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Decarbonizing Bitcoin: Law and policy choices for reducing the energy consumption of Blockchain technologies and digital currencies

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ABSTRACT

The vast transactional, trust and security advantages of Bitcoin are dwarfed by the intentionally resource-intensive design in its transaction verification process which now threatens the climate we depend upon for survival. Indeed Bitcoin mining and transactions are an application of Blockchain technology employing an inefficient use of scarce energy resources for a financial activity at a point in human development where world governments are scrambling to reduce energy consumption through their Paris Agreement climate change commitments and beyond to mitigate future climate change implications.

Without encouraging more sustainable development of the potential applications of Blockchain technologies which can have significant social and economic benefits, their resource-intensive design combined now pose a serious threat to the global commitment to mitigate greenhouse gas emissions. The article examines government intervention choices to desocialise negative environmental externalities caused by high-energy consuming Blockchain technology designs.

The research question explores how to promote the environmentally sustainable development of applications of Blockchain without damaging this valuable sector. It studies existing regulatory and fiscal policy approaches towards digital currencies in order to provide a basis for further legal and policy tools targeted at mitigating energy consumption of Blockchain technologies. The article concludes by identifying appropriate fiscal policy options for this purpose, as well as further considerations on the potential for Blockchain technology in climate change mitigation.

1. Greenback or back to green: how green is your digital currency?

1.1. Bitcoin threatens our existence while Blockchain can benefit us

The purposefully energy-intensive design of many Blockchain[1] technologies [1,2] means that combined they now pose a serious threat to the global commitment to mitigate greenhouse gas emissions (GhGs) pursuant to the Paris Agreement [3]. One of the many adoptions of Blockchain technology has been in financial technology such as digital currencies, the most famous being Bitcoin [4].[2] Despite digital currencies providing considerable potential transactional, security [5], and financial access benefits [6], the design of Bitcoin's mining and trading system requires such a vast consumption of electricity that it is equivalent to powering Denmark [7]. This threatens the planet to the extent that intervention is necessary to prevent similar models emerging. Even the processes involved in a single Bitcoin transaction could provide electricity to a British home for a month [8,9], with environmental costs socialised for private benefit [10].

Indeed the libertarian promise[3] [11] of a decentralized and secure

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[1] "Blockchain is a type of distributed ledger, comprised of digital records of transactions or assets, accessible to and trusted by all participants running the same protocol.… The fundamental innovation of blockchain is that it creates a means of establishing and maintaining consensus among the participants in a transaction without the need for either an established trust relationship or a central intermediary." See [1].

[2] For a background of its functionality, see Part I of A. Welch [4].

[3] See [11] at p. 6.

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peer-to-peer payments system [12] have largely been substituted with the speculative pursuit of private wealth creation with little social utility [13].[4] The problem will only worsen. The higher the value of Bitcoin, the greater the incentive to mine, and new digital currencies will be developed with similar carbonized models. Giungato et al. demonstrate that Bitcoin's system has been designed to require even greater computational power and therefore energy consumption to be mined in future.[5] Bitcoin has been designed with no consideration of its environmental impact. This is an inefficient use of scarce economic resources at a time when world governments are seeking to reduce energy consumption [14].[6] However, as the underlying technology can offer significant benefits, it is here to stay, so future models must be designed without reliance on energy consumption so disproportionate to their economic or social benefits.

1.2. How can we encourage tech to develop decarbonised Blockchain?

Nevertheless, the financial [15] and multi-sectoral [16,17] utility benefits of Blockchain technology are potentially enormous, with skilled job creation, investment and wealth creation going hand in hand with considerable advances in security and applications that can produce innumerable functions to benefit society, industry, and governance [18]. Blockchain technology has been advocated as being capable of delivering environmental and social benefits under the UN's Sustainable Development Goals [19]. It has already proven itself to be useful across a range of sectors including the financial technology sector. Financial technology is one sector that ought to be encouraged and facilitated, given its significant potential for economic gains and social utilities [20]. It is a paradigm shift in the economic structure of the market, the way transactions are carried out, and the way wealth is held. Nations discouraging Blockchain innovation will miss out on the infancy of the industry and the future benefits it brings once it is established, and those jurisdictions focusing upon restricting digital currencies will not prevent it from becoming universally accepted but will miss out on the benefits of its growth.

The question is how to encourage a shift to less energy intensive Blockchain technology without damaging the sector. Any market interventionist measure into the industry developing Blockchain technologies ought to be clearly measured to avoid harming or discouraging the financial technology sector or, indeed, the cryptocurrency industry per se.[7]

1.3. Research design

The article's research question examines how to desocialise the environmental costs of Blockchain technologies in a manner that will incentivize the development of a less energy intensive means of wealth creation, without discouraging the industry overall [21]. This could produce far-reaching benefits not just in terms of the development of an environmentally sustainable and profitable financial technology sector but it could go further in directing the technological innovators towards climate mitigation goals. The approach is structured as follows.

1.3.1. Rationale for market intervention

Prior to any exploration of government intervention choices, the article reviews compelling reasons why market failure is causing negative climate implications. Building on existing scholarship, this section identifies that technological advancements that were expected to produce positive results are now threatening our existence. Drawing upon the global programme for climate change mitigation and international principles of environmental law, it then provides a reasoned argument why a failure to intervene in the design of Blockchain technologies is not an option. This invokes key debates in economic and legal philosophical theory as well as international environmental law principles and global agreements. Word constraints limit this section, which is indeed an article in itself, so only a summary is provided.

This section points out that perversely taking no action means we are actually subsidisizing high energy-consuming technology and causing future developers to follow the same harmful path. It provides an explanation of the rationale for the internalization of negative environmental costs in order to reduce energy consumption of Blockchain technology applications. This is needed prior to any meaningful discussion of policy choices to achieve such internalization to promote behavioural change in the type of technology being designed.

1.3.2. Existing policy choices

Existing policy measures towards Blockchain technologies have focused upon one segment of their uses, namely digital currencies. This has included both regulating their use and consequently taxing their ownership. As the only precedent available of policy measures towards Blockchain technologies, this section analyses how the law has managed in differing jurisdictions to bring digital currency ownership within charge. Understanding this makes it possible to consequently determine how fiscal policy tools can apply to other applications of Blockchain technology in order to internalize negative externalities.

This first requires a qualitative assessment of case law, regulatory decisions, and policy to determine how regulators are to legally define digital currencies, before providing an overview of methods to bring them within the purview of the tax code. This shows that existing approaches have commonly utilized regulatory tools at first and followed this up with fiscal tools including taxes. Having brought this form of financial technology within the jurisdiction of taxation, this dual regulatory and fiscal approach provides an established path for further fiscal tools to incentivize reduced energy consumption Blockchain technology design.

1.3.3. Policy choices

After establishing how the law has managed to classify digital currencies and consequently receive revenue from them, the article enables an understanding of the legal and policy options available for environmental cost internalization and how they could be associated with existing taxes. The article then evaluates possible fiscal tool options upon Blockchain technology generally, that both facilitates digital currencies but also other utilities such as smart contracts [22].[8]

The article concludes by identifying appropriate fiscal policy options for this purpose, as well as further considerations on the potential for Blockchain technology to achieve climate change mitigation. The implications of the findings are global, with the intention to present policy tools available to different lawmakers depending on the reality of the situation. As such the article is not focused upon any particular jurisdiction and takes examples from various States.

[4] Joseph Stiglitz [13]: "[Bitcoin] doesn't serve any socially useful function" and "[Bitcoin] out to be outlawed."

[5] Since the majority of Bitcoins have been mined already. Bitcoin's "system has been built in a way almost like the mining of a natural resource: costs and efforts rise as the system reaches the ultimate resource limit…the "mining" of new bitcoin requires more and more hardware resources necessary to "mine" each bitcoin when approaching the capped limit of the bitcoin system." [14].

[6] As argued by Jeff Spross [15]. See also [11] at p. 3.

[7] The author is grateful for the advice in helping define the topic of Dr. Raphael Brown, Law Professor and Researcher at the Centre for Law & Development, Qatar University.

[8] "The idea of smart contracts is that by formulating contractual arrangements between parties into computer code format and storing them into a blockchain, contracts can be made tamperproof, self-executing and automatically enforceable." [23].

2. Rationale: are we subsidizing power-thirsty technology?

2.1. Technology benefiting the environment

Technological innovation has largely been expected to produce positive benefits for the environment, such as being able to find solutions to environmental problems and produce clean energy [23]. Thus far Bitcoin's energy-intensive design has proven this not to be true. Referring to technological advancements often being the "myth of progress" [24] in society, Stirling had (skeptically) pointed to the hopes that a "'progressive' transformation" in energy, technology and society that would "harness diverse proven viable global renewable resources and innovations to deliver energy services at the same time as eliminating carbon emissions and realising other Sustainability benefits" [25]. The utilization of technology that produce energy inefficiencies would be a perverse use of such technology.

Chapron advocates in *Nature* for the adoption of Blockchain technology to more effectively protect the environment [26]. This would be counter-productive if the governance technology is itself environmentally harmful. Bitcoin's own website claims that "Bitcoin Mining is intentionally designed to be resource-intensive and difficult so that the number of blocks found each day by miners remains steady over time, producing a controlled finite monetary supply" [27]. The miners verify the transactions of Bitcoin, and receive Bitcoin as a reward. Though the economic reasoning has produced a lucrative business model, the intentionally resource-intensive nature of the mining process causes undue environmental damage through high rates of electricity consumption and emissions. Based on its decentralized network, the peer-to-peer verification processes is itself a polluting process. To work effectively, the machine hardware used to "mine" Bitcoin consumes electricity at a high rate 24 h a day, producing vast amounts of heat and emissions. One of the best models weighs 8.1 pounds and has an energy consumption rate of 0.098 W/Gh [28]. Professional mining "farms" have warehouses full of such machines [29], often opting for cold climates to avoid the need to air condition or ventilate the room [30].[9]

Bitcoin has been used here as an example of the polluting nature of Blockchain technology. A similar study on the growing demand for energy to power internet traffic and data access was conducted by Morley et al. [31]. This identified that some service providers are aware that their services cause high energy consumption and have modified or advanced their technology to enable "data efficiency." It cites Netflix as having improved technology to deliver "the same services but with less data" due to improved "efficiency of encoding and transmission of data [32]." The purpose herein is to propose that other digital currencies and applications of Blockchain technology adopt less energy intensive alternatives.

2.2. Government intervention and cost internalisation

The decision to intervene in the free market (and in this case risk damaging a vital economic industry) is never an easy one; legal philosophers and economists have been debating this throughout history. The free market advocate Mill's utilitarian justification for intervention was strictly limited as "the only purpose for which power can be rightfully exercised over any member of a civilised community, against his will, is to prevent harm to others" [33]. In this case environmental harm would meet such a criteria.

Bitcoin's decentralized model has made regulatory efforts difficult, so determining who ought to be responsible for taxes or charges, and how a State may implement them, is problematic. *Pigouvian* economic theory promotes intervention and cost internalisation to correct market failures and internalise negative externalities [34]. Coase's criticisms [35] of Pigou on the basis that the market itself is best placed to correct such externalities was described as a fantasy by both Halpin [36], who identified that Coase did not take into account real-world economic factors, and Chen who described Coase's world with zero transaction costs as a "fantasy" [37].

Internationally accepted environmental principles advocate the need to internalise negative externalities such as from polluting industries [38].[10] Within the EU (European Union) this polluter-pays principle is enshrined in Article 191(2) of the Treaty on the Functioning of the European Union, the Organisation for Economic Cooperation and Development have for long been an advocate of this principle [39], and is endorsed by virtue of Principle 16 of the Rio Declaration [40]. The purpose is not simply to raise revenue, but making polluters financially responsible for the harm caused encourages a switch in the activity to a less polluting method as well as de-socialising the cost [41,42]. The OECD refer to this as a "continuous incentive for pollution abatement and technical innovation" [43]. Taxing plastic bags, for example, leads to a switch to paper bags. The design of the tax has to take account of who should ultimately be responsible for the charge or where "final incidence" should fall, in this case the consumer shopper, as opposed to the supermarket.

The decision to internalize such costs ought to be an easy one. Every signatory to the UN Paris Agreement [3] has not only agreed to attempt to hold global temperatures within 2 °C above pre-industrial levels (Article 2(a)). They have also agreed that global finance ought to flow towards enabling low greenhouse gas emissions, (Article 2(c)) so arguably those nations enabling finance to flow towards a highly polluting industry are violating the Agreement. Furthermore, the Agreement mentions numerous times that technology should be utilized to achieve greenhouse gas mitigation, whereas a highly polluting use of technology would very much go against the spirit of the agreement, if not the commitments made. Stiglitz makes the case that by not pricing global external costs that are harmful to the environment, nations are actually contributing a de facto subsidy to the polluter since the external costs are then costs to the public at large and thus the responsibility of the taxpayer [44]. Such failure to charge would meet the OECD definition of "implicit subsidies [45]."

2.3. Path dependence and intervention

A failure to intervene would also mean future applications of Blockchain technology would not be discouraged from designing similarly energy-intensive technology. Indeed, a lack of intervention may make it more likely that new technologies would follow the route taken by Bitcoin. This is known as "path dependence," which is described as the "inertia of prior choices constraining future pathways, based on self-reinforcing limits like sunk investment costs; increasing returns; interrelatedness of technologies; and network effects. . . this idea explains why new energy technology, may not be adopted even if it is superior and/or economically feasible" [46,47].

As such, the decision for policymakers ought to be how, not whether to, internalize such costs. In *Choices on the Road to the Clean Energy Future*, Cash identifies that the "most successful examples of clean energy economic growth, innovation and deployment are in areas where smart government regulation has provided clarity and certainty and rules that incentivize a robust market. In these areas, the right market signals create the right landscape for investment, adoption of technologies and clean energy job growth" [48]. Demonstrating the need for some kind of government intervention to promote clean economic growth, in the sector in question, there are a variety of regulatory and fiscal tool options available to policymakers.

[9] Cheap electricity and a cool climate are two of the three factors determining where to locate such mining farms [31].

[10] The Stern review advocated using carbon pricing [39] through taxation so that "people are faced with the full social cost of their actions."

3. Has Uncle Sam taxed Bitcoin?

Before determining how to introduce any type of government intervention, it is necessary to consider existing measures that have been applied to Blockchain technology. Regulatory measures to promote and control the trading and holding of the financial technology sector for economic reasons has been examined in existing literature [49–51], though the challenge of regulating the designs of Blockchain technology, itself, for environmental purposes has not been taken up by regulators.

Much focus has instead been on the earliest fruits of Blockchain technologies, digital currencies. Since tokens or digital currencies are being traded, they have recently been open game for revenue authorities seeking to draw them within the realms of taxation. Many digital currencies are established only to provide initial income for Blockchain technology applications, to fund wider uses such as to enable enhanced digital transactions, and the currencies are often only intended to fund development of such technologies. For example, Ripple is digital currency but its underlying technology asset is used for a variety of other purposes; it recently was adopted by money transfer service MoneyGram to speed up money transfers from around an hour to 2–3 seconds via its Blockchain technology [52]. Energy is utilized in both applications of the technology, and no lawmaker has thus far attempted to internalise environmental costs, only to seek to bring digital currencies within the tax system or otherwise legitimize their existence. It should therefore first be considered how the law has managed to treat and ultimately tax digital currencies as this is the first and only relevant precedent. To understand how tax authorities and regulators have brought such activities into charge first requires an examination of how digital currencies are legally classified. This then impacts upon their treatment for tax purposes of those utilising and holding them. This section demonstrates the – often confused – approaches taken to classifying digital currencies, which leads to an undertanding of how they can be subjected to tax.

3.1. Are digital currencies money?

If digital currencies are currencies then it would be administratively straightforward to introduce taxes, charges, or fees on currency transactions based upon their related energy consumption, payable at the exchange and collected by brokers who ultimately pay the revenue authority. Whether a digital currency can be considered "money" is an issue faced by lawmakers and regulators worldwide, and impacts upon how digital currency is treated for tax purposes. The Bitcoin symbol was accepted in 2015 [53] as a unicode character, meaning future keyboard updates of Unicode version 10.0 will include the Unicode Character 'BITCOIN SIGN' (U + 20BF) [54]. The symbol uniquely identifies Bitcoin, which may be perceived by keyboard users as one similar to a currency symbol, potentially leading users to believe that Bitcoin is a currency. If it had been considered money then the tax implications differ from if it is a commodity. Christine Legarde, Head of the IMF, gave a number of reasons why digital currencies could not be considered currency, one of which being that it was too energy intensive [55].

The Bank for International Settlements provides no definition of "money" or "currency" [56]. It defines "central bank money" as "[a] liability of a central bank, in this case in the form of deposits held at the central bank, which can be used for settlement purposes." Similarly it defines "commercial bank money" as "[a] liability of a commercial bank, in the form of deposits held at the commercial bank, which can be used for settlement purposes" [57]. The definitions refer to the place in which the liabilities are held, but the overall idea of money within the definitions is that deposits held can be used for settlement purposes. Therefore the utility of the deposit is of relevance.

A report by the Bank for International Settlements identifies that the belief that a digital coin may be exchanged for goods, services, or sovereign currencies is what provides it value. Some digital currencies do have utilities other than simply being a store of value. Bitcoin has been accepted as payment for property[11] [57] and services [58], is exchangeable for sovereign currencies, and its futures are traded on Wall Street [59]. In the U.S., a magistrate judge in *SEC v. Shavers*[12] [60] ruled[13] [61] Bitcoin to be a currency or form of money, since it could be used to purchase goods and dollars [62]. Though the Securities and Exchange Commission (SEC) have subsequently provided a different definition (as explained below), the focus on utility was paramount in the decision here.

However, the Bank for International Settlements take the position that the lack of government control and the decentralized nature of digital currencies mean they have, until now, not been guaranteed by any central bank or other authority [63]. This distinction is used to separate digital currencies from being considered as an actual currency. The U.S. Treasury Department in 2013 followed a similar logic and added that Bitcoin has not been accepted as legal tender in any state, considering digital currencies to be "convertible virtual currencies" which are "money-like instruments" [64]. The Treasury Department's interpretation depends on its definition of fiat currencies as being designed as legal tender and being customarily accepted as such, [65] as highlighted by Pflaum & Hately [66]. The International Monetary Fund recognises there is no one definition of currency, but argue that it should be issued by a central bank and supported by a government [67]. A Bank of Canada study points out [68] that digital currencies cannot be legal tender in Canada since they are not issued by the Royal Mint or the Bank of Canada, as per the Currency Act, and similar rules exist in many nations [69]. This could change however with several nations developing plans to accept it as legal tender; in Canada it would merely require an amendment to the Currency Act or issuance from one of its specified institutions. Canada is itself examining the prospect of issuing digital currencies as legal tender [70].

3.2. Can they tax digital currencies as commodities or securities?

In the U.S., the SEC examined the definition of an "investment contract" [71] pursuant to the Securities Act [72] and the Securities Exchange Act [73]. Relying on *SEC v. W.J. Howey Co.* [74] and *SEC v. Edwards* [75], it determined that pursuant to case law "investment contract" means "an investment of money in a common enterprise with a reasonable expectation of profits to be derived from the entrepreneurial or managerial efforts of others" [76]. Where digital currencies involved an investment contract, it considered this broad definition would apply and would treat them as securities [77] and therefore governed by the Securities Exchange Act. It also considered that other types of distributed ledger technology offerings could be classified as securities. This is important when designing a fiscal tool for Blockchain technologies that go beyond digital currencies (see 4.2.3).

The U.S. Commodity Futures Trading Commission provided an alternative definition of digital currencies as a "commodity." In *In re Coinflip, Inc. d/b/a Derivabit, and Francisco Riordan*, it relied upon Section 1a(9) of the Commodity Exchange Act [78], which provides that a commodity includes "all services, rights, and interests in which contracts for future delivery are presently or in the future dealt in" [79]. The situation in the U.S. is therefore confused with each regulator defining digital currencies in different ways, and some leaving the door

[11] For example [58], a mansion in Notting Hill was advertised for sale where vendors would only accept Bitcoin as payment.

[12] In the Shavers case [61], the accused had set up a virtual Ponzi scheme and the decision of the court enabled the SEC to pursue the accused for disgorgement plus interest totalling a decided liability of $40.7 million, which when awarded me the criminal endeavour unprofitable.

[13] The defendant also received [62] a civil penalty based on the precedent of SEC v. Offill, in which the court reasoned that the purpose of civil penalties is to "deter future violations of the securities laws."

open to extend the definition to distributed ledger technologies generally.

Walker demonstrates that Australian law similarly differentiates between different types of digital currencies or tokens, depending on their functions [80]. Their distinctions determine whether they are treated as a commodity, which would not be regulated by the Australian Corporations Act 2001; as securities, which would be subject to its provisions and restrictions; or as a digital currency listed on an exchange, which would also be regulated.

3.3. The IRS will come knocking somehow: property, income tax, and chargeable gains

The U.S. Internal Revenue Service provides alternatively that following the definition of the Treasury Department as convertible virtual currencies, digital currencies are not currency for tax purposes. It defines digital currencies as "property" and subject to taxation [81]. This means they are subject to property transaction under Federal tax law. In the U.S., where payment for goods or services is accepted in a digital currency, the "fair market value" must be used for computation of federal tax [81]. Notably, miners of digital currencies are also subject to income tax [82].

Other nations have similarly brought owners of digital currencies within their tax code. The Canadian Revenue Agency considers them taxable [83] as both a barter transaction [84] when used to pay for goods or services, and as a taxable gain as a commodity for income tax purposes [85]. In the UK, HMRC (Her Majesty's Revenue and Customs) consider transactions and miners as VAT exempt, but treat profits on digital currency as chargeable gains which means they can be charged to tax under Capital Gains Tax, inheritance tax, and corporation tax [86]. Although exempt currently, the treatment of HMRC towards transactions and miners does provide an option for future taxation and this could be utilized as a fiscal measure in the case of low-energy Blockchain.

All of these tax agencies have relied upon existing legislation and existing powers to define the jurisdiction of the relevant legislation to tax digital currencies, so new laws have not been necessary. For applications other than digital currencies, whether they are property or securities depends upon their characteristics.

3.4. Let's summarise this

The approach in these jurisdictions has evidently been to employ primarily regulatory techniques to determine the definition of digital currencies, which ultimately brings them within the tax code. On the basis of such existing abilities to charge to tax, it can be examined how environmental taxes or other fiscal tools can be either incorporated into the existing tax code or otherwise introduced. It will also be shown how fiscal tools can effectively provide the incentive to promote behavioural modifications in Blockchain technologies to reduce energy consumption. Non-fiscal types of policy interventions will also be examined in the next sections.

4. Computing the pollution puzzle

This section analyses possible policy intervention tools and factors to motivate the market to switch to low-carbon Blockchain technology. It commences in (4.1) by studying the need for appropriate policy tools to differentiate between low and high energy consumption Blockchain technologies, affecting demand or availability of technologies causing significant environmental negativities. It considers the possibility of subsidizing or rewarding technologies that provide neutral or carbon negative benefits, which goes further than the original research question [87]. These points are returned to later. The possible points of transaction and types of charges are then proposed and evaluated in 4.2, providing policy-makers with informed choices.

4.1. Green tech is the new gold

The focus by regulators on Blockchain technology has until now been on financial technologies, largely establishing a legal basis to regulate digital currencies, to prevent money laundering and ultimately to bring them within the realms of tax authorities to treat profits in line with how other assets are taxed. There has been no recorded attempt to differentiate between rates charged on digital currencies based upon their carbon footprint, perhaps because such environmental externalities are only now becoming evident. Other types of Blockchain technologies do not long appear to have been targeted. Non-environmental regulatory measures associated with Blockchain generally are assessed by De Filippi and Wright [88], whilst Athanassiou examines regulations specifically on financial technology [89].

Overly concentrating policy measures on digital currencies over other Blockchain technology may be relatively easier but could distort growth in the market. Rather than harming this growing technology sector, the purpose of any fiscal policy would be to compel the industry to recognize and take account of the negative environmental impacts caused by the technology. By doing so, the objective would be to motivate a switch in the type of technology to a less energy intensive model. Regulation is one possible choice as is using fiscal tools to incorporate the costs to the environment in the design of the Blockchain technology, encouraging the production of more sustainable models.

In order to do this, it would be necessary for any policy tool to differentiate between energy intensive Blockchain technologies and less intensive versions. For example, some digital currency transactions do not require verification based upon the solution of a cryptographic algorithmic puzzle, or if they do, they can utilise more efficient versions with lower computational energy demands. Some do not require the acquisition of a physical computing device such as the Bitcoin mining device, and if they do, there are low energy versions available.

It is also possible that the technology could produce an environmental positivity that could be rewarded or subsidized. For example, Gogerty and Zitoli proposed "solarcoin," a digital currency that rewards investments in renewable energy [90].

A report by ING bank demonstrates the considerable and unsustainable usage of electricity in Bitcoin transactions, as shown in Fig. 1 [10], and argues that a less energy intensive method of verifying the transaction ought to be introduced.10 It suggests for example, a switch to "Proof of Stake," which would be a less energy intensive process than proof of work[14] [91]; this was a model proposed by Bentov et al. [92]. Differing types of consensus algorithms (see 4.2.1) dependent on varying computational energy levels are explored in Zheng et al., such as "proof of work," "practical byzantine fault tolerance," and "delegated proof of stake" as explained therein [93]. While determining the most efficient technological design options exceeds the ambit of this article, there are clearly less energy intensive options available for Blockchain designers [94].

Differentiating between the types of technology will be a burdensome task. One rudimentary project named the Energy Consumption

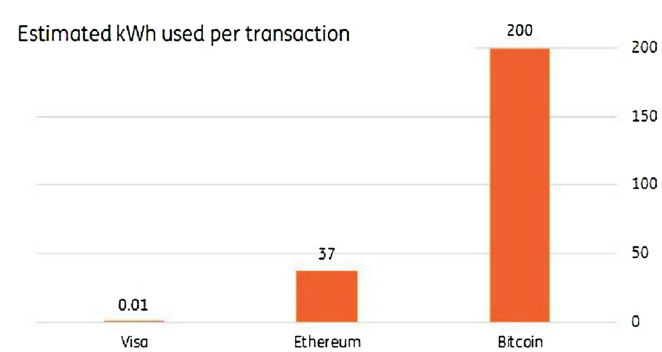

Fig. 1. Comparative transactional energy consumption.

Index seeks to differentiate between the various digital currencies based on their energy consumption [95]. The methodology for such estimations has nevertheless been disputed on the basis that there are more efficient mining tools available than those provided in the study [96]. Government agencies would be required to develop their own assessment model as they have done with other sectors.

4.2. Which geeks will inherit the earth's problems?

The appropriate type of fiscal tool depends upon which point it will have the required impact, the legal availability for such tools, and where final incidence ought to fall. It will also depend upon which part of the process is within jurisdictional control of a particular nation.

For policymakers wishing to amend a behavioural choice for a desired impact, such as to incentivize a company to reduce its energy consumption, it requires a determination of which person or entity to target with measures that will ultimately have the required effect. It is not completely straightforward because targeting somebody with policy tools who does not have the ability to realise the required outcome will be ineffective. It is essential to ascertain the point in the chain from development to use that will cause a behavioural shift.

Jaffe and Stavins studied the example of encouraging a switch to energy efficient household appliances in tenanted residential properties [97]. The tenant would benefit from the reduced cost savings of more efficient appliances, whereas the landlord would have to pay for the replacement but not benefit. Ultimately targeting the tenant with policy tools such as informational campaigns on cost savings or reduced VAT rates [98],[15] may not be sufficient to achieve the desired effect of reducing energy consumption. When one person (an agent) is capable of making a decision that impacts upon another person, this is known as the Principal Agent problem [99].

Vranken indicates that energy consumption is commonly not a concern in the design of Blockchain technologies [100]. Ultimately it is the technology developers who are capable of designing cleaner technology, but they may not be motivated to do so as long as the rest of the chain, including manufacturers and end users, continue demand for high-consumption technology.

This section discusses the different options available particularly considering the point at which to target any policy measure. Such options are not mutually exclusive.

4.2.1. Persuade the tech developer to improve the technology?

Focusing policy instruments upon the developer of Blockchain technology through regulatory or fiscal measures is theoretically possible but fraught with jurisdictional, economic, practical and policy obstacles.

A policy tool can differentiate technologies based on their levels of environmental impact. The objective would be to focus on demand-side low-carbon innovations as studied in F.W. Geels et al. [101]. Giungato points to The Long Future Foundation's proposals to differentiate technologies based upon the required energy consumption for the system to run effectively. Greater hash rates are equated to more powerful miners. It is suggested this could be electricity consumption per gigahash. A second differentiation would be country-specific, considering the source of the energy used; if renewable, then it is less harmful.[16]

To simplify this, this author proposes an alternative measure of computational energy required to add to the Blockchain based upon CO_2 emissions per gigahash (CO_2 /Gh). Recognising F.W. Geels et al.'s observation that "energy efficiency improvements are considered to be the most promising, fastest, cheapest and safest means to mitigate climate change,"[17] the measurement proposed would ultimately have several assessment factors related to electricity efficiency but lowering CO_2 emissions would be the overall goal.

With existing Blockchain applications, the objective of any measure focusing upon developers can be to instigate the developer to amend the protocol's[18] [102] consensus algorithm[19] [103] requiring less computational energy. Some proof types are more sustainable than others. As indicated at 4.1, the proof method could otherwise be amended to also require less computational energy. Zheng et al. explain that for example "Proof of Work" requires much greater energy usage than alternatives [104].[20] The Long Future Foundation are further critical of this method, stating "Proof of Work cryptocurrencies have no place on a planet with a biosphere. With that said, some of the cryptocurrencies that use different proofs could prove to be very valuable for the transition to a sustainable economy" [105].

Recognising inefficiencies in both time and energy consumption in existing protocols, technology designers actively seek to propose new types[21] of protocols [106]. If measures can successfully achieve such an amendment of a developer's protocol consensus algorithm, both the policy measures and path dependence theory will come into play to also minimise the chances of future developers developing energy intensive technology.

Nevertheless, a major practical obstacle particularly with digital currencies is that confidence in their system depends upon there being no alteration to the basic framework of the system. Imposing regulatory restrictions or financial costs (such as through taxation) upon developers of existing technology with an interventionalist purpose of amending the algorithm or framework the system depends upon would be problematic if the Blockchain technology is already developed and in operation. The governing nature of the protocols proposed in their White Papers often does not allow for amendments to the overall framework or type of verification of transactions as this is the basis for the entire trust in the system. Some do however proceed to upgrade and retain trust. For example, while Bitcoin's designers have not permitted any upgrade, the digital currency Bitcoin Cash has increased its block size [107].

Ultimately any intervention to differentiate would be targeted to result in the protocol either being amended, or otherwise to render it obsolete in favour of those requiring lower CO_2 /Gh. Again, the problem with this approach is the potential for a misunderstanding of its intention. It may be seen as an attack on the industry and provoke the relocation of technology designers who are adding significant value to a country's economy. It would also have to be a major jurisdiction to have any significant impact; smaller nations would struggle to impact a technology used globally. This does however, promote the case for international cooperation on such measures.

Any measure focusing on technology developers would risk going against government policy of promoting the industry. Many nations are competing for financial technology start-ups to be hosted within their jurisdiction [108,109]. For example, the UK's Financial Conduct Authority has developed a regulatory "sandbox" regime to host financial technology start-ups [110]. Such companies are both highly mobile, not

[14] "In proof of work, miners compete to add the next block (a set of transactions) in the chain by racing to solve [an] extremely difficult cryptographic puzzle." [93].

[15] See a discussion of this problem related to environmental considerations in Næss-Schmid et al. [100].

[16] [11], p. 5.

[17] [102], p. 30.

[18] "…a set of rules governing the format of messages that are exchanged between the participants" contributing to the Blockchain [106].

[19] A consensus algorithm protects the integrity of the Blockchain by verifying that each additional block is the truthful block, so there is no need for trust, see [107].

[20] "In PoW, miners hash the block header continuously to reach the target value. As a result, the amount of electricity required to process has to reach an immense scale. As for PoS and DPOS, miners still have to hash the block header to search the target value but the work has been largely reduced as the search space is designed to be limited. As for PBFT, Ripple, and Tendermint, there is no mining in the consensus process. So it saves energy greatly." [108].

[21] Milutinovic et al. seek to develop an "Energy and network communication efficient protocol" known as "proof of luck" in [110].

required to be located in a particular jurisdiction, and often operate outside of major jurisdictions. Bitcoin's website is owned by a limited liability company in the Federation of St. Kitts and Nevis, for example, and its decentralized nature and lack of central authority means it not being registered or located in one State. Instead, the exchanges and transactors operate from a State using the digital currency [111]. As such, attempts to introduce regulations, taxes, or charges on financial technology companies may risk relocation, causing tax leakage (see further 4.2.2.1) [112].

In summary, a range of fiscal policy instruments are available to be imposed upon the developer of the technology. Regulations can directly limit developers from developing Blockchains above a certain CO_2/Gh, though the choice to regulate technological innovation in a growing sector is fraught with both risk and possibility [113]. The impracticality of implementing environmental taxation on developers based upon what they develop (given that they even are located within a jurisdiction) would prima facie mean this option cannot be considered. However, alternative fiscal tools such as governmental grants, academic research funds, or the development of a regulatory business-friendly safe space for developers focusing upon low CO_2/Gh Blockchains could stimulate the sector.

Despite the difficulties, the purpose is to create a behavioural shift in the technology, which the technology developer is best placed to achieve. Due to the problems with focusing on the developer itself, this may be more effectively achieved by focusing more upon those utilizing the technology which will in turn impact upon the demand for the technology. This involves both the computational machinery as well as the end user such as of financial products.

4.2.2. Stop the polluting machinery?

Blockchain technology depends upon a trustless peer-to-peer verification process, with anonymous "nodes" jointly verifying a transaction [114].[22] Nodes can represent one or many computational devices. Each verification can require computational power from a machine in order to add to the Blockchain. The verification process required for a Bitcoin transaction for example involves an energy intensive machine requiring significant computational power, commonly referred to as a Bitcoin "miner". Bitcoin mining alone consumes 0.14% of global supplies of generated electricity, and it is only part of the process of one type of Blockchain technology [115]. De Vries' research estimates that Bitcoin miner machines have a combined electricity consumption of 8.92 Gigawatts, and there are additional cooling costs as they emit heat; it is expected that the consumption will continue to rise as the price rises [116].

Where any Blockchain technology requires such an energy intensive device to perform the verification, it is possible to implement policy tools to restrict the type of device being used. Giungato et al. emphasise the need to study the machinery involved in the context of digital currencies, and the same can be applied for other types of Blockchain.[23]

The goal of any intervention focused upon the machinery would be to indirectly impact upon the behaviour of developers, motivating them to amend the model of existing and particularly future systems towards a less polluting and more sustainable transaction verification model. It could also motivate manufactures of such devices to produce low energy versions.

Garrick and Rauchs' study of Bitcoin miners found that "large miners in particular are aware of the environmental impact of their activities," that they considered taxation as a major risk and did not want to see any VAT [117]. Policy intervention such as the introduction of taxation may therefore impact upon the behaviour of mining businesses. At the minimum, it can motivate mining businesses to shift to acquiring more efficient machinery for future purchases. It would not impact upon existing purchases.

Depending on the level of intervention it could go as far as to dissuade miners from running the machines and therefore providing the verification processes required by a particular technology's protocol, causing no further blocks to be added to the Blockchain and therefore the whole process would not work, ultimately ending the technology's life. This would be the most drastic option, but the policy implications for promoting the financial technology sector in a jurisdiction may make this option unattractive. The publicity of a particular nation being unfriendly towards a type of technology would be seen as a threat to the whole industry.

4.2.2.1. Regulatory options. Differentiating between devices based upon their energy consumption can be undertaken in a similar manner as other electronic appliances are treated. Major jurisdictions tend to have the structure in place already to limit the import and production of energy inefficient products for households and businesses. The EU, not having the jurisdiction to introduce taxation in member states, instead utilises regulatory rules to achieve this. The EU's Ecodesign Directive imposes mandatory energy efficient standards [118] on products, and complements this with its Energy Labelling Regulations [119] which provides information on associated energy costs for consumers, enabling informed choices. Harmonised European standards through technical specifications apply to different products, such as on the energy efficiency of refrigerators in the EU [120]. Sensibly it introduces such regulations in consultation with stakeholders, which would help improve the soundness of measures if introduced to the financial technology sector.

Technical standards imposed on the energy efficiency of mining devices or verification processors that are manufactured or imported in a country could prove highly effective with a jurisdiction. Rather than banning them completely at the point of importation, it would facilitate the purpose of distinguishing between efficient and inefficient types of mining machinery. This option is attractive and can work to achieve decarbonisation goals when the Blockchain technology relies on physical machinery, but not when it is electronic or otherwise.

A limitation of the regulatory options are that due to electricity prices, much of the mining globally is undertaken in countries offering cheaper energy costs which are often low regulation countries, lacking the necessary structure to impose technical specifications. The majority of mining activity is reported to take place in China [121]. A further possible option is to introduce a voluntary code of technical standards with manufacturers, such as the U.S. Energy Star programme [122]. Again this would require the countries hosting the manufacturers to introduce such a programme. China has itself determined to reduce the consumption of miners through regulation; by instructing local governments to gradually reduce power consumption of miners, though it is unclear how this can happen [123].

4.2.2.2. Fiscal options. This section considers first mining businesses and secondly manufacturers of mining devices. Multiple fiscal tools are available to internalise costs and encourage behavioural change amongst miners' use of verification devices. Where the device is imported, it is possible to introduce a customs duty or excise tax charging based upon the energy consumption. So long as the domestically produced devices are subject to an excise tax of equal measure this should not contravene World Trade Organisation rules[24] [124] as it will not be anti-competitive based upon the origin of the device [125]. Belgium's Ecotax Law achieved a similar result [126].

Where the device is purchased domestically, a VAT (Value Added Tax) can be imposed upon less efficient machines to make them less attractive. Importantly it should not be a tax deductible expense for businesses. In the UK, expenses that are "wholly and exclusively" for

[22] See "How Blockchain Works" sidebar in [118] and also see [12].
[23] [11] at p. 5.

[24] On WTO rules and environmental issues see [126].

the purpose of a business are usually deductible against tax, and this is the norm elsewhere [127]. For example, VAT is commonly refundable to businesses, and the purpose of such businesses would be to mine for profit [128]. In the UK, capital allowances are available for "plant and machinery" and are tax deductible [129]. For existing businesses operating as a mining business that are subject to income tax or corporation tax, capital allowances can be offered to reduce the tax burden for those upgrading operations through the purchase of more efficient equipment.

A further option is to require registration of such devices and introduce an annual emissions tax, differentiating in rates charged based upon the emissions output of the device. The UK had an annual vehicle fee differentiating in rates based upon each vehicle's emissions (see further 4.2.4.2 Registration charge) [130]. The Czech Republic, for example, charges different rates on different types of emissions used in industry [131].

Another option is to introduce a surcharge on the existing tax on profits declared by miners. The UK introduced an 8% profits surcharge on banks [132] to encourage more sustainable practices, and a 3% Stamp Duty Land Tax surcharge on second home owners to discourage buy-to-let investors from raising house prices, in favour of first-time buyers [133]. Both were for social policy and in the present case it can be for environmental policy. The complexity is it would require self-disclosure of the type of device used to produce the income, adding a further administrative tier for the tax authorities to ensure compliance. Furthermore, such devices may be tax deductible where it is wholly and exclusively for the purpose of the business. For example in the UK, expenditures need to be "wholly and exclusively" for the purposes of the trade, profession or vocation to be tax deductible against profits [134]. Therefore this is not the preferred option.

Since the business model of miners depends upon electricity consumption for the primary part of their business, a further alternative is to include them in an existing emissions scheme. Such schemes price carbon by auctioning carbon permits to companies based upon an annual cap on the levels of emissions [135]. The maturity and scale of mining businesses could qualify them to join this scheme at some point [136]. The EU have such a scheme (see [42]) though it has been subject to significant criticism and problems [137].

Rather than focusing upon the miner, the focus instead could be on the manufacturer.

An attempt could be made to tax profits or exports from manufacturers of these products, but those produced in regimes with lower regulatory standards it would require such countries to introduce the taxes. The disadvantage of these tax options is that many such operators may simply shift location to undertake the "mining" in a different nation. Furthermore, investors worldwide are able to buy shares or rights in mining cooperatives located in places such as China that provide investors a share of the profits without having to undertake the activity of mining. The "race to the bottom" theory of nations competing to offer lower regulatory standards in order to attract businesses seeking reduced environmental operating costs, is applicable [138,139]. Such practices mean that the climate continues to be damaged in the same way, and perhaps even more if the host country produces the electricity consumed in a less efficient manner with reliance on hydrocarbons. It also means "tax leakage," with the nation seeking to protect the climate through taxation losing both the business and the related taxes it could charge to protect the environment, to the nation offering lower regulatory standards on the environment.

The use of border tax adjustments to prevent this risk of carbon leakage is examined in Truby [140] with a view to achieving sustainable development and environmental protection. This suggested the products produced in nations not applying carbon taxes would be subject to additional taxes at the border upon importation to a nation applying carbon taxes. Doing so is intended to reduce the incentive for a business to shift manufacturing to low environmental regulation nations, by making the products produced using carbon-intensive techniques priced as if the carbon tax had applied in the importing nation. It considers the option of "Best Available Technology" techniques, which allow imports of least polluting approved technology devices and treat all such imports the same way in terms of regulation, border controls, and duties.

In the case where the "product" produced in the carbon-intensive nation is not physical but digital, the risk of tax leakage and the race to the bottom [141] of environmental standards[25] [142] may not be preventable via border tax adjustments as with products [143]. This would normally be the case in the present circumstances. The problems with the solution described are first, the extreme complexities involved in calculating and administering border tax adjustments and similar services taxations, and secondly the need for due consideration of World Trade Organisation rules [143]. Nevertheless, the impact upon demand of a major market introducing such taxes could be significant enough to encourage a switch in the type of device available or the process itself. For example, since the EU hosts major global vehicle manufacturers, the types of vehicles it produces impact upon the type of vehicles purchased and operated in most non-EU countries, affecting global demand by altering choice.

The converse argument to this is that "mining" has become a major business operation. Small household miners have evolved into major players running multi-billion dollar businesses of bitcoin "farms" and even striking deals with nuclear power plant operators to supply reliable and affordable energy [144]. Relocation may not be a realistic option in such cases, and since the businesses have become legitimised and mature, they may be more prepared to be subject to taxation or regulation. Therefore, the optimal intervention measure may very much depend on the reality of the situation.

The final option that should always be mentioned is, of course, to do nothing and leave it to the free market to rectify [145], relying on energy prices to impact upon behaviour [146]. However given the enormity of the problem and the likelihood of it getting worse as the sector expands, and its threat to energy supplies and climate change, the market has evidently failed, which justifies, and indeed necessitates, intervention.

In summary, it is feasible to shift demand of carbon-intensive machinery by focusing taxes on mining businesses at the point of acquisition or through usage charges. Manufacturers can also be targeted with similar taxes. None of these options are radical and all are within existing legal frameworks. These measures will have an impact on demand-side low-carbon innovations of the machines being utilised and developed, as well as ultimately indirectly impacting upon the technology developer.

4.2.3. Point of transaction or use

Differentiation between transaction types based upon their carbon output could instigate users of Blockchain technology to switch to less carbon intensive Blockchain technology. For example, a person conducting an electronic transaction would be discouraged to utilise a certain technology if a tax were payable. Any quantity of tax payable may be sufficient to motivate the user to switch to a zero tax method attributable with a less carbon intensive technology. As the use of such technologies expands, technologies could be banded to tax based upon their carbon attributes. Rather than using CO_2/Gh, it would be necessary in this instance to utilise the measure of CO_2/transaction. It could apply to brokers of financial products such as Bitcoin exchanges, but furthermore it could apply more generally for example to those utilising smart contracts such as insurance companies.

This would indirectly impact upon the technology developers' choices of technology and would require an examination of the whole process including the types of consensus protocols involved and the

[25] Kiekebeld warned harmful tax competition would serve no environmental benefit in [145].

verification machinery involved. The type of consensus protocols in operation is publicly available information in the online White Papers of the technology, making it simpler for the enforcement agencies. Equally, the available machinery used by miners and those on the market are both publicly accessible.

As a tax on services dependant on carbon-intensive technology applied neutrally, it would be a singular taxation in a single nation which would differentiate rates based upon the type of technology relied upon to enable its operation. This should eliminate the need for consideration of World Trade Organisation rules. It is similar in practice to taxing a good produced using renewable energy sources higher than a similar good produced using hydrocarbons.

One possible method is to use regulation to prohibit certain types of transaction with CO_2/transaction above a particular threshold. This would apply to such transactions within its jurisdiction and would require monitoring and assessment by regulatory enforcement agencies. There are precedents, such as when the Reserve Bank of India restricted banks [147] from facilitating digital currency transactions [148]. This type of measure could be qualified to permit transactions within a threshold of CO_2/transaction. The comparative efficiencies of utilising regulation and taxation has long been debated, with market inefficiencies frequently being associated with regulation [149,150].

It is also feasible, alternatively, to introduce fees, taxes, or charges at the point of a transaction involving Blockchain based upon CO_2 /transaction. This could happen in the case of digital currency transactions or smart contract executions where they occur within the jurisdiction. For example, this would apply upon brokers of digital currencies or upon legal firms or insurance companies utilising smart contracts. Those executing certain types of contracts within a jurisdiction are already subject to tax, such as the insurance premiums tax in the UK [151], and this could apply to smart contracts executed within a jurisdiction. Rates of VAT or premiums tax on the transaction could apply that differ based upon energy efficiency, which would deter traders from utilising certain transaction types depending upon the type of Blockchain they use. Since the tax would apply to persons or bodies who are making the transaction, it could feasibly work within a jurisdiction.

For brokers based within the jurisdiction, it would be reasonably straightforward to introduce. In the U.S., the types of digital currencies that fulfil the criteria to be securities require registration with the SEC to be sold [152]. Other distributed ledger technology application may also be deemed to be securities, applying this option beyond digital currencies see 3.2. It is realistic that a tax could be introduced at the point of sale which would be tiered based upon CO_2/transaction. The means around this would of course be to design the digital currency so that it does not constitute a security, although this in itself is a grey area given the extent of the powers of the SEC. Capital or investments raised through distributed ledger or Blockchain technology are deemed to be securities that must be registered with the SEC [153]. In terms of administrative efficiency [154], this structure would only require reporting from brokers selling to U.S. customers, and the broker would be responsible for collecting the fee, as happens with VAT declared from merchants.

The difficultly would be ensuring compliance and countering the lack of jurisdiction over foreign websites, which could mean domestic brokers being hurt at the expense of foreign ones. To avoid such leakage[26] [155] the compliance technique could utilize similar IP address recognition as is used in gambling websites that can prevent use of virtual private networks distorting the location. Alternatively, it is provable using the Blockchain technology, itself, to show that the transaction took place at a certain point within the jurisdiction [156]. The irony is that in order to tax Blockchain technology, it would also have to rely upon it.

4.2.4. *Ownership: ethical investments*

4.2.4.1. Profits surcharge. As has been shown in 3.3, owners of digital currencies are subject to tax on chargeable gains. Enforcing the declaration of such income is within the powers of the tax authorities. A surcharge on corporation tax or personal income tax could be applied to those holding certain types of digital currencies or smart contracts executed with energy-intensive Blockchain. This is not easily escapable, especially for taxpayers who are responsible to declare foreign income. It would encourage more ethical investment practices as the value of holdings produced from energy intensive technology would fall. It would also affect the type of technology being produced and offered in future Initial Coin Offerings and related White Papers.

It could further be the case that carbon-neutral or carbon-negative models are actually rewarded through such a fiscal policy. If the revenues raised are hypothecated [157] to allow for such rewards, the tax could be designed as a revenue-neutral scheme. This is on the basis of the Pearce report which proposed revenue-neutral taxation for climate change mitigation [158]. This could give tax credits or tax deductions to such positive technology, and business models of technology developers would be designed accordingly.

4.2.4.2. Registration charge. The second means is via a registration fee. It is now commonplace for EU member states to introduce a CO_2 emissions based taxation or charge on the registration of passenger vehicles. The UK's Finance Acts includes such a registration charge based on emissions that encourage low emissions or zero emissions vehicles purchases and consequently motivates manufacturers to switch production to such vehicles due to a shift in demand [159]. A charge introduced at the point of registration would be administratively simple and collected by brokers.

The EU is planning to counter money laundering and terror finance through proposed revisions [160] to its Fourth Anti-Money-Laundering Directive. This would require amendment of Directive (EU) 2015/849 (the Fourth Anti-Money-Laundering Directive) and Regulation (EU) 2015/847. The plan includes the development of a central database which would be a register of the identities and digital wallet addresses of digital currency users [161]. Expected to become available in 2019, this database could be used to collect emissions-based registration fees with very limited administration once it is developed. Within the EU, environmental protection is within the remit of the European Commission, though taxation can only be introduced at member state level, meaning a fee could be the most effective. Registration fees pose perhaps the most direct option for introducing fiscal tools which affect investment behaviour based upon energy consumption. The elasticity caused by increased or decreased demand would affect the value of the holding – whether it be a coin or contract - that those designing the technology would have to take it into consideration with it affecting a market of 500 million people in the EU.

Similar schemes may well be set up elsewhere, especially following future Financial Action Task Force setting new international money laundering recommendations which may mean such a register becoming standard practice for nations to combat money laundering [162]. The limitation is that although it could effectively be introduced for digital currencies, it may be administratively impossible to introduce for all applications of Blockchain technology and doing so may serve as a deterrent to the financial technology industry. In the US, those securities that must be registered with the SEC could also become the point at which brokers register and become obliged to collect fees from clients, or pay a lump sum themselves that would be passed onto clients as final incidence.

5. Conclusion

The possibilities of Blockchain are endless and incentivisation can

[26] The problem of carbon leakage from high mobility taxpayers is explored by Babiker [158].

help solve various climate change issues, such as through the development of digital currencies to fund climate finance programmes. This type of public-private finance initiative is envisioned in the Paris Agreement, and fiscal tools can incentivize innovators to design financially rewarding Blockchain technology that also achieves environmental goals. Bitcoin, for example, has various utilitarian intentions in its White Paper, which may or may not turn out to be as envisioned, but it would not have been such a success without investors seeking remarkable returns. Embracing such technology, and promoting a shift in behaviour with such fiscal tools, can turn the industry itself towards achieving innovative solutions for environmental goals.

This article has sought to find options for policymakers worldwide without focusing upon a particular jurisdiction. As such it has explored the benefits and drawbacks of each option without proposing any as a definitive choice since it certainly depends on the economic reality of the country in question. Some nations are more able to affect technological design choices than others. There have been limits to the article's potential to provide universal solutions which could be expanded in further research.

While determining the most efficient technological design options exceeds the ambit of this article, there are clearly less energy intensive options available for Blockchain designers. One limitation has been as to how to determine the correct price or rate of any fiscal tool to make a difference without damaging the sector, and this can be explored in further studies by building on existing literature [163,164] related to sustainable growth and environmental policy tools [165]. The policy tools examined also assume rational decision making by businesses and consumers, though this is subject to the limitations highlighted in Stern et al. [166] there could also be further research as to how earmarking revenues to fund sustainable growth in the sector could be effective.

Though there is no perfect solution, there are certainly options to achieve the internalization of such negative externalities with a view to switching the type of technology developed to more sustainable alternatives. Since a catch-all for all types of Blockchain technology may not be possible, the products of the technology (such as digital currencies or smart contracts) can be targeted to affect demand to limit the development and application of the most energy consuming technologies and promote more sustainable alternatives. The options to target physical machines such as miners easily fall within the remit of the existing excise powers, enabling both importation and sales charges. This would reduce such consumption within a jurisdiction but may drive it overseas to the benefit of other nations, though the overall demand would be reduced especially when introduced in a major market such as the EU or U.S. The EU's fees on motor vehicles has impacted upon the type of vehicles being manufactured globally (see [42,131]).

Targeting ownership and transactions through existing or new legislation, can also serve effective in altering the demand for such technology. Profits surcharges relative to existing taxation may be introduced which can also reduce the profitability of using such technologies. Where administratively possible, registration fees on ownership that differentiate in cost based upon energy consumption of the Blockchain technology, could prove effective with digital currencies and even smart contracts but not be possible for other applications.

All such tools can be designed unilaterally by an environmentally conscious State, but the limitations overwhelmingly point to the need for an international response. The purpose would not be to harm the industry overall, but to develop sustainable alternatives: this is already happening due to electricity costs, but the greater the value of the product of the technology (such as holding Bitcoin), the greater the incentive to participate and the worse the harm caused to the environment. A common theme found with all policy tools available has been the global mobility of the economic actors in question. This provides a strong base for international cooperation to jointly implement measures, as has already happened in the efforts to regulate digital currencies for financial stability and to reduce money laundering.

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