreements that are relevant to climate mitigation. RCC{t} will have the units of USD per 1000 kg of $CO_2$-e mitigation. 4C units are equivalent to RCC divided by 10, and so will have units of USD per 100 kg of $CO_2$-e mitigation.

The RCC{t} will be revised annually and presented as the 100-year schedule for risk management; and will be the primary reference data for central banks when setting the price of 4C in the Forex (see Figure 1). By establishing the 4C price in the Forex, a global reward price for a spectrum of mitigation options is created, and it is also possible to communicate the climate systemic risk to the world in a manner that is immediately acceptable to market actors. It is acceptable because 4C will allow actors to plan for mitigation work decades in advance and based on published 4C prices. The 4C is the instrument that can address Aglietta and Espagne's (2016, 7) request ' … to get the central banks on board in the low-carbon transition'. See Appendix A for further clarification of the RCC based on a hypothetical example.

### 3.14. Total cost of carbon (TCC) & cost interactions

The SCC and RCC are hypothesised to be the complementary externalised costs of greenhouse pollution. The (Type I) SCC is the marginal damage to society because of GHG pollution and it relates to taxes on pollution, whereas the (Type II) RCC is the risk-cost of reducing climate systemic risk and it relates to rewards for GHG mitigation services. The SCC and RCC may have some covariance if a rising SCC corresponds to an overall riskier situation. A total cost is also introduced, called the (Type III) *Total Cost of Carbon* (TCC), which equals the SCC plus the RCC (see Appendix A for clarification).

A general feature of the SCC is that it reflects the cost of climate-related damages that occur within the market economy, as perceived using a neoclassic economic framework. The RCC, on the other hand, refers to the cost of managing unwanted climate events within a complex system, as perceived using a thermodynamic framework. The RCC does not require an analysis of future damages related to extreme events, as is required by the SCC when 'fat tailed' probability distributions arise (e.g. Weitzman 2011). The RCC is actually a macro-prudential metric based on subjective and politically chosen probability limits and heuristic cost-effectiveness analysis for carbon mitigation. The SCC-RCC cost duality and the TCC therefore represent a shift in perception, because it allows for a new balance of complementary policy values and probabilities (refer Discussion).

New value associations may be made with the RCC, including an association with subjective and intangible values, such as the value of ecosystem capital, species diversity, relationships, culture and aesthetics. Another important association is a capacity to control dirty growth and counter Jevons effect, which are typically ignored in conventional economic models (refer System Thermodynamics and Discussion).

### 3.15. System networked intelligence

Since the mid-1990's, digital communications for peer-to-peer (P2P), business-to-business (B2B) and machine-to-machine (M2M) have expanded. Mobile phone subscriptions passed 98 per 100 people in 2015, and Internet users passed 44 per 100 people in 2015 (World Bank 2017). This digital interconnectedness is revolutionising business and is promoting knowledge sharing and collaborative innovation: creating an emergent socioeconomic property that Tapscott and Williams (2010) term 'networked intelligence'. A *Networked Intelligence Principle* (NIP) is proposed here as a socioeconomic principle that networked intelligence can be utilised for meeting an environmental mitigation objective that requires major new innovation and scaling.

### 3.16. System thermodynamics

Adam Smith in his 1776 treatise, 'The Wealth of Nations', established the idea that land, labour and capital are primary factors in productivity growth (Smith 1937). In more recent times it has been found that energy supply is actually a major factor in productivity growth (Kümmel and Lindenberger 2014). The role of energy in the economy is also highlighted with the so-called *Embodied Energy Theory of Money* (e.g. Costanza 1980; Costanza and Herendeen 1984), which is a theory that the average purchasing power of all currencies is a reliable index of total exploited energy because currencies intermediate the trading of goods and services.

Garrett (2012) has fortified the Embodied Energy Theory of Money by developing a thermodynamic-economic model of civilisation and by showing how the average purchasing power of all currencies is correlated to total primary power being generated. The historical global average for this correlation was determined by Garrett (2012) to be relatively stable at USD \$1 (adjusted to 1990) per 9.7 milliwatts (mW) of primary power. This correlation does not imply that currencies transfer energy, but rather it says that the average purchasing power (inflation adjusted) of currencies will automatically respond to changes in energy throughput.

Given that the majority of primary energy is currently sourced from fossil fuels, economic activity and growth are major drivers of global $CO_2$ emissions. Mir and Storm (2016) undertook an analysis of production-based and consumption-based $CO_2$ emissions, to reveal that $CO_2$ emissions have increased monotonically with GDP per capita, leading Mir and Storm (2016) to conclude that '… there is no such thing as automatic decoupling between economic growth and GHG emissions'. The Global Commission on Economy and Climate (2014) appears to be optimistic about GDP, by claiming that global growth can de-couple from $CO_2$ emissions if well-designed regulatory and market-based policies are implemented over the next 15 years. The Global Commission on Economy and Climate (2014) also claims that: '… if climate change is not tackled, growth itself will be at risk'. This worldview differs from Garrett's (2012) forecast that if growth is not limited '… $CO_2$ levels will likely end up exceeding 1000 ppmv'. This is an example of the growth dilemma in economics, and it contributes to the wicked problem of climate change because, according to Kallis, Kerschner, and Martinez-Alier (2012, 172), 'Growth economies do not know how to degrow. They Collapse.'

The IEA (2016) reported that global $CO_2$ emissions from energy consumption had stayed flat between 2013 and 2015, at about 32.1 Gt $CO_2$ $a^{-1}$, while the economy grew by about 3% per annum. In contrast to this short-term decoupling, the analytical forecast of Garrett (2012) is that civilisation, based on a homogenous utility-energy model, is structured to grow its $CO_2$ emissions over the long run, and with dire consequences for the climate. A critical part of the problem, according to Garrett (2012), is that gains in energy *efficiency* will stimulate additional economic growth to create a deadly pollution rebound (i.e. Jevons paradox). This problem strikes at the heart of the global sustainability question that was studied by the UK's Sustainable Development Commission (2009). Garrett's (2012) analysis indicates that orthodox pro-growth policies that rely on energy efficiency improvements could fail to de-couple $CO_2$ emissions from economic growth this century. The risk of an energy-rebound highlights a need to consider new policies that can limit carbon emissions by managing energy throughput.

Garrett's (2012) correlation, of USD \$1 (adjusted to 1990) to 9.7 mW of primary power, is one of the most important relationships considered in this exposition, and it guided Chen, Cloud, and van der Beek (2015a) to devise Global 4C as a partial solution to the growth dilemma based on the energy indexed by 4C. Given that 4C will have a rate of supply that is coupled to the carbon mitigation rate, it was proposed that, by raising the 4C price, it should be possible to incentivise a higher $CO_2$-e mitigation rate and increase the percentage of energy/resources allocated to the task of decarbonisation. Global 4C can therefore provide additional control over energy allocation in the economy. This monetary approach relies on transitioning Gross World Product (GWP) from its current homogenous mix of national fiat, into a heterogeneous mix of national fiat and the parallel 4C currency. This will introduce uniform inflation in national currencies, as national currencies gradually surrender some purchasing power to 4C.

Global 4C is a macro-economic policy that attempts to pivot decarbonisation on the 4C exchange rate (an asset price). This new pivot is intended to synergise with conventional policies that currently attempt to pivot decarbonisation on carbon prices (a tax liability). Whilst Chen, Cloud, and van der Beek (2015a) do not provide a quantitative analysis of 4C, the approach appears to alleviate the growth dilemma without relying on taxes, regulations, austerity or other harsher policy.

It is assumed here that the Embodied Energy Theory of Money and Garrett's (2012) model results allow us to qualify market-based policies for climate mitigation in terms of the 1st and 2nd Laws of thermodynamics. The 1st Law states that energy is conserved, such that the Earth's biosphere is like a chemical battery that is 'trickle charged' by photosynthesis (Schramskia, Gattie, and Brown 2015). The 2nd Law states that entropy of an isolated system can only increase, such that it is necessary to dissipate energy to capture and sequester carbon from the atmosphere. England (2013) also shows that the 2nd Law can be used to explain natural self-replication via emergent structures that dissipate heat (e.g. abiogenesis); and this concept of 'emergent structure' under the 2nd Law is interpreted here to mean that 4C rewards (and embodied energy) can incentivise the emergence of new socio-economic structures for the abatement, capture and sequestration of carbon. Naturally occurring examples of self-replicating carbon-capture appear in nature, and a major example is the existence of photosynthetic plants that capture atmospheric carbon dioxide to produce sugars. Global 4C satisfies this thermodynamic requirement for carbon capture, because it can (i) supply energy 'embodied' in 4C rewards; and (ii) promote market reorganisation via innovation and digitally-networked intelligence. It can also (iii) allow international 4C trade for Coasian bargaining and dynamic market feedbacks.

## 4. Global 4C policy architecture

### 4.1. Policy architecture

The architecture of Global 4C includes (a) a global carbon mitigation market that invites actors to mitigate GHG emissions and earn 4C; (b) open trading of 4C in foreign exchange currency markets where central banks will play a price setting role; and (c) a *Carbon Exchange Standard* for central banks to set the 4C price (see Figure 4).

The mitigation market is an international market where enterprises and communities build their own social networks, mitigate carbon, submit mitigation claims, receive 4C as rewards, and maintain service agreements. The currency market is an international market where actors can trade 4C for self-interest, but where central banks are the price setters (via monetary policy) and will accumulate 4C for an indefinite period. Global 4C is compatible with conventional policies (e.g. taxes, cap-and-trade, regulations, subsidies, baseline-and-credit, etc.) as long as the administration of 4C prevents the double-payment of 4C for carbon. Beyond this requirement, it appears that Global 4C has the mutualistic attributes of a global umbrella policy.

### 4.2. Carbon exchange standard (CES)

Under Global 4C policy, central banks will finance carbon mitigation by buying 4C with hard currency generated with an internationally coordinated monetary policy. This hard

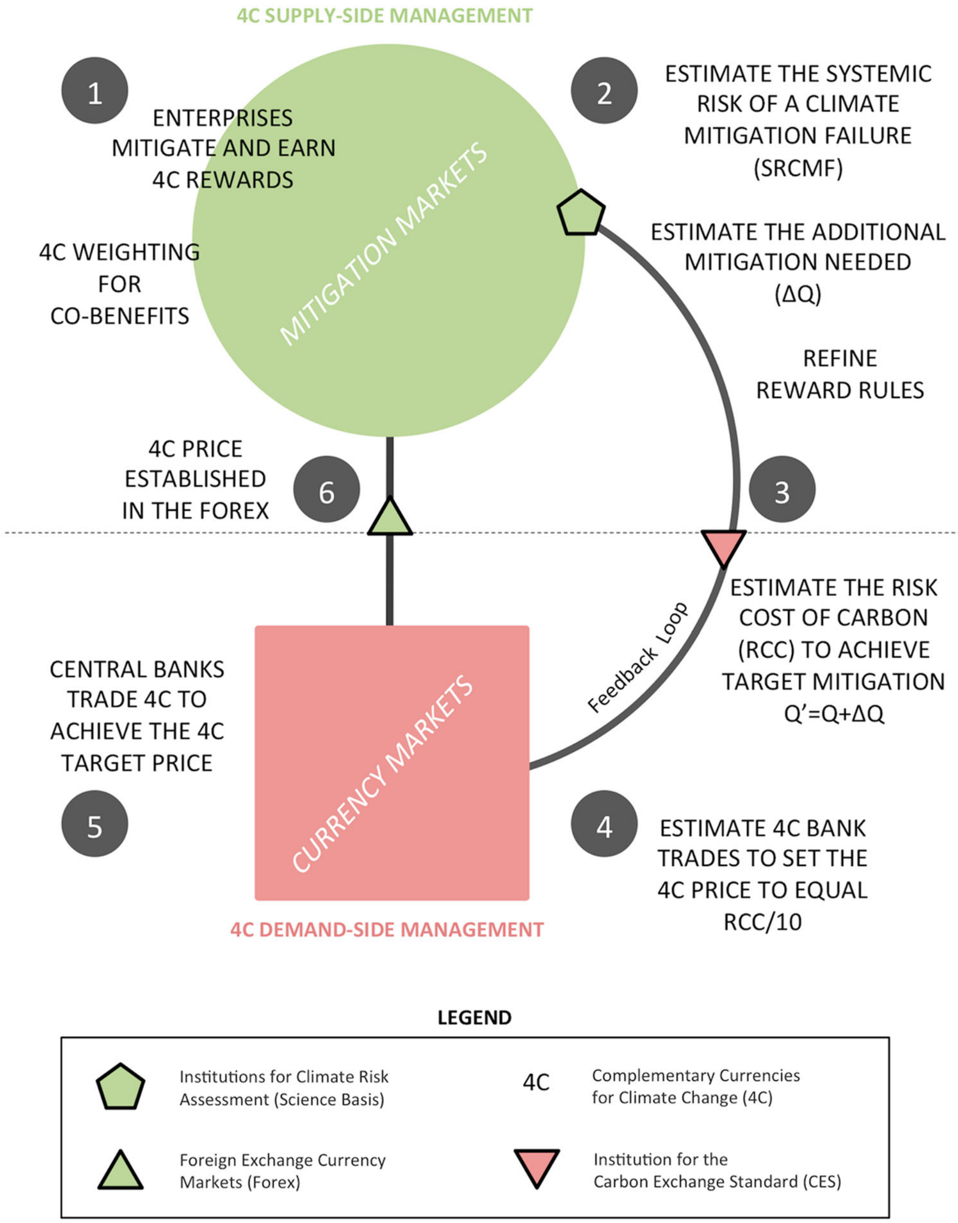


**Figure 4.** The 4C pricing mechanism, including major institutions and operations to assess risk (2), price risk (3) (4) (5) (6), and reduce risk with climate mitigation (1). Further details are presented in Figure 5.

currency trading will guarantee the '100-year advance 4C price alert' (refer Figure 1). The monetary policy and currency trading protocols are collectively termed the *Carbon Exchange Standard* (CES) (see Figures 4 and 5).

The CES will be designed for international equity, and it will declare 4C as an official international currency, but it will not require national governments to accept 4C for the payment of national taxes (this is optional). The CES will manage the 4C price as a monetary intervention, and this will occur with continuous 4C trading by central banks.

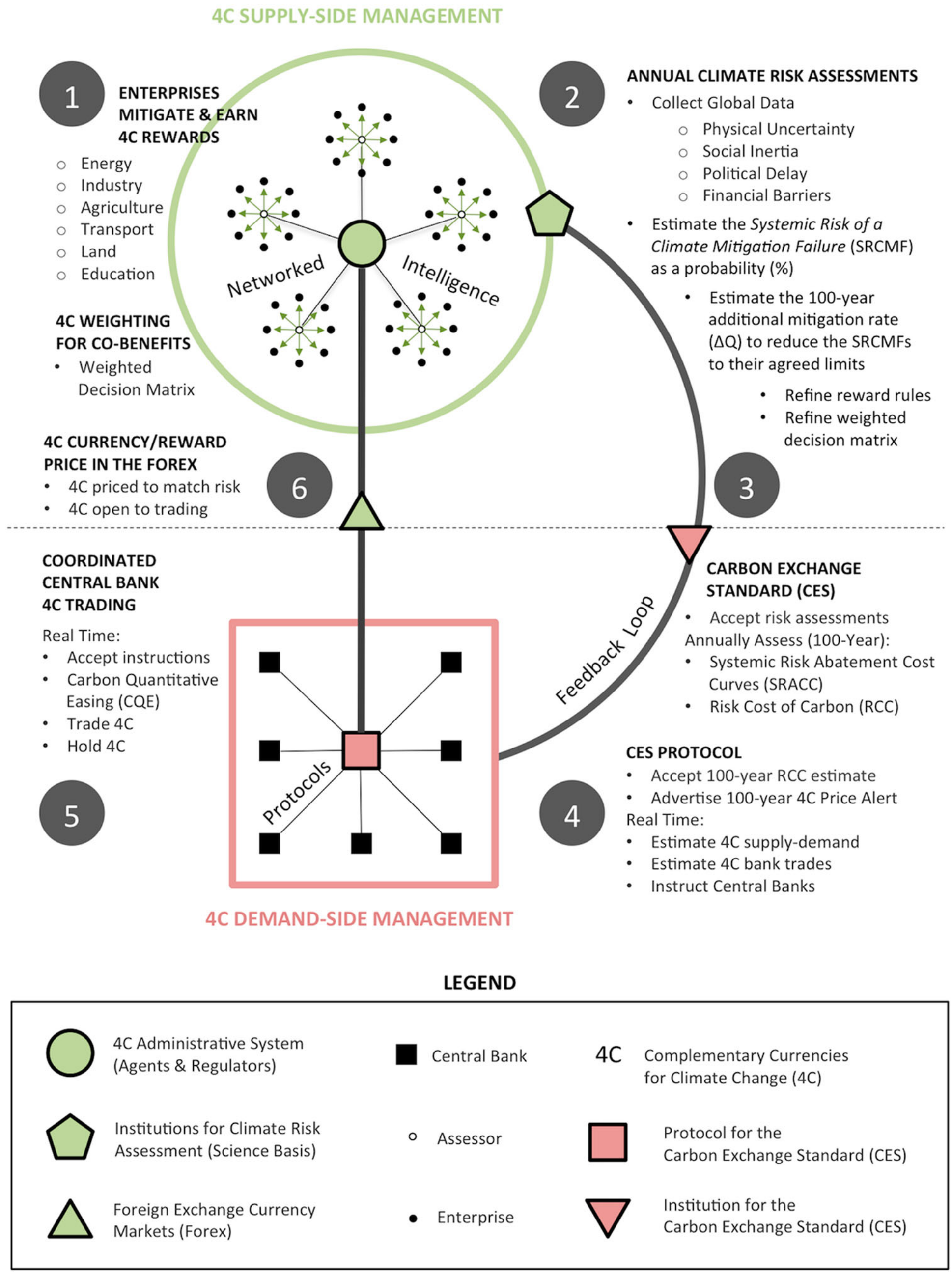


**Figure 5.** The 4C pricing mechanism, including major institutions and operations to create a feedback-loop in the 4C price by feeding probabilistic risk assessments into the Carbon Exchange Standard (CES). As the 4C price rises over time, networked intelligence and the rate of innovation should improve.

Central banks will access sufficient hard currency primarily by expanding the supply of their national fiat with Quantitative Easing (QE). To avoid influencing international trade (other than GHG mitigation) the CES will spread the monetary inflation uniformly across the world economy.

By adaptively setting the 4C price with the CES, the central banks should be able to deliver almost any '100-year advance 4C price alert' that is required for systemic risk management (refer Figure 1). The 100-year advance 4C price alert will attract private equity into climate mitigation services to earn 4C, and it will also attract private traders to buy 4C for its guaranteed yield. In terms of macro-prudential governance, the CES can underwrite mitigation costs with a uniform inflation levy, and this inflation will help to limit dirty economic growth. The inflation levy offers a part solution to the dirty growth problem that the UK's Sustainable Development Commission (2009) had previously identified. The approach also has many similarities with macro-prudential policy - as described by the IMF (2013).

The CES protocol includes an annual public announcement of a revised '100-year advance 4C price alert', based on the results of a risk-cost-effectiveness assessment (refer Figures 4 and 5). The publicly announced '100-year advance 4C price alert' will mirror the latest RCC{t} estimate for limiting the probability of failure. The price-quantity relationship for ΔQ{t} is the SRACC, which is the expected market price for GHG mitigation (refer Figure 3).

The 100-year advance 4C price alert will globally communicate the climate systemic risk, and it will incentivise markets for GHG mitigation. Importantly, it will also facilitate a deliberate 'bull market' in 4C trading for the period when the 4C price is appreciating above the rate of inflation (refer Figure 1, B to C). A 4C bull market will likely have a profound effect on market sentiment, society, and politics, and a key benefit will be an international transfer of financial liquidity into climate mitigation. Enterprises that wish to mitigate will have the certainty that they will need for financial planning over years and decades. The 100-year advance 4C price alert mechanism is further explained in Figures 4 and 5.

### 4.3. 4C demand-side management

The Carbon Exchange Standard (CES) guarantees that central banks will underwrite the 100-year advance 4C price alert that reflects the estimated RCC divided by 10 (refer Figure 1). Market demand for 4C will therefore be generated via the CES that will include instructions for central banks to: (a) undertake Quantitative Easing (QE) to create new fiat; (b) to trade this fiat for 4C; and (c) to store 4C in official reserve holdings (refer Figure 5). For example, the Bank of England will issue new pound sterling (GBP) with QE, buy 4C in currency markets with the GBP, and then add the 4C to its reserve holdings. The protocol will be designed to spread the monetary inflation as evenly as possible across the world economy, but giving awardees of 4C a *seigniorage* income in return for their mitigation services.

By financing 4C assets with international QE (refer Figure 5), the 100-year advance 4C price alert will be disassociated from national fiscal budgets and taxation; and the world economy will be given a clean growth bias with concomitant inflation. The CES will not replace the floating exchange rate system for fiat currency convertibility because, while the 4C price will reflect systemic risk, the prices of existing fiat currencies can continue to float. Market actors will be able to trade 4C with the benefit of predictable prices defined by the 100-year advance 4C price alert. Rising 4C prices, for rising mitigation stringency, will stimulate trading in the deliberate 4C bull market (refer C in Figure 1).

This phase of 4C price appreciation will create private demand for 4C, thereby transferring mitigation costs into the private sector. The bull market will, by definition, provide a social 'tipping point' and momentum for decarbonising the economy. If the global mitigation effort is successful, then the RCC will tend to decline, as illustrated in phase D of Figure 1.

### 4.4. 4C supply-side management

The supply of 4C is managed through a common window: the 4C assessment system (refer Figures 4 and 5). This system will request 4C claimants to provide their data, and it will calculate 4C rewards based on rules and statistical significance tests. The system will also allow claimants to undertake self-assessments before applying for 4C rewards.

The recommended business model for 4C is a collaborative and decentralised commission-based system that offers auditing and assessment licenses through the Internet. Auditors and assessors will be assigned to 4C claims in ways that can reduce chances of collusion. The 4C assessments will adopt transparent rules that are tailored for each market sector and technology. An administrator will maintain a transparent ledger for each claimant's 4C carbon account and 4C service agreement lasting up to 100 years. 4C agreements may be enforced with digital contracts (e.g. Buterin 2014) that can cross-reference various databases. 4C systems can be rolled-out in stages for pilot testing and to help manage the supply of 4C (refer B in Figure 1).

### 4.5. 4C rules of assessment

Rules for assessing mitigation and 4C rewards will be devised to address each sector of the economy and a wide spectrum of technologies – to incentivise carbon abatement and sequestration, to account for additionality, and to support the risk management objective. The assessment rules will include a statistical assessment of historical emissions baselines, and a weighted decision matrix will also be applied to bias the rewards for social and environmental co-benefits. The details of all of the rules are beyond the scope of this exposition, however basic assessment rules for cleaner energy and industry are presented to be consistent with the policy's main aims.

The 4C rule for awarding cleaner energy supplies will be devised to assess energy delivered as solids, gases, liquids, grid electricity, batteries, etc., as required for decarbonisation (e.g. Heinberg and Fridley 2016). The rule will be to offer 4C when the embodied GHG intensity of the energy is less than a baseline defined by a suitable market average. Reward rules for energy will also include adaptive factors, so that cleaner energy technologies that have a significant capacity to scale-up are assigned a higher weighting relative to other energy technologies.

The 4C rule for rewarding industrial decarbonisation may be devised from the Kaya identity (Kaya and Yokoburi 1997). This rule should aim to incentivise cleaner growth by communities and enterprises, by accounting for the pollution embodied in their consumed goods, services and activities. The rule should not limit or penalise an enterprise if it experiences absolute growth or greater profitability. The 4C rule will assess GHG directly emitted and sequestered, and will assess the mass of GHGs embodied in the goods and services listed in outgoing cash-flow statements.

The Kaya-styled rule for industry may define the GHG mass mitigated ($m$) as follows: If the net consumptive GHG mass flux is $f$, and the outgoing cash flow is $c$, then the GHG emissions intensity of cash flow ($h$) equals $f$ divided by c. A percentage reduction ($r$) in $h$ relative to an individual historical baseline value, $h_o$, will be used to assess the relative mitigation performance of an enterprise. The GHG mass mitigated ($m$) equals $r$ multiplied by $f$.

### 4.6. 4C circulation

The Carbon Exchange Standard (CES) of Global 4C will ensure that market actors who are awarded 4C will be able to trade this 4C for other currencies and at prices publicly announced in the 100-year advance 4C price alert. The policy is to allow 4C to circulate globally in a low-cost (frictionless) digital network for trade. A digital computerised ledger that can reliably prevent 'double spending' is essential to this policy objective.

The policy is to ensure that each unit of 4C is digitally traceable to a valid mitigation audit. The integrity of 4C will be maintained by accounting for any defaulting of service agreements, such as when firms become insolvent or when policy freeriding or corruption occurs. Defaults will be reconciled with a globally uniform demurrage fee[3] that will be applied periodically and charged to all holders of 4C (globally) as a uniform percentage reduction of 4C held. This will recoup 4C that cannot otherwise be recovered from defaulted service agreements. The demurrage charge will be completed as a routine reorganisation of a computerised 4C ledger, and to ensure that all 4C in circulation remains digitally linked to valid mitigation audits. Specific rules and penalties for deterring freeriding and corruption may be negotiated as part of an international agreement.

### 4.7. Relationship to existing carbon markets

4C will be an international currency and will be created/issued as a reward for carbon abatement and sequestration. The relationship of 4C to existing carbon markets needs clarification, especially given that 4C has no precedents in the history of money.

It is already established that, under the Clean Development Mechanism (CDM) of the 1997 Kyoto Protocol (COP3) and 2012 Doha Amendment (COP18), carbon offsets/credits and Certified Emissions Reductions (CERs) can generate financial rewards for actors who mitigate carbon. These carbon offsets/credits attain their market value from cap-and-trade systems for polluters, and they can also attain value through voluntary purchases (e.g. when consumers voluntarily buy carbon offsets with airline tickets). Although 4C and carbon offsets/credits are both rewards, the Global 4C policy will only provide 4C rewards for carbon that is removed from carbon markets. In this respect, 4C will not be used to offset any pollution. This approach will be possible because the 4C currency will be directly valued as an asset under monetary policy (refer the Carbon Exchange Standard), and not indirectly through taxes and caps on pollution. As more carbon is rewarded with 4C, the quantity of carbon available for trading as carbon offsets/credits will decline. The 4C price can thus force higher prices for carbon offsets/credits by outbidding the market price of carbon offsets/credits. The operational objective of this 4C system will be to incentivise actors to earn 4C in return for abating carbon emissions at their point of release (esp. in Annex I countries), for sequestering atmospheric carbon, and for avoiding goods and services that have high embodied carbon emissions.

Given that 4C will be priced independently of existing carbon markets, the awardees of 4C might not be required to meet the same additionality conditions that are essential to the CDM. This is because 4C will be issued under its own baseline-and-reward rules to achieve a global risk management objective. There may be a temporary testing phase when 4C is traded like CERs under the CDM, but if this were to occur, the 4C units that are traded as CERs would be deposited into 'frozen' accounts and removed from circulation.

## 5. Normative policy justification

### 5.1. National responsibilities & climate pledges

Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC) are principles that were written into Article 3 of the UNFCCC (1992) at the 'Rio Earth Summit'. CBDR-RC provides clarity that, whilst nations have a common responsibility to address climate change, nations may respond in proportion to their historic and economic situation. The Intended Nationally Determined Contributions (INDCs) accepted under the Paris Agreement (UNFCCC 2015) are consistent with these CBDR-RC principles, but unfortunately the aggregate of the INDCs has resulted in an emissions gap (e.g. Rogelj et al. 2016) and might fail to protect '… the climate system for the benefit of present and future generations of humankind … ' (UNFCCC 1992). It is suggested here that CBDR-RC principles should be complemented with new principles that can address the emissions gap and respond to the emerging risk (see below).

### 5.2. Collective insurability & insurance premium

A major new principle is suggested here for inclusion in the UNFCCC to address the emissions gap and the emerging climate risk, and to create a roadmap for the Global 4C policy. This principle is called *Collective and Systemic Risk Insurability* (CASRI), and it is complementary to CBDR. The CASRI principle is to accept that the CBDR principle is imperfect, and that all nations should insure against a climate systemic failure. The insurance premium should be sufficient to safeguard the world's people, ecosystems, and economies against the possibility of dangerous-to-catastrophic climate change and cascading impacts.

CASRI requires that a risk limit be defined (refer the SRCMF), and that additional required climate mitigation be financed by the insurance premium. The CASRI principle relates to Article 8 of the Paris Agreement ('Risk insurance facilities, climate risk pooling and other insurance solutions') but it does not relate to compensation for damages.

By combining CASRI with Respective Capabilities (CASRI-RC), all market actors are invited to mitigate GHG emissions in return for financial rewards. Policies based on CASRI would support the Paris Agreement (Article 2) by evaluating top-down quotas for cumulative global GHG pollution and mitigation. This approach is complementary to the bottom-up approach of voluntary INDCs under the Paris Agreement.

### 5.3. Global 4C rewards

4C rewards (ex-post) for mitigation services may be justified as a Payment for Ecosystem Services (PES). Historically, PES is paid to farmers and landowners in private agreements for undertaking a variety of ecosystem services (e.g. UNEP 2007; Jayachandran 2013). Tacconi (2012) defines PES broadly as ' … a transparent system for the additional provision of environmental services through conditional payments to voluntary providers'. 4C rewards only differ from PES by setting the goalposts at the global scale for systemic risk management. PES helps to validate the 4C approach by providing social and scientific benchmarks.

By offering 4C rewards for climate mitigation services, a new global service industry for parties to the Global 4C policy would be created, because nations could earn 4C as foreign income. The new opportunities in mitigation would be on a par with international tourism, but would also generate multiple co-benefits that include food, water and energy security, and new employment in sustainable development.

### 5.4. Central bank role

The Global 4C policy would give central banks the macro-prudential role of managing climate systemic risk and within a broader mandate for ensuring financial stability (e.g. IMF 2013). This role would involve charging an inflation levy (as a kind of insurance premium based on the CASRI principle) and spreading the inflation uniformly across the world economy. This inflation levy would be managed under the Carbon Exchange Standard (CES). At the heart of the CES is the adoption of '100 kg of $CO_2$-e mitigation services' as the *unit-of-account* for the 4C currency, and this would integrate carbon directly into international finance. This macro-prudential role for central banks (refer Figure 5) may be further validated if it can be shown that: (a) carbon affects the long term stability of the climate and the health of the economy; (b) monetary policy can reliably generate climate finance over the long term; and (c) the 100-year advance 4C price alert (Figure 1) and the uniform inflation levy can reduce climate systemic risk.

### 5.5. Carbon quantitative easing (CQE)

Around the time of the 2007–8 global financial crisis, quantitative monetary easing (QE) (Werner 1995) had become an intermittent policy of some central banks to increase financial liquidity in markets and to deleverage debt (UNEP 2009; Roxburgh et al. 2011; Dobbs et al. 2015). This QE involved 'printing' digital fiat, and the various QE programmes were controversial because some of the financial liquidity did not transmit through the financial sector and into the real economy (e.g. Lyonnet and Werner 2012).

The Carbon Exchange Standard (CES) invites a new method of QE that should be more strategic and coordinated than previously experienced, and it is termed *Carbon Quantitative Easing* (CQE). CQE will be different to regular QE by allowing the central banks to transmit financial liquidity past the financial sector and directly into projects that provide climate mitigation services and related environmental and social co-benefits. Central banks will achieve this transmission by continuously setting the 4C price and yield with currency interventions that are funded by CQE. CQE will enable the transfer of purchasing power directly into 4C for globally rewarding climate mitigation, thereby boosting long-term green investment and incentivising cleaner economic activity in terms of new infrastructure, R&D, employment and training. The CQE concept has some overlap with proposals for *Public Money Creation* (van Lerven 2016) and *Green Quantitative Easing* (e.g. Ferron and Morel 2014), but CQE has a much more focused agenda and is reliant on the 4C currency instrument.

## 6. Discussion

### *6.1. Holistic market hypothesis*

The Holistic Market Hypothesis (HMH) is a new hypothesis that the market failure in GHG pollution is creating two externalised costs: (Type I) the Social Cost of Carbon (SCC); and (Type II) the Risk Cost of Carbon (RCC) (refer Table 3). The epistemology of Market Policy Dualism (MPD) was used to derive Global 4C as a complementary market policy that can internalise the RCC by directly limiting the risk of catastrophe. The HMH aims to verify that the SCC and RCC coexist in a cost *duality*[4] and without paradox (see Figure 6). By a duality, it is claimed that the two costs are associated with independent modalities, policy objectives, and instruments, and are therefore soluble under the Tinbergen Rule (Tinbergen 1952). A key inference of the HMH is that the RCC is an externalized cost that should be added to the SCC to demarcate the Total Cost of Carbon (TCC), as illustrated in Figure 7. A theorised interdependence between the SCC, RCC and TCC is described in Appendix A based on a hypothetical example.

The SCC-RCC duality is an understanding that two complementary price signals are needed to manage the economy for stabilising the Earth's climate system. The duality is the result of two stakeholders with mutual goals and modalities, namely: (Type I) many

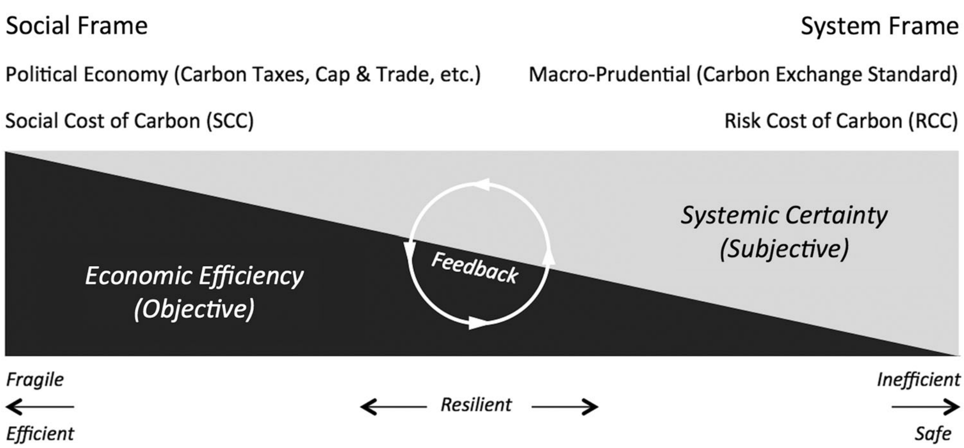


**Figure 6.** The SCC and RCC exist in a duality, based on complementary frames of reference: (left) a social frame that seeks objective efficiency by internalising the SCC, and (right) a system frame that seeks subjective certainty by internalising the RCC.

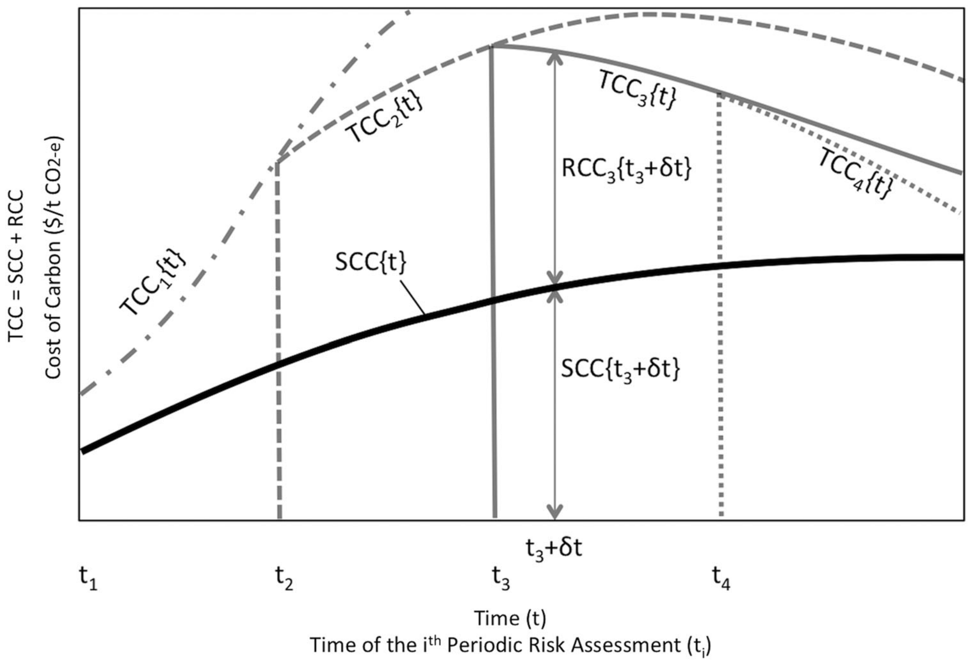


**Figure 7.** Hypothetical storyline for the SCC, RCC and TCC when correcting a market failure in greenhouse pollution. The figure shows the three costs retrospectively, such that the SCC is shown ex-post, and the RCC is shown ex-ante based on four hypothetical risk assessments (see Appendix A for clarification).

individuals in a society who are concerned with costs and objective efficiency, and (Type II) a single institution for the world economy that is concerned with systemic risks and subjective probability. A metaphor is to consider the Type I stakeholders as a collection of cells that comprise an animal, and the Type II stakeholder as the animal's cognition. If a carnivorous predator chases the animal, the animal will flee with a Type II response, and the energy expended by the cells is the premium of a biological insurance policy for managing systemic risk.

The HMH is a theory that the SCC and cost-benefit analysis are inadequate for addressing the problem of climate systemic risk, primarily because the SCC framework is not designed to account for thermodynamic boundaries and emergent socio-physical behaviours within the economy: features that may greatly influence climate systemic risk. For example, integrated assessment models (IAMs) for the SCC cannot predict the full consequences of shifting political power, radical financial innovations, institutional failures, or resource wars. The SCC is typically estimated using models of the economy-climate system that are limited to neoclassical economic methods, including a subjectively chosen rate of time discounting to represent society's willingness to pay for future benefits (e.g. Weitzman 2012). An example of a systemic risk is the observed sea-ice melt and thawing of permafrost that may be a harbinger of a climate tipping point (Lenton 2012; Cai et al. 2015). Further contributing to the systemic risk problem is the possibility that the Earth's climate sensitivity could increase with global warming (Sherwood, Bony and Dufresne 2014; Friedrich et al. 2016). In light of these and other uncertainties inherent to the SCC, certain published SCC estimates and associated cost-benefit analyses have attracted criticism and counter claims (e.g. Weitzman 2009a, 2009b, 2011, 2012, 2013; Nordhaus 2009; Dietz 2011; Hwang, Reynès, and Tol 2011; Pindyck 2010, 2013). Weitzman (2011, 8) brings these issues to a head by stating:

> An unprecedented and uncontrolled experiment is being performed by subjecting planet Earth to the shock of a geologically-instantaneous injection of massive amounts of GHGs. Yet the standard CBA [cost-benefit-analysis] seems almost impervious to the extraordinarily uncertain probabilities and consequences of catastrophic climate change.

Indispensable to the HMH, and an enhancement to Coase's (1960) original article on social cost and agent bargaining, is Garrett's (2012, 2014, 2015) top-down understanding of civilisation as a system that dissipates energy to maintain its structure - as defined by the 1st and 2nd Laws of thermodynamics. Garrett's (2012, 2014, 2015) model of the world economy crystallises this view, by relating civilisation's dependence on energy to an empirical measure of its accumulated wealth, as follows:

$$E(t) \simeq c(t)\,\lambda \sum_{i=1}^{t} \mathrm{GWP}(i) \quad (1)$$

where, $E$ = total mass of $CO_2$ emissions per year; $c$ = average $CO_2$ emissions intensity of energy; $\lambda$ = average power consumption per unit of currency ($9.7 \pm 0.3$ mW per 1990 USD); *GWP* = Global World Product as an empirical feature of wealth; and $t$ = time in years.

Garrett (2012) assumes that civilisation's wealth can be reliably modelled as a single homogeneous process with characteristic energy throughputs and $CO_2$ emissions. Because the model is well calibrated to historical data, Garrett (2012) is able to give a prognostication of civilisation's future $CO_2$ emissions. His forecast is that an extremely dangerous amount of anthropogenic $CO_2$ is likely to be released this century, thus posing a systemic risk that could be much greater than the risk posed by uncertainty in the underlying climate sensitivity. Garrett's (2012) forecasting is based on the idea that civilisation has a characteristic socio-physical structure that determines its future energy demand – similar to the way that the biology of an organism determines its energy requirements.

The HMH can address the energy and $CO_2$ inertia identified by Garrett (2012) by introducing the concept of a 'latent cost', which is a cost that is missing in standard SCC estimates but can be accounted for with the RCC and risk-cost-effectiveness analysis. The latent cost is analogous to the latent internal energy of water as it undergoes a structural change when it melts from ice to liquid. The latent cost of civilisation's decarbonisation is likely to be invisible in a bottom-up analysis of abatement costs and marginal damages, because it is an emergent property of the system and is determined by structure. This structure is an ensemble of social and physical relationships that are analogous to threads interwoven into a fabric.

According to Garrett's (2012) model, the fabric of relationships is biased for wealth preservation and dirty growth: an example of Jevons effect. Contributing to this fabric of relationships is the fiat currency system with its innumerable agreements for commercial money lending that oblige economic growth to repay debt with interest (e.g. Lietaer et al. 2012). An observable effect of the fabric is political conflict and delay over carbon pricing and cost sharing (e.g. Rogelj et al. 2013).

A policy for internalising the RCC with currency/rewards (i.e. Global 4C) should incentivise new social networks that can bypass the old relationships and abate dirty growth and provide co-benefits (refer b & c in Figure 2; refer Figure 5). The currency/rewards for internalising the RCC are channels for the precautionary principle, but they also require a subjective political decision for placing a limit on systemic risk. This politically decided limit to climate systemic risk should generate a single RCC estimate that complements all regional SCC estimates. In broad terms, the RCC is defined as a latent cost of climate mitigation that results from (a) scientific understanding of the thermo-economic system, and (b) normative preferences for macro-prudential governance. If the Holistic Market Hypothesis (HMH) is correct, then the RCC should be added to the SCC to define the Total Cost of Carbon (TCC) (see Appendix A for clarification). The resulting SCC-RCC duality also invites a reinterpretation of Coase's (1960) theory for managing social costs under the 'Pigovian tradition', and more specifically, it invites a new and more general theory for global carbon pricing.

Although economists have been successful in addressing efficiency for over a century (e.g. Pigou 1932; Coase 1960; Fama 1970), the economic efficiency paradigm is failing to address climate systemic risk, as exemplified by unrelenting dirty growth (e.g. Sustainable Development Commission 2009; WEF 2016) and the anticipated Jevons effect (e.g. Garrett 2012). Given that the HMH seems to address some major economic dilemmas with an interdisciplinary system theory, the term 'Holistic' was chosen to name the hypothesis. By deduction, the SCC-RCC duality of the HMH is ultimately a dualism between (Type I) maximisation of utility and neoclassical economics, and (Type II) macro-prudential governance and *Systemic Darwinism* (Winther 2008). This dualism offers a fundamentally new climate mitigation roadmap (refer Discussion) that might reduce incoherence in the narrative of stakeholders, especially in regards to the various scientific, political and ethical perspectives on climate uncertainty and risk (refer Knutti and Rogelj 2015; IPCC 2014b). In the very least, the HMH and the SCC-RCC duality offers some additional defense against radical uncertainties, or the unknown-unkowns, as described by Knight (1921), Keynes (1921), King (2016) and others.

Testing the HMH ought to include analytical solutions and falsifiable examples based on Integrated Assessment Modelling (AIM), agent-based modelling, field studies and analogues. A partial validation of the HMH is provided by Andreoni, Harbaugh, and Vesterlund (2003), who investigated the social implications of 'carrots and sticks' under controlled conditions. They found that these complementary incentives improve social cooperation when compared with 'just carrots' or 'just sticks'.

### 6.2. Parallel world currency for climate change mitigation

Complementary Currencies for Climate Change (4C) could be the world's first official *service currency* (i.e. the unit-of-account defines a service). It would also be a parallel currency with a managed price. The Carbon Exchange Standard (CES) should dynamically set the value of 4C to hard currencies, and in doing so it should also set the minimum value of $CO_2$-e mitigation services in international, national and local markets. 4C is not intended as a replacement or rival to national currencies.

The CES is a monetary institution that may be loosely compared with the Gold Exchange Standard of the 1944 Bretton Woods Conference (i.e. when the USD was fixed to gold commodities at USD $35 per 1 oz. of gold). The CES is unique because an intentional multi-decade 4C bull-market is proposed for the rising phase of the 100-year advance 4C price alert (see C in Figure 1). This 4C bull-market (mirroring the 100-year RCC estimate) will attract private equity into 4C and a new market/group dynamic that could see reticence and deliberation replaced with strong action on climate mitigation. The 4C bull-market could stimulate massive new innovation, including a plethora of new micro-financial relationships between people (P2P), between businesses (B2B) and between machines (M2M) around the globe.

Over the long term, 4C might incentivise a myriad of new 'intelligent' social networks that unite people for 4C rewards. It is speculated that these social networks could enhance global unity over mitigating climate change, and may even emerge as a decisive factor in avoiding a dangerous tipping point. In the short- to long-term, 4C is recommended as the most practical instrument for delivering the following services:

- global rewards for financing GHG mitigation and accounting for carbon,
- global pricing for communicating systemic risks and mobilising markets,
- global rulings for coordinating market actors and sharing data,
- global incentives for ecological and social co-benefits, and
- global valuation for scaling solutions and maximising innovation.

### 6.3. Roadmap for policy adoption

The roadmap for Global 4C is pro-active and may begin by inviting economists, scientists, actuaries and bankers to provide their interpretations of the SCC-RCC duality. A vigorous discussion of climate systemic risk may attract the attention of governance and policy institutions, and it may inspire validation studies and economic policy evaluations.

The roadmap to policy adoption will seek the help of a consortium to finance 4C system research and development, and to establish standards for 4C interoperability. This may include venture partnerships, capital raising, share offerings, and crowd funding for seed finance. The 4C system architecture and business model should be designed for scalability and to synergise with social networks. 4C should also be trustworthy and reliable, and should utilise new digital technologies such as smart contracts. Investors stand to earn percentage commissions on future 4C trade in climate mitigation, and the global market is potentially worth 100's billions to trillions of USD-equivalent per annum (e.g. IEA 2015; Global Commission on Economy and Climate 2014).

Governance and political discussions about 4C should occur in parallel with the development of 4C pilots. Support from parties to the Paris Agreement (COP21) may bring 4C into the UNFCCC and Clean Development Mechanism (CDM) for field testing, and this will give central banks an opportunity to test interconnections with 4C via the Forex. 4C may be officially discussed and negotiated under the UNFCCC or in the U.N. Security Council (Caraman 2015).

This roadmap would be less arduous with the help of a grassroots movement that holds 4C as a partial 'solution' to the climate crisis and a farsighted response to moral hazards in the economy. To aid such a movement, the authors recommend the '*Solar Dollar*' (SOL) as a culturally suitable trading name for 4C (and ISO 4217 registration).

Policy adoption cannot rely on ad-hoc academic research that could take decades. A compressed research schedule is needed, perhaps akin to a private 'Manhattan Project' (but costing less). The other side of the coin is the political risk of investing in the 4C parallel currency. To offset this risk, there needs to be a clear commitment from a world institution or banking/insurance association that has an appetite for a 'Marshal Plan' for the climate. Important to note is that the 4C system can be developed prior to inter-governmental agreements.

## Notes

1. This is investment additional to USD $318 trillion that is expected to be invested anyway in a business-as-usual 6°C warming scenario of the IEA (2015).
2. The Tinbergen Rule states that for each and every policy target there must be at least one tool, and if there are fewer tools than targets then some targets will not be achieved (Tinbergen 1952; Knudson 2009).
3. 4C that is 'frozen' in accounts as part of an interfacing carbon-trading scheme may need to be isolated from demurrage fees because this carbon may be permanently allocated.
4. An example of a 'duality' is the wave-particle dualism expressed by the quantum wave function and in accord with the complementarity principle of Niels Bohr (1937). The complementarity principle, along with the uncertainty relations of Heisenberg (1999) and other related works, demarcate the great transition from classical physics to quantum physics during the early 20th century.

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## Notes on contributors

*Delton B. Chen* is an Australian civil engineer who holds a Bachelor of Civil Engineering and Ph.D. in Chemical Engineering from the University of Queensland. Dr Chen received his Ph.D. for his research on the hydrogeology of Heron Island in the Great Barrier Reef. Dr Chen has developed a variety of models for assessing groundwater, mine plans, environmental impacts, 'hot rock' geothermal power and greenhouse mitigation. Dr Chen is a co-founder of 'Global 4C' and a pioneer in monetary philosophy.

*Joel van der Beek* is a Dutch economist who holds a Master of Arts in Development Economics and International Development from Erasmus Universiteit, Rotterdam. Mr van der Beek is owner and chief economist at EconoVision and manager of EconoTalent based in the Netherlands. Mr van der Beek has worked in various fields of economics, including infrastructure, development, healthcare, and international aid. Mr van der Beek is co-founder of 'Global 4C' and serves on the board of Economists for Peace and Security.

*Jonathan Cloud* is an American sociologist who holds a Master in Sociology from York University in Toronto, and a Bachelor Degree in Psychology from Victoria University of Wellington, New Zealand. Mr Cloud is executive director of the Center for Regenerative Community Solutions and New Jersey PACE (501(c)(3) non-profit) and is senior fellow at the Institute for Sustainable Enterprise, Fairleigh Dickinson University. Mr Cloud has developed legislation for small hydro, energy, and PACE; and consults on sustainability and renewables. Mr Cloud is co-founder of 'Global 4C' and serves on the boards of several non-profits.

## ORCID

*Delton B. Chen* http://orcid.org/0000-0001-6519-5302
*Joel van der Beek* http://orcid.org/0000-0002-9899-268X

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## Appendix A – Additional Information for the Holistic Market Hypothesis

*Total Cost of Carbon (TCC)*

Two types of externalised cost related to GHG pollution are theorised with the Holistic Market Hypothesis (HMH), namely: (Type I) the Social Cost of Carbon (SCC) as conventionally defined in the literature (e.g. Tol 2009; IAWG 2013); and (Type II) the Risk Cost of Carbon (RCC), defined as the market price of each metric tonne of additional $CO_2$-e mitigation service that is needed to reduce climate systemic risk to an agreed limit. Estimating the RCC requires a risk-cost-effectiveness analysis, and it is expressed as a price ($) per 1000 kg of $CO_2$-e mitigation assuming reliable service for up to 100 years. The RCC is internalised into the economy with currency/rewards for the additional mitigation service, and although the RCC is presented as a cost, the currency/reward will be treated as an asset under monetary policy. The Total Cost of Carbon (TCC) is the sum of these two externalised costs, as follows:

$$\mathrm{TCC}_i\{t\} = \mathrm{SCC}\{t\} + \mathrm{RCC}_i\{t\} \quad (2)$$

where SCC = Social Cost of Carbon ($/t $CO_2$-e); RCC = Risk Cost of Carbon ($/t $CO_2$-e): SRCMF Actual→ SRCMF Limit; TCC = Total Cost of Carbon ($/t $CO_2$-e); SRCMF{ΔT,Y} = Systemic Risk of a Climate Mitigation Failure (probability %); ΔT = global average surface temperature anomaly (°C) as a systemic risk; Y = future time of a systemic risk (calendar year); $t$ = time; $i$ = time period of a periodic risk-cost-effectiveness assessment.

*Hypothetical mitigation storyline*

A hypothetical retrospective storyline is illustrated in Figure 7 to illustrate the potential behaviour of the SCC, RCC and TCC as cost metrics. This storyline assumes that carbon taxes (not shown) and 4C rewards (not shown) were applied during four time periods to address a market failure in GHG pollution. It is assumed that the 4C price was managed to reflect the four RCC time-series that were estimated with risk assessments at the start of each period (see $t_1$, $t_2$, $t_3$ and $t_4$ in

Figure 7). It is assumed that the risk assessments took into account structural barriers to mitigation, including physical, social, political and financial barriers.

In the hypothetical storyline, the SCC varied while the market responded to the price signals for pollution and mitigation. The RCC and TCC estimates were the greatest at time $t_1$ because there was (hypothetically) least certainty about the market's ability to address structural inhibitors to mitigation. The four RCC and TCC forecasts in Figure 7 may be metaphorically described as casting a reward 'net' into the future to increase mitigation rates, and potentially to produce structural change. A larger RCC forecast implies that a more steeply rising '100-year advance 4C price alert' and a bigger 'net' are needed (refer Figure 1). In this hypothetical, the RCC and TCC forecasts lessened with time, and this is to illustrate a case when a market failure is ameliorated (hypothetically). If the TCC were to increase progressively with each risk assessment, which is not the situation shown in Figure 7, then the market failure might be described as an uncontrollable hazard.