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ARTICLES

USING BLOCKCHAIN TO ADDRESS THE IPCC'S CLIMATE CHANGE MITIGATION STRATEGIES

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SUMMARY

Many believe blockchain technologies (BCTs) will soon permeate our lives. In particular, they can be utilized to help tackle global climate change. This Article provides a baseline description of BCTs, and ways they can be utilized to reduce GHG emissions in electricity and energy generation; agriculture, forestry, and other land use; industry; and transport. It addresses BCTs' potentially carbon-intensive nature, identifies ways to utilize them in a less energy-intensive manner, and discusses currently implemented and potential ways in which BCTs can be harnessed to mitigate the main causes of climate change.

Less than 20 years after "the computer" was pronounced "Man of the Year" by *Time* magazine,[1] we face another technological revolution: the emergence of blockchain technologies (BCTs). Many believe BCTs, like the Internet, will soon permeate every inch of our lives.[2] Also like the Internet, BCTs are here intending to solve many of our problems.[3] In particular, BCT is a powerful tool that can be utilized to help tackle global climate change.

Global climate change is caused by both natural (e.g., solar variability and volcanic activity)[4] and anthropogenic outputs and processes.[5] Increases in anthropogenic greenhouse gas (GHG) concentrations—carbon dioxide, methane, nitrous oxide, and fluorinated gases (hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride)[6]—account for "more than half of the observed increase in global average surface temperature from 1951 to 2010."[7]

To address this temperature increase, the global community established the United Nations Framework Convention on Climate Change (UNFCCC)—the main, and only broadly legitimate, source of international climate change law and policy.[8] The UNFCCC provides expertise, reviews and analyzes climate change information, and assists 195 countries and regional organizations all over the world with negotiating international climate change agreements.[9] Through the UNFCCC, many countries involved in the international climate change mitigation community have enacted and ratified international laws such as the Kyoto Protocol and the Paris Agreement. The UNFCCC aims to "hold[ ] the increase in the global average temperature to well below 2°C above pre-industrial levels and

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[1] Computer History Museum, *Internet History of 1980s*, https://www.computerhistory.org/internethistory/1980s/ (last visited Feb. 5, 2021).

[2] Although many argue otherwise. *See* Jude Umeh, *Blockchain Double Bubble or Double Trouble?*, 58 ITNOW 58, 58-61 (2016), *available at* https://academic.oup.com/itnow/article/58/1/58/2392029.

[3] For example, transactional efficiency, data protection, entrance into the international market for developing countries, and so on.

[4] *See* National Aeronautics and Space Administration (NASA), *The Causes of Climate Change*, https://climate.nasa.gov/causes/ (last updated Feb. 4, 2021) (referring to the Little Ice Age).

[5] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2013: The Physical Science Basis 13 (Thomas F. Stocker et al. eds., 2013) [hereinafter IPCC, Climate Change 2013], https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_all_final.pdf; Wouter Poortinga et al., *Uncertain Climate: An Investigation Into Public Scepticism About Anthropogenic Climate Change*, 21 Global Env't Change 1015 (2011), *available at* https://reader.elsevier.com/reader/sd/pii/S0959378011000288 ("One in three Americans, and about 44% of those polled in the UK, are climate change 'attribution skeptics,' believing most of the effects seen today are caused by natural processes rather than human-induced GHG [greenhouse gas] emissions.").

[6] IPCC, Climate Change 2014: Mitigation of Climate Change 142 (Ottmar Edenhofer et al. eds., 2014) [hereinafter IPCC, Mitigation 2014], https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf.

[7] IPCC, Climate Change 2013, *supra* note 5, at 17.

[8] IPCC, Mitigation 2014, *supra* note 6, at 1005.

[9] *Id.* at 102. UNFCCC, *About the Secretariat*, https://unfccc.int/about-us/about-the-secretariat (last visited Feb. 5, 2021).

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pursu[e] efforts to limit the temperature increase to 1.5°C above pre-industrial levels."[10]

Climate change mitigation policies can come in all shapes and sizes: "economic incentives, such as taxes, tradeable allowances, and subsidies; direct regulatory approaches, such as technology or performance standards; information programs; government provision of technologies or products; and voluntary actions."[11] The policies are typically intended to assist nations in meeting UNFCCC-implemented laws' benchmarks and goals, especially when the country fails to ratify the goal-setting international law.[12]

However, the institutional effectiveness of international climate change law and policy depends in large part on compliance, and achieving sufficient policy compliance requires reliable enforcement mechanisms and accurate systems of measurement.[13] On the global scale, incentives to free-ride on other countries' mitigation efforts,[14] and the lack of universally accepted global authority to enforce participation in international agreements,[15] pose substantial barriers to international compliance. Voluntary carbon markets, for example, are fragmented and nontransparent,[16] thus lacking adequate participation and flexibility despite the fact their effectiveness "depends on good accounting and enforcement," which is often not apparent.[17]

In 1988, the United Nations Environment Programme (UNEP) established the International Panel on Climate Change (IPCC) to serve as a global scientific fact-based information resource, contributed to by scientists around the world and accessible by all levels of government entities, to aid in implementing effective and enforceable climate policies.[18] The IPCC acknowledges international cooperation plays a vital role with mitigation policies, "because most GHGs have long atmospheric lifetimes and mix throughout the global atmosphere."[19] Like the UNFCCC's international policy concerns, the IPCC argues when multiple separate countries attempt to solve a large-scale problem in a small-scale way, their "diverse . . . perceptions of the costs and benefits of collective action, [unevenly distributed] emissions sources . . . , heterogeneous climate impacts that are uncertain and distant in space and time, and [varying] mitigation costs" hinder progress.[20] However, by working and cooperating as one cohesive unit, the international community can potentially avoid such problems and meet large-scale and long-term goals.

The IPCC's 2014 report[21] is the most recent of its comprehensive reviews of global climate change measures and goals[22] and, viewed as a whole, shows the existing climate change law and policy framework's flaws. Thus, this Article relies on the report for mitigation information and suggestions.[23] "Despite a growing number of mitigation policies, GHG emission growth has accelerated over the last decade."[24]

Further, and although it is important to account for the infancy of many national and subnational mitigation policies, "[t]here has been a considerable increase in national and subnational mitigation plans and strategies since [2007, . . . yet,] to date these policies, taken together, have not yet achieved a substantial deviation in GHG emissions from the past trend."[25] Indeed, "[w]ith 3.1% annual growth in energy supply sector emissions, the decade with the strongest-ever mitigation policies was the one with the strongest emissions growth in the last 30 years."[26] The IPCC's suggestion? We need a fundamental departure from business as usual if the global community is to meet its climate change goals.[27]

The Article will first provide an explanation of how BCTs operate. It will then identify, based on the IPCC's 2014 report, the main sources of global GHG emissions and major climate change mitigation strategies currently in place. Simultaneously, it will discuss the multitude of ways in which BCTs can be utilized in the fight to combat global climate change, despite scholars' warnings of the technology's immense carbon footprint.

I. BCTs Explained: Background and Overview

Discussion of BCTs' place in the future of combatting climate change is already prevalent. Mark Copeland, chief executive officer of SmartMinds—"a values-driven consul-

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[10] IPCC, Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty 79 (Valérie Masson-Delmotte et al. eds., 2018) [hereinafter IPCC, 2018 Special Report], https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_Chapter1_Low_Res.pdf.

[11] *Id.* at 239.

[12] Anja Kollmuss et al., WWF, Making Sense of the Voluntary Carbon Market: A Comparison of Carbon Offset Standards v (2008), https://www.globalcarbonproject.org/global/pdf/WWF_2008_A%20comparison%20of%20C%20offset%20Standards.pdf (arguing "[t]he voluntary carbon market enables those in unregulated sectors or countries that have not ratified Kyoto, such as the US, to offset their emissions").

[13] IPCC, Mitigation 2014, *supra* note 6, at 1007 ("Effective common property management of the atmosphere would require applying such management at a global level, by allocating rights to emit and providing disincentives for overuse through sanctions or pricing emissions.").

[14] *Id.*

[15] *Id.* at 295.

[16] *Id.* at 102.

[17] *Id.* at 305 ("[B]ut what will be enforced will depend on the accounting measures agreed upon."); *see also id.* at 155-56:

> Governments debating the merits of a carbon tax may turn to cost benefit analysis or cost-effectiveness analysis to justify their positions. They may need to take into account that firms who utilize formal approaches, such as decision analysis, may not reduce their emissions if they feel that they are unlikely to be penalized because the carbon tax will not be well enforced.

[18] IPCC, *About the IPCC*, https://www.ipcc.ch/about/ (last visited Feb. 5, 2021).

[19] IPCC, Mitigation 2014, *supra* note 6, at 114.

[20] *Id.* at 1005.

[21] *Id.* at 9.

[22] Note there are multiple, but not immense, IPCC special reports since 2014, but these are less "comprehensive" than the full report and are targeted at narrow issues.

[23] IPCC, 2018 Special Report, *supra* note 10, at 79.

[24] IPCC, Mitigation 2014, *supra* note 6, at ix; *see also id.* at 6.

[25] *Id.* at 95.

[26] *Id.* at 523.

[27] *Id.* at ix.

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tancy company in the field of organizational development and innovative technology"—discussed his company's project, Earth Ledger, which has "found the solution to resolving climate change using [BCTs]."[28] The World Bank has also stated that BCTs "should be considered in the future design of climate markets."[29]

To effectively present and explain ways in which BCT will serve as a helpful tool in achieving global climate change mitigation goals, a background of the technology itself is required. To some, the term "blockchain" invokes feelings of panic, confusion, and, perhaps, disbelief. This part will attempt to strip down the layers of preconceived notions and the anticipation of confusion, and will hopefully present BCT at its most accessible level—a "trustless" and "immutable" technology.

A. *"Trustless" Database Management*

With traditional databases, all decisionmaking power is held by a central authority whereby all computers in the network communicate only with centralized authority and never with each other.[30] Initially, this central authority was intended to make computing more uniform and efficient, requiring all information to pass through the same intermediary before wide distribution, which was critical for the implementation of e-commerce. However, having one single computing decisionmaker has its failures: there is no efficient auditing to determine when computing decisions are made with bias, the decisions take time to process and are expensive, and having one single point of authority means there is one single point of failure—whether it be a power outage or a hacking incident. For this reason, we must rely on intermediaries to reprocess and audit the information to ensure reliability.

In contrast, BCTs are distributed databases (oftentimes referred to in the singular as distributed ledger technology or DLT). Each participating computer ("node") stores its own full copy of the blockchain data ledger.[31] BCTs are "peer-to-peer" networks (as compared to a traditional database with a central authority); all nodes are given equal decisionmaking power and are in constant communication with each other.[32]

Some describe BCT as "trustless," a term not to be confused as something that cannot be trusted, but rather meaning we need not rely on trusting intermediaries.[33] In order to add, change, or remove the data stored on a blockchain, all nodes must consent to the change—the network must reach a consensus.[34] This quality effectively renders data hacking nearly impossible, because in order to interfere in the data, a hacker would need to simultaneously take control of multiple nodes around the globe. Further, whenever a transaction takes place on a blockchain, all computers equally and independently work to verify the data. In other words, we can trust the information stored on any given blockchain is original, accurate, and unaltered—all without engaging (and trusting!) intermediaries' auditing and processing services.

B. *"Immutable" Data Organization and Processing*

When a person initially interacts with a blockchain, he or she is given a "public key" and a "private key."[35] The public key can be compared to the address of a mail slot, while the private key provides access to, and the ability to remove or retrieve, the contents within.[36] The public key is the identification number a person will provide to a sender when requesting, for example, money or the deed of his or her home. A complex, one-directional algorithm is automatically applied to the public key to determine its associated private key.[37] This creation process results in a completely encrypted and confidential association between the two keys—in other words, a person's public key is "connected" to his or her public key, but the private key is never accessible by anyone or anything other than the person to whom it is prescribed.[38] Because the algorithm is one-directional, it is virtually impossible to apply the algorithm to the public key in reverse to determine its associated private key.[39]

When data are entered into a blockchain ledger—for example, when a transaction takes place—a new block encompassing that new data is added to the end of the chain.[40] One can imagine the new data looks like a string of information. If the data to be entered on the blockchain is the simple letter "B," the string will be one letter; if the data are a 200-page dissertation, the string will be incredibly long. However, the nodes apply a "hashing function"[41] to the string, converting it into a completely unique combination of 64 letters and numbers,[42] no matter how large or complex the original string. Each data block is thereaf-

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[28] Press Release, Earth Ledger, United Nations Invites Earth Ledger to Present Its Blockchain Solution to Climate Change (Sept. 3, 2018), https://www.prweb.com/releases/united_nations_invites_earth_ledger_to_present_its_blockchain_solution_to_climate_change/prweb15732718.htm.

[29] World Bank Group Climate Change, Blockchain and Emerging Digital Technologies for Enhancing Post-2020 Climate Markets 14 (2018), https://openknowledge.worldbank.org/bitstream/handle/10986/29499/124402-WP-Blockchainandemergingdigitaltechnologiesforenhancingpostclimatemarkets-PUBLIC.pdf.

[30] Daniel Drescher, Blockchain Basics: A Non-Technical Introduction in 25 Steps 11 (2017), https://link.springer.com/content/pdf/10.1007/978-1-4842-2604-9.pdf.

[31] *Id.* at 199.

[32] *Id.* at 24.

[33] Liehuang Zhu et al., Blockchain Technology in Internet of Things 16 (2019), https://www.springer.com/gp/book/9783030217655.

[34] *Id.*

[35] Drescher, *supra* note 30, at 98-99.

[36] *Id.* at 99.

[37] *See id.* at 73 (describing one-directional hashing functions).

[38] *Id.* at 98-99.

[39] *See id.* at 73 (describing one-directional hashing functions).

[40] *Id.* at 87 (referring to the most recently added block as the "head of the chain").

[41] Andrew W. Appel, *Verification of a Cryptographic Primitive: SHA-256*, 37 ACM Transactions on Programming Languages & Sys. 1 (2015), *available at* https://oar.princeton.edu/jspui/bitstream/88435/pr19p42/1/AppelACMTrans2015.pdf.

[42] When using SHA-526 hashing function, the output will consist of 64 letters and numbers. However, there are multiple available hashing functions. *See* Drescher, *supra* note 30, at 77 fig.10-1 (demonstrating the use of four different hash functions to the same input data).

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ter represented by its unique "hash,"[43] the contents within which are accessible only to those with the appropriate private key (i.e., the key to unlock the mailbox's contents). To retrieve the data from the blockchain, the authorized person with the appropriate private key now only needs to search for his or her data's unique hash rather than the potentially astronomical amount of raw input data.

BCT ensures data security by organizing the blocks sequentially (blocks are only added to the end of the chain) and by prescribing each block its unique hash in sequential order.[44] For instance, someone creates a brand new (and very hypothetical) blockchain called "BogartLedger." The first block to be added to BogartLedger is called Block #1 and represents the sale of a home located at 2020 Boydlaw Way, Ames, Iowa 02016. The computers participating in BogartLedger apply the hashing function to the real estate transaction's long string of input data, prescribing Block #1's input data with the following hash:

> 8202g0wl104383093444zls9fnsi83ln98chenlis8hc8diiiffkfeo448kp1v

As you can see, the hashing function produces a completely random set of letters and numbers. Unfortunately, this hash is no good, because all valid blocks on BogartLedger must begin with six leading zeros.[45] The hashing function therefore must process the data string while using what is called a "nonce" function—applying a single-use number to the hashing function in order to produce a different hash for the same string.[46] This process is repeated until the hashing function +nonce ascribes the data string the proper hash[47]—one that begins with six zeros, and is less than or equal to the target hash. It may look like:

> 000000jsu2995jcnghdliiebr8394582sklnc83n5m69cnwls93b582l2n7ebwl

Once a node has successfully attributed a valid hash to the real estate transaction, Block #1 is officially added to BogartLedger.

Now suppose, less than two milliseconds later, a baby is born. The birth certificate is the next piece of data entered onto the BogartLedger and would be represented by Block #2, placed directly after Block #1 on the chain. To ensure Block #2 is placed after Block #1 on the chain, the hashing function determines Block #2's hash based on that of Block #1. The real estate transaction data in Block #1 can thereafter never be altered, because any alteration will cause the hashing function to produce an entirely new, invalid hash. Further, because Block #2's originally valid hash is determined by Block #1's originally valid hash, it now itself would no longer be valid. Any data interference will therefore breach the BogartLedger blockchain, and it will cease to operate until the source of the invalid hashing sequence is resolved—thus, the blockchain is immutable.

Further, because the blockchain is "trustless," all nodes, having their own copies of the complete BogartLedger, will scan all past blocks to verify the data being added at the end of the chain. Imagine three years have passed since the Block #1 real estate transaction, and the current owner of 2020 Boydlaw Way has agreed to sell the home for $450,000, would like to transfer the deed to the buyer, and attempts to enter the closing documents onto BogartLedger as Block #7083. Before the transaction's block is added to the blockchain, all nodes will audit Blocks 1-7082 to verify the previous transaction in which the seller became the lawful owner of the property (Block #1), the existence of the buyer's bank account, and whether the buyer's account has sufficient funds to pay the purchase price. If the verification succeeds, the hashing process begins, and the transaction becomes Block #7083 when the proper hash is computed. If a node discovers a prior transaction whereby the seller had already transferred 2020 Boydlaw Way's deed to a third party, the transaction automatically fails.

The trustless nature of the blockchain should not be confused with accuracy of data located within each block, however. It is a common misconception that data on a blockchain is automatically trustworthy in the sense that a person reading the data located on the blockchain can trust what it represents—whether it be the existence of 2020 Boydlaw Way in the form as it was represented to the purchaser, or the existence of the baby born milliseconds after the real estate transaction. Placing trust in the value of the data point on a blockchain can be dangerous.

The blockchain's "trustlessness" and immutability rests only with regard to data permanence: a person can trust that the record was placed on the blockchain at a certain time, and as long as the block remains in the blockchain sequence, the content within the block remains unchanged or unaltered. But to trust the value and quality of what the data point represents, there must be an external validation mechanism outside of the blockchain. When in doubt, consider the trustworthiness of the person, corporate entity, organization, artificial intelligence program, etc., that wrote the data, and ask whether they ran the proper due diligence to validate the existence of the thing the data block represents.

C. *Different Blockchain Types for Different Purposes*

So far, this Article has described BCTs in a very overarching and generalized way. However, not all blockchains operate in the same manner as BogartLedger. There are three main types of blockchain: public, private, and consortium. The name "public blockchain" describes what it is—a blockchain data ledger that is available to the public. So long as a person has the computing power required to run a node, a person can read, enter, and audit the data

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[43] Drescher, *supra* note 30, at 76-77 (explaining combined hashing).

[44] *See* Zhu et al., *supra* note 33, at 13 (explaining how blocks are connected on a "chain," the oldest is called the "genesis block," and each subsequent block is added to the tail of the chain).

[45] Each blockchain has different hash requirements.

[46] Drescher, *supra* note 30, at 13, 16.

[47] *Id.* at 16.

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on a public blockchain. Because more nodes are involved in public blockchains, more computers are participating in data auditing and reaching a consensus, so the public blockchain is theoretically the most "trustless" and "immutable" use of BCTs. The hypothetical BogartLedger likely falls within this category.

Private blockchains, on the other hand, are designed to restrict participation in and access to the ledgers' data storage. Because of such restrictions, the private blockchain relies on selective authorized nodes to do all reading, entering, and auditing of the data. If this sounds a lot like the central authority in a traditional database, your instinct is not completely misguided. In fact, some argue private blockchains are arguably BCT by name only, because they lack trustlessness—by requiring trust in the few authorized nodes—and offer decreased immutability—the fewer nodes there are auditing, the easier it is to achieve a consensus.

The third main type of blockchain attempts to address private blockchains' disloyalty to BCTs' two main assets. A consortium blockchain acknowledges that BCTs may be very useful to private groups and industries and may serve populations and interests that would not otherwise—or for various reasons, elect not to—utilize a public blockchain. Consortium blockchains simply take the fundamentals of a private blockchain and add a few extra controlling nodes to increase the technology's immutability and trustlessness, although not to the same extent as those that are public.

D. Mining and Cryptocurrency

The computing necessary to achieve trustlessness and immutability can require an extensive amount of power.[48] Because of the financial burden of this power usage on the individual nodes, the first node in the network that finds the desired hash through repeated application of the hashing function +nonce is paid for its time and money expended. Such positive reinforcement may be paid in Bitcoins or other, perhaps less familiar, forms of "crypto" currency—currency that derives its value from the processing power expended rather than, like the U.S. dollar, from the current value of a nation's government.[49] The process of expending computing power to find the proper hash is referred to as cryptocurrency "mining."

Different blockchains may require different mining processes, which use different levels of energy, produce different types of cryptocurrencies, and ensure different levels of immutability. Bitcoins, for instance, represent the computing power expended on the first-ever public blockchain.[50] This genesis blockchain is simply referred to as "Bitcoin," because interestingly—like the chicken-and-egg genesis conundrum—it was not until the implementation and expansion of the Bitcoin cryptocurrency that scientists, computer programmers, and mathematicians realized the value of its underlying technology: the blockchain.[51]

E. Computing on the Blockchain: An Energy Drain?

Scholars often criticize BCTs for being extremely energy-intensive. However, as previously stated, blockchains come in all shapes and sizes—each having its own unique carbon footprint determined by several individual factors. A blockchain's immutability level and the energy efficiency of each participating node all factor into its carbon footprint. Bitcoin is a notoriously energy-intensive blockchain network, and is often the source of environmentally conscious scholarly criticisms. Its unfaltering immutability and globally derived trustlessness are the source of the environmental trade off.

For example, when a Bitcoin node has produced the desired hash for new input data, it receives what is called a "proof of work" (PoW)—a certificate of honor and integrity that is required to add a block to the end of the Bitcoin blockchain.[52] Without a PoW, a node is unable to add data to the Bitcoin blockchain. Since more than 100,000 nodes[53] are simultaneously competing to determine the proper hash, it is less likely the node that receives the requisite PoW is an ill-intended hacker.[54] The PoW therefore automatically authenticates the transaction and provides yet another assurance the blockchain is secure and immutable.

As blocks are added to the Bitcoin blockchain, the computing required by each node intensifies because hashes become more complex, and therefore the odds of achieving the desired hash for a new block by applying the algorithm quickly begin to decrease. Authenticating PoWs are therefore an *increasingly* difficult computing task demanding immense energy inputs.[55] In fact, one single Bitcoin transaction expends roughly the same amount of energy one-and-a-half American homes expend in an entire day.[56] One scholar projects if Bitcoin's technological process maintains its current growth trajectory (and assuming the source-type of general electricity remains unchanged over time), the carbon emissions from the Bitcoin mining process alone "could fall within the range of emissions likely to warm the

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[48] *Id.*

[49] *Id.*

[50] The creator of Bitcoin, the first ever use of BCTs, is named Satoshi Nakamoto—a person (?) who seemingly disappeared after the public release of Bitcoin. Controversy over Nakamoto's true identity is still debated. *See* Rakesh Sharma, *Three People Who Were Supposedly Bitcoin Founder Satoshi Nakamoto*, Investopedia, https://www.investopedia.com/tech/three-people-who-were-supposedly-bitcoin-founder-satoshi-nakamoto/ (last updated June 25, 2019).

[51] Vinay Gupta, *A Brief History of Blockchain*, Harv. Bus. Rev., Feb. 28, 2017, https://hbr.org/2017/02/a-brief-history-of-blockchain.

[52] *Id.*

[53] Matthew North, *Bitcoin Network Surpasses 100,000 Nodes, New Data Shows*, Bitcoinist, May 6, 2019, https://bitcoinist.com/bitcoin-network-surpasses-100000-nodes-new-data-shows/.

[54] *Id.*

[55] World Economic Forum, Building Block(chain)s for a Better Planet (2018), http://www3.weforum.org/docs/WEF_Building-Blockchains.pdf.

[56] *Id.*

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planet by 2°C within only 16 years,"[57] and another scholar argues the entire network's emissions resemble those produced by countries like Ireland or Austria.[58]

However, not all blockchains are exclusively bound to the Bitcoin-like PoW authentication mechanism in executing transactions. For example, some blockchains operate on a less energy-intensive "proof of stake" (PoS) protocol.[59] PoS differs from PoW, because "[i]nstead of mining, users can validate and make changes to the blockchain on the basis of their existing share ('stake') in the currency."[60] The data verification process is less complex with a PoS than with a decentralized PoW protocol, thus requiring less computing power.[61]

Emerging blockchains such as Ethereum, NEO, and Waves are using carbon-friendl(ier) PoS verification,[62] consuming "approximately 12-14 times less energy" than their PoW-utilizing counterpart, Bitcoin.[63] However, the complexity of Bitcoin provides it with its treasured immutable quality. The more complex the verification system, the more difficult it is to alter the information. Thus, it is possible that reducing a blockchain's complexity for the sake of reducing its carbon footprint will reduce its fundamental revolutionary benefits.

Some scholars present the even less complex "proof of authority" (PoA) networks—those that allow only authorized authorities to validate data entered on the blockchain—as a "green" way to reach consensus.[64] They argue "[w]hen authorities don't have to 'compete' for access, as in crypto-mining, there is less energy consumption throughout the network as a whole."[65] However, this authority-based verification system raises a further, fundamental question: who will hold the verification authority? This "green" use of BCTs may be useful in more economically developed countries, but presents issues when the authority likely to be making such verifications, such as a country's central government agencies, struggles with corruption or time and resource constraints.

Fortunately, BCT can find its way into the "green" without overly prejudicing its immutability by utilizing renewable energy sources to power the nodes' units. Although it would be nearly impossible to ensure each individual node derives its power from renewable energy sources (especially with the most decentralized and "trustless" networks),[66] on a grander level, the nodes themselves should increase in energy efficiency in the future. "[N]ext-generation computers, including projects such as HPE's [Hewlett Packard Enterprise's] 'The Machine,' aim to significantly increase computational speed and power at a lower energy usage."[67]

Prior to the global distribution of such next-generation computers, the question then becomes: what is the marginal benefit to reducing a particular blockchain's immutability and trustlessness levels while increasing the blockchain's energy efficiency? A particular blockchain's functional goals determine the answer.

II. BCTs Applied: A Tool for Combatting Climate Change

Despite BCTs' mining processes' potential energy usage and carbon emissions, this part will provide ways in which BCTs can be used as tools to not only mitigate the causes of global climate change, but also improve the efficiency and enforcement of current climate change mitigation laws and policies.

Most economic theories suggest economywide policies focusing on one singular objective will be the most cost-effective climate change mitigation approach.[68] However, recent data demonstrate "administrative and political barriers may make economy-wide policies harder to design and implement than sector-specific policies."[69] Instead, the IPCC suggests sector-specific policies be implemented, as they "may be better suited to address barriers or market failures specific to certain sectors, and may be bundled in packages of complementary policies."[70] Because of this economic justification, political acceptability, and the proportionally sizable impact on climate change, this Article will focus exclusively on BCTs' potential benefit to mitigation measures within the four most-responsible global economic sectors, cumulatively accounting for 84% of all GHG emissions: electricity and heat production (25%), agriculture, forestry, and other land use (AFOLU) (24%), industry (21%), and transport (14%).[71]

A. *Electricity and Heat Production Sector*

The electricity and heat production sector is responsible for GHG emissions caused by the burning of fossil fuel for heat and energy *across all sectors*. This is demonstrated pictorially in Figure 1, showing the proportional responsibility for electricity and heat production emissions among all sectors.[72]

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[57] Camilo Mora et al., *Bitcoin Emissions Alone Could Push Global Warming Above 2°C*, 8 Nature Climate Change 931 (2018), *available at* https://www.nature.com/articles/s41558-018-0321-8?.

[58] Alex de Vries, *Bitcoin's Growing Energy Problem*, 2 Joule 801 (2018), *available at* https://reader.elsevier.com/reader/sd/pii/S2542435118301776.

[59] *Id.*

[60] World Economic Forum, *supra* note 55.

[61] *Id.*

[62] *Id.*

[63] *Id.* at 25.

[64] *Id.*

[65] *Id.*

[66] de Vries, *supra* note 58, at 801 (arguing "[e]ven though we can easily estimate the total computational power of the Bitcoin network, it provides only little information on the underlying machines and their respective power use").

[67] *Id.*

[68] IPCC, Mitigation 2014, *supra* note 6, at 28.

[69] *Id.*

[70] *Id.*

[71] IPCC, Climate Change 2014: Summary for Policymakers 9 (Ottmar Edenhofer et al. eds., 2014), https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf; U.S. EPA, *Global Greenhouse Gas Emissions Data* [hereinafter U.S. EPA, *Emissions Data*], https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data (last updated Sept. 10, 2020).

[72] IPCC, *supra* note 71; U.S. EPA, *Emissions Data*, *supra* note 71 ("In contrast, the U.S. Sources discussion tracks emissions from the electric power separately and attributes on-site emissions for heat and power to their respective

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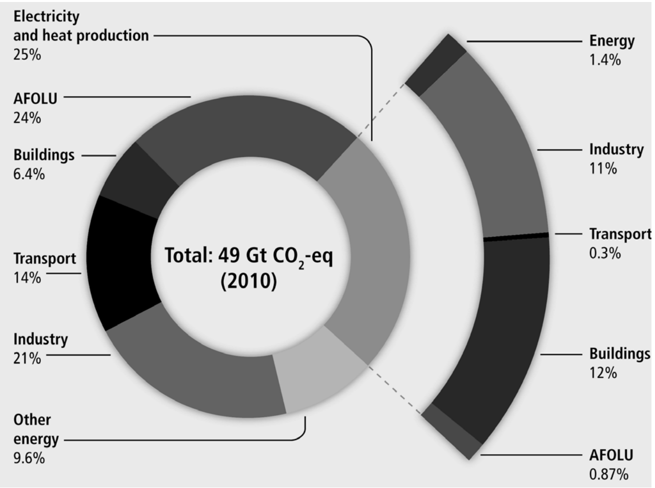
Figure 1. Greenhouse Gas Emissions by Economic Sector



There are three categories of energy system-related mitigation measures: (1) the decarbonization of the energy supply sector (i.e., reducing the carbon intensity of the electricity generation process); (2) final energy demand reductions (i.e., behavior and lifestyle changes in consumer-side energy use—such as "mobility demand and mode, energy use in households, [and] choice of longer-lasting products"); and (3) the switch to low-carbon energy carriers (i.e., efficiency improvements in energy conversion, transmission, and distribution systems).[73]

Of these three, decarbonization of the energy supply sector is identified as key to cost-effective GHG-related mitigation strategies.[74] The IPCC suggests utilizing renewable energy, nuclear power, and carbon capture and sequestration (CCS) to reach decarbonization goals.[75]

1. Supply Side

BCTs can be used as a tool to decarbonize energy generation by facilitating access and contribution to transactions resulting in low-carbon renewable energy on the electrical grid.[76]

Energy consumers, such as homeowners and small business owners, are becoming increasingly able to contribute to the electricity grid themselves (feed-in tariffs) through the use of solar panels.[77] This shift transforms the average energy consumer into what is often referred to as a "prosumer,"[78] an energy-conscious individual or small business consumer too small to otherwise capitalize on current carbon cap and trading policies implemented in countries throughout the world. Prosumers interested in capitalizing on their energy generation—in addition to the traditional use of feed-in tariffs (varying state to state)—can use BCTs to participate in peer-to-peer distributed energy and carbon trading.[79]

Weiqi Hua and Hongjian Sun, engineers at Durham University in the United Kingdom, propose and explain the logistics of a blockchain-based carbon emissions trading mechanism whereby prosumers are both the electricity generators and consumers, and can flexibly propose and select offers for the sale of renewable energy.[80] Such peer-to-peer BCT-based mechanisms "[differ] from trading mechanism[s] in conventional markets which requires a central authority to match bids and offers and publish unique market cleaning prices." However, because prosumers will be able to use BCT-based peer-to-peer distribution networks to offer renewable energy for sale and directly consummate the transaction without any intermediary action, the entire trading scheme will become more efficient.

We are already seeing BCTs used in this way. Households generating solar energy for some large utility companies are earning "SolarCoins"; the more solar power generated and subsequently authenticated by the blockchain, the more SolarCoins the consumer and/or the node earns.[81] This process not only financially incentivizes solar usage (a much less carbon-intensive energy source than nonrenewables such as coal), but also verifies the renewable nature of the energy source, thus assisting consumer choice down the road to reduce final energy demand.[82]

2. Demand Side

BCTs can be used to reduce final energy demand in two main ways: (1) by providing a verification mechanism for a product's individual carbon footprint to aid in consumer choice, and (2) by evaluating and analyzing

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sectors (i.e., emissions from gas or oil burned in furnaces for heating buildings are assigned to the residential and commercial sector).").

[73] IPCC, Mitigation 2014, *supra* note 6, at 65, 66, 69.

[74] *Id.*

[75] *Id.* at 66. Although some scholars argue, for varying reasons, CCS as a decarbonizing mechanism is less desirable than its two alternatives. *See* James G. Groesbeck & Joshua M. Pearce, *Coal With Carbon Capture and Sequestration Is Not as Land Use Efficient as Solar Photovoltaic Technology for Climate Neutral Electricity Production*, 8 Nature 13476 (2018), https://www.nature.com/articles/s41598-018-31505-3.pdf; *see also* Chaz Coleman, *A Policy Analysis of the Driving Factors Behind Carbon Capture and Storage Facilities*, 6 LSU J. Energy L. & Resources 557 (2018), *available at* https://digitalcommons.law.lsu.edu/cgi/viewcontent.cgi?article=1141&context=jelr.

[76] *See generally* International Finance Corporation: World Bank Group (WBG), Using Blockchain to Enable Cleaner, Modern Energy Systems in Emerging Markets (2018) [hereinafter WBG, Using Blockchain], https://openknowledge.worldbank.org/bitstream/handle/10986/31200/133881-EMCompass-Note-61-Blockchain.pdf.

[77] *Id.* at 2.

[78] *See*, *e.g.*, Weiqi Hua & Hongjian Sun, *A Blockchain-Based Peer-to-Peer Trading Scheme Coupling Energy and Carbon Markets*, 2019 Int'l Conf. on Smart Energy Sys. & Techs. (SEST) (2019), *available at* https://www.semanticscholar.org/paper/A-Blockchain-Based-Peer-to-Peer-Trading-Scheme-and-Hua-Sun/e834ace1631f2093f798b97353ef4cc94a91a6fa; *see generally* WBG, Using Blockchain, *supra* note 76.

[79] Hua & Sun, *supra* note 78.

[80] *Id.*

[81] *Id.*

[82] This commodity is otherwise known as distributed renewable energy sources (DRES). Hua & Sun, *supra* note 78. For another example of similar BCT use, see The Apparatus and Method of Activation for Energy Transaction by Using Blockchain of Hybrid, S. Korea Patent No. KR102019478B1 (published Sept. 6, 2019) (located at https://patents.google.com/patent/KR102019478B1/en?q=blockchain&q=energy&oq=blockchain+energy).

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electricity use based on emission allowances within a particular household.

Studies show nearly 80% of consumers are willing to change their lifestyles to protect the environment.[83] Yet as companies feverishly work toward marketing their low-carbon products to smart-carbon consumers, it is increasingly difficult to decipher, as a consumer, whether one product is truly "greener" than another.[84] Fortunately, Hua and Sun's blockchain-based carbon emission trading scheme could allow consumers to purchase products exclusively manufactured using renewable energy without having to trust intermediaries' unverified claims.

For example, if a manufacturing company operates exclusively on solar power generated by local prosumers and verifiably registered on a blockchain similar to that of Hua and Sun's, the company could advertise as such. Carbon-conscious consumers could then either access the blockchain directly to determine the advertisement's accuracy, or an independent organization could survey the blockchain's data and provide verifiably carbon-neutral products with a special certification with few or no in-person visits or personal investigation; the blockchain does the bulk of the certification work.

Further, BCTs provide platforms for efficient energy usage metering[85] and billing.[86] For example, electric vehicle charging stations can run all transactions through the blockchain, assuring precise and accurate transactions and maintaining all of the transaction information in one place. Utility companies attempting to hit their carbon-reduction goals can require their customers to use smart thermostats, appliances, and batteries within their households—tools that measure and report to the blockchain all energy usage and the usage's associated transaction costs, all while protecting the individual household's identifying information from non-authorized access through encryption, hashing, and private keys.[87] Such tools can assist consumers in making more informed energy choices both at home and at work,[88] and "improv[e] grid communication, resiliency, and reliability, all of which are necessary to increase renewables market share."[89]

Scholars also argue BCT positively impacts consumer energy use decisions, because when consumers are participating in the energy market through the blockchain—an activity otherwise unavailable to the typical consumer with the use of central authorities—they are "exposed to the real cost of energy, which might result in more rational energy consumption or suitable price signals for demand response."[90]

3. Switching to Low-Carbon Energy Carriers

BCTs may improve efficiency in energy conversion, transmission, and distribution systems by facilitating and promoting the use of microgrids—electrical grids that operate within a small, regional area. The purpose of microgrids is to minimize the distance generated energy must travel to reach the end-use consumer, because indeed, it takes energy to move energy.[91] As an ancillary benefit, microgrids can "provide . . . frequency and voltage support[ ] to aging power systems with the potential to defer expensive network upgrade investment."[92] So not only do microgrids keep energy markets local, they can improve old and inefficient power distribution systems—lowering the grid's carbon use during transport.

Scholars Merlinda Andoni et al. provide an in-depth description of how BCT can be practically utilized to

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[83] *See* Press Release, Compass Marketing, Climate Change, and the Internet of Carbon, Is Now in Our Hands (& on the Supermarket Shelves) (Dec. 19, 2018), https://www.prweb.com/releases/climate_change_and_the_internet_of_carbon_is_now_in_our_hands_on_the_supermarket_shelves/prweb15998512.htm; *see*, *e.g.*, Press Release, Poseidon, Poseidon Foundation Launches First Retail Platform That Allows Consumers to Support Climate Action Using Blockchain Technology (May 24, 2018), https://ecosphere.plus/wp-content/uploads/2018/06/press-release_b_j_final.pdf, presenting

> [t]he world's first retail platform that connects consumers to their own carbon footprint has been launched in London by non-profit organization the Poseidon Foundation ('Poseidon') . . . [for example,] a pilot is currently underway at Ben & Jerry's . . . [f]or every scoop of ice cream sold the values-led ice cream company is contributing towards carbon credits from a forest conservation project in Peru, and is offering their customers the opportunity to join them in taking action at the point of sale, using blockchain technology.

[84] Merlinda Andoni et al., *Blockchain Technology in the Energy Sector: A Systematic Review of Challenges and Opportunities*, 100 Renewable & Sustainable Energy Rev. 143, 155 (2019).

[85] *See Will Blockchain Define Smart Electric Meter Market Trends of the Future?*, Smart Energy Int'l, Sept. 10, 2018, https://www.smart-energy.com/industry-sectors/smart-meters/blockchain-define-smart-electric-meter-market-trends/.

[86] *See* Seohyeon Jeong et al., *Blockchain Based Billing System for Electric Vehicle and Charging Station*, 2018 Tenth Int'l Conf. on Ubiquitous & Future Networks (ICUFN) (2018), *available at* https://ieeexplore.ieee.org/document/8436987; *see generally* WBG, Using Blockchain, *supra* note 76.

[87] *See generally* WBG, Using Blockchain, *supra* note 76; *see*, *e.g.*, Methods, Systems, Apparatuses, and Devices for Facilitating Provisioning of Audit Data Related to Energy Consumption, Water Consumption, Water Quality, Greenhouse Gas Emissions, and Air Emissions Using Blockchain, U.S. Patent No. 376,124 (filed Apr. 5, 2019) (located at https://patentimages.storage.googleapis.com/86/f3/9b/ba884fd265ad5e/US20190311443A1.pdf); *see also* Andoni et al., *supra* note 84, at 157-58.

[88] Cletus Crasta & Hannes Agabus, *Data Analysis of Building Sensors for Efficient Energy Management and Future Trends in the EU*, 2019 Elec. Power Quality & Supply Reliability Conf. (PQ) & 2019 Symp. on Elec. Eng'g & Mechatronics (SEEM) (2019), *available at* https://www.researchgate.net/publication/335494804_Data_Analysis_of_Building_Sensors_for_Efficient_Energy_Management_and_Future_Trends_in_the_EU.

[89] Rebecca Duff & Michael Lenox, Batten Institute, Path to 2060: Decarbonizing the Electric Utility Industry 4 (2018), https://issuu.com/batteninstitute/docs/batten_briefing_path_to_2060-v7; *see also* Energy Supply System and Method for Operating the Same, European Patent No. EP3300206A1 (published Mar. 28, 2018) (located at https://patents.google.com/patent/EP3300206A1/en?q=blockchain&q=energy&oq=blockchain+energy) (describing the state of the art as:

> Power supply systems supply subscribers connected thereto with, for example, electrical energy via a supply network. It is possible that subscribers not only receive energy from the supply network, but can also feed from renewable energy sources, such as local photovoltaic systems, biogas plants and the like. Injected energy is reimbursed to the subscriber while related energy is charged to the subscriber. Modern metering devices are capable of registering both fed-in and drawn-in energy and transmitting measured values to the operator for billing the amount of energy.

[90] Andoni et al., *supra* note 84, at 155.

[91] *See id.* at 154 (finding "[m]icrogrids promote localised energy production and consumption, which may lead to significant distribution and transmission losses reduction").

[92] *Id.*

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facilitate and encourage the use of microgrids. The authors summarize the currently existing Brooklyn Microgrid—"a blockchain-based P2P [peer-to-peer] energy trading platform" wherein 300 local consumers participate[93]:

> [P]rosumers [(in this case study, there are about 50)] can sell their energy surplus directly to their neighbours by use of . . . smart contracts. . . . Energy surplus is measured by specially designed smart meters that can handle physical energy measurements and data, and sequentially transformed in equivalent energy tokens that can be traded in the local marketplace. Tokens indicate that a certain amount of energy was produced from the solar panels and can be transferred from a prosumer's smart meter wallet to end-consumers by use of blockchain technology. Tokens are deleted by the consumer's smart metering device, as purchased energy is used in the house. Microgrid users interact with the platform by specifying their individual price preferences in the form of willingness to pay or sell electricity. The platform can display location-specific and real-time energy prices. In the initial phase of the project, users manually trigger an agreement in the platform, whose terms are recorded in the blockchain. The ledger records contract terms, transacting parties, volumes of energy injected and consumed as measured by metering devices and crucially the chronological order of transactions. In addition, payments are automatically initiated by self-executed contracts. Every member of the community can have access to all historic transactions in the ledger and verify transactions for themselves.[94]

However, it is important to note that with the use of BCT in this specific instance—in facilitating and participating in a microgrid—some scholars express concern regarding the technical feasibility of every node's ability or likelihood of responding to grid conditions, prices, and local supply and demand.[95] Although outside the scope of this Article, it seems as though widespread implementation of artificial intelligence and machine learning within the microgrid management systems have potential to solve this problem.[96]

B. AFOLU Sector

The AFOLU sector—responsible for about one-quarter of net anthropogenic GHG emissions—can be divided into three main causal categories: (1) deforestation, (2) agricultural emissions from soil and nutrient management, and (3) livestock.[97] To tackle GHG emissions associated with deforestation, the IPCC suggests afforestation (along with the reduction of deforestation) and sustainable forest management are the most cost effective of available mitigation mechanisms.[98] Similarly, agricultural GHG emissions from soil and nutrient management can be cost effectively mitigated through "cropland management, grazing land management, and restoration of organic soils."[99]

Finally, GHG emissions associated with livestock can be reduced with demand-side mechanisms such as better supply chain management to reduce food (and energy inefficiency) waste and changes in consumer behavior—though the global community remains uncertain about the required quantitative scope of such shifts.[100] To reduce food waste on the supply side, the IPCC suggests increasing investments in "harvesting, processing and storage technologies in the developing countries, awareness raising, taxation and other incentives to reduce retail and consumer-related losses primarily in the developed countries."[101] However, scholars have found consumer-side mechanisms, such as changes in diet, have "substantially higher [GHG emission mitigation potential] than that of technical mitigation measures." The potential is not only greater, but indeed consumer-based changes "strongly affect future GHG emissions from food production."[102]

1. Reducing Deforestation

BCTs can be used, and are currently being used on a small scale, to reduce deforestation through smart contracts. GainForest, a cryptocurrency similar to the previously mentioned SolarCoins, "us[es] smart contracts to incentivize farmers in the Amazon to preserve the rainforest in return for internationally crowdfunded financial rewards."[103] Satellites survey plats of forestry, the data are entered onto the blockchain, and the blockchain verifies the extent to which the farmer responsible for each plat is meeting preset conservation goals.[104] If and when the goals are met, the blockchain automatically and instantaneously transfers to the farmer a predetermined payment, providing an incentive for sustainable farming practices[105] and addressing land conflicts, tenure security, and land rights.[106]

Additionally, like one use of BCT in the electricity and heat production sector, BCT can provide the AFOLU sector with "transparency and auditability of commodity supply chains linked to deforestation"[107] by certifying products cultivated with sustainable farming practices, "mobilizing demand for deforestation-free commodities in emerging markets, redirecting finance towards deforestation-free supply chains, and improving the quality and availability of deforestation and supply chain data."[108]

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[93] *Id.* at 155.
[94] *Id.*
[95] *Id.*
[96] *Id.*
[97] IPCC, Mitigation 2014, *supra* note 6, at 24.
[98] *Id.*
[99] *Id.*
[100] *Id.* at 816, 838.
[101] *Id.* at 840.
[102] *Id.*
[103] World Economic Forum, *supra* note 55, at 18.
[104] *Id.*
[105] *Id.*
[106] *Id.*
[107] *Id.*
[108] *Id.* at 13, 18.

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Current sustainability certification schemes operate with two main deficiencies. First, chain of custody (COC) traceability certifications do not actually trace materials to their source—the buck stops at the factory processing the raw materials.[109] Second, companies that rely on these sustainability certifications to attract consumer interest are able to actually choose which company will do the auditing. Companies are able to utilize private auditors who are willing to collude with the company to falsify reports.[110]

However, when all data are stored on the same immutable blockchain ledger from the moment of sale to arrival on the consumer's doorstep, consumers and/or independent third-party certification organizations can provide verifiable and consistently applied sustainability certifications, because numerous individual computers around the globe are verifying the products' COC sustainability, rather than an overworked junior auditor hired by the company that benefits from a positive report. Cryptographic seals (a tool encompassing the previously discussed +nonce hashing function) "can be applied to the wood itself or to individual shipments," providing a COC from the initial market activity to the time the timber makes it to a Lowes near you.[111]

Beyond consumer-side transparency, BCTs can also assist governments and organizations in policing criminal violations of sustainability laws, by more accurately identifying the location and occurrence of criminal acts and preventing criminals from altering the transaction data to conceal wrongdoing.[112] Despite national and international policies attempting to reduce deforestation, illegal logging activities continue to degrade the world's precious carbon-sink resources. "[L]ogging of protected species, logging in protected areas, and logging with fake or illegally obtained permits" is a "multi-billion dollar industry, depressing timber prices and generating $10-15 billion annually in criminal proceeds."[113] BCTs' potential role in tracking lumber's COC can help enforcement agencies identify at which points on the supply chain illegal activities are occurring.[114]

For example, if a lumber distributer is legally authorized to export 20 tons of lumber per auditing period and the company brings in more cash than 20 tons of lumber could feasibly be worth on the market, the blockchain will reflect such—allowing enforcement agencies to take note. BCTs can also provide necessary and lacking information accuracy. Remember, data stored on the blockchain are immutable—keeping criminals within the logging industry from fabricating lumber's source. For example, legal enforcement agencies can scan lumber's grain by using near-infrared spectroscopy (NIRS) to ensure it is derived from a non-endangered species.[115] "NIRS determines a wood's species by comparing its surface spectrum to a database of surface spectra for different tree species, particular to its area of origin, one at time."[116] The scanners can be used at any stage in the lumber supply chain, and the data can be inputted into the blockchain where it sits unchanged and accessible by enforcement agents.[117]

2. Improving Soil and Nutrient Management

Farmers can utilize BCTs to cost effectively improve cropland management, grazing land management, and restoration of organic soils all while lowering the associated GHG emissions by participating in the data ledger. Unlike databases with a central authority, distributed participants operate blockchains. AgUnity, a cooperation-based app applied primarily in Ethiopia, Indonesia, and Papua New Guinea, "enables restoration of trust between smallholder farmers and farming cooperatives by recording [farmers'] transactions via [BCTs]."[118] Because of BCTs' trustlessness, farmers are encouraged to individually participate in the app's service rather than rely on an unfamiliar corporate intermediary likely based in a distant country.

AgUnity "lets farmers schedule various farming activities—such as sharing farming equipment and recording transactions when buying and selling with cooperatives and other third parties, as well as managing their incomes using the in-built digital wallet."[119] Collaboration amongst farmers increases both efficiency and profits.[120] As an ancillary benefit, an increase in farmers' earning potential may provide new opportunities to invest in more sustainable, energy-efficient farming equipment—further tackling agricultural emissions.

Insurance companies can also use BCTs to reduce their own costs while improving cropland efficiency and preventing agricultural waste. Theoretically, an increase in agricultural efficiency and decrease in waste should in turn reduce the required energy input for a particular food product, thus decreasing the GHG input required to produce the same amount of food. To aid in this efficiency-increasing and waste-reducing measure, BCT-based apps similar to the Chinese-applied SmartCrop app can encourage farmers to "hedge against crop volatility through the use of smart [insurance] contracts and intelligent weather

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[109] Changing Markets Foundation, The False Promise of Certification 10-11 (2018), https://changingmarkets.org/wp-content/uploads/2018/05/False-promise_full-report-ENG.pdf.

[110] *Id.* at 31-32; Tansy Hoskins, *Supply Chain Audits Fail to Detect Abuses, Says Report*, Guardian, Jan. 14, 2016, https://www.theguardian.com/sustainable-business/2016/jan/14/supply-chain-audits-failing-detect-abuses-report.

[111] *See* Samantha Radocchia, *How Deforestation and Timber Issues Can Be Battled With Blockchain*, Forbes, May 15, 2018, https://www.forbes.com/sites/samantharadocchia/2018/05/15/how-deforestation-and-timber-issues-can-be-battled-with-blockchain/#1093d5e35347.

[112] World Economic Forum, *supra* note 55, at 18; Radocchia, *supra* note 111.

[113] Radocchia, *supra* note 111.

[114] *Id.*

[115] Julia John, *Portable Scanners That Identify Timber Species Could Detect Illegal Logging*, Mongabay, Apr. 4, 2016, https://wildtech.mongabay.com/2016/04/portable-scanners-identify-timbers-detect-illegal-logging/.

[116] *Id.*

[117] Radocchia, *supra* note 111; John, *supra* note 115.

[118] Jaclyn Bolt, Climate Change, Agriculture, and Food Security [CCAFS], Financial Resilience of Kenyan Smallholders Affected by Climate Change, and the Potential for Blockchain Technology 21 (2019), https://library.wur.nl/WebQuery/wurpubs/fulltext/472583.

[119] *Id.*

[120] *Id.*

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predictions."[121] A smart contract (also used by the Gain-Forest app[122]) exists when contract language is entered into the blockchain whereby the transaction occurs automatically upon satisfaction of the contract's conditions.

By using smart contracts, both parties benefit from avoiding the time and monetary expense of filing and processing a claim, auditing a loss, and waiting to pay or receive loss compensation. For example:

> [Ten] days prior to a hurricane striking, a consumer can initiate an early pay-out beginning with a 90% reduction in the overall sum of the policy coverage. With each day inching closer to the hurricane striking, that 90% will increase by 1% until it reaches the incident date in which the consumer can collect 100% of their insurance policy up to 30 days following the hurricane, which serves as the standard terms for today's weather-related insurance coverage . . . [T]he opportunity cost of choosing to be paid 10 days prior to an event occurring is the difference between receiving 90%-99% of the policies coverage as opposed to 100% . . . .[123]

A farmer benefits from the use of BCTs in their crop insurance smart contracts, because "the ability to salvage the harvest prior to an event striking is a far bigger gain in the long run,"[124] and the insurance company benefits because it mitigates its potential liability based on authorized and verifiable data in the blockchain ledger. Plus, the crops that would have been completely destroyed in the potential catastrophic weather event do not go to waste, and there is one less emission-producing inefficiency in the AFOLU sector.

3. Reducing Livestock Emissions

As with many of the previously discussed economic sectors, BCTs can help streamline food supply chain management to reduce food (and energy inefficiency) waste and can help change consumer behavior. Similar to certificates of origin for renewable energy purchased from the electrical grid or sustainably farmed lumber, food products' carbon inputs can be tracked from their origin to the grocery store all with the use of BCTs. Since nearly 80% of consumers are willing to change their lifestyles to protect the environment,[125] and livestock production accounts for a substantial portion of deforestation efforts,[126] farmers will be eager to track their products on the blockchain—allowing them to market their low-carbon livestock and agricultural products to smart-carbon prosumers and manufacturers selling to smart-carbon prosumers.[127] And since BCTs can verify carbon-smart products, farmers will actually have to drive down their carbon footprints to capitalize on this growing market.

C. Industry Sector

As for the industry sector, there is good news and bad news. The bad news is, as more mitigation technologies are required and produced for reducing GHG emissions in other sectors, the industry sector may be emitting even more GHGs.[128] Similar to the familiar phrase "you have to spend money to make money," we may need to emit GHGs to reduce the net GHG emissions.

It is therefore important, when analyzing—and scrutinizing—the industry sector, to identify those GHG emissions attributable to inefficiencies and those attributable to an increase in mitigation technology production. The good news? Emission-reducing options in the industrial sector can be cost effective, profitable, and are even associated with both private and public benefits such as "enhanced competitiveness through cost reductions, new business opportunities, better environmental compliance, health benefits through better local air and water quality and better work conditions, and reduced waste."[129]

Some industries simply require more energy than others. Thus, even after implementing state-of-the-art technologies to increase efficiency, these remain extremely energy-intensive. Despite this energy-requirement discrepancy, the solution to GHG emission reduction within the industry sector may be one-size-fits-all. The IPCC suggests "[c]ross-cutting technologies such as efficient motors, electronic control systems, and cross-cutting measures such as reducing air or steam leaks help to optimize performance of industrial processes and improve plant efficiency cost effectively with both energy savings and emissions benefits" in all industries—big, medium, or small.[130] On the consumer side, GHG emissions can be reduced by "[e]xtending product life and using products more intensively" while also assessing actual demand for products and services.[131]

1. Supply Side

BCT can help track and manage the food chain and supply system through its decentralized and immutable data platform, and thus reduce unnecessary GHG emissions in the supply side industry sector.[132] Fortunately for the climate change movement, many, if not most, GHG emission-reducing changes in the industrial sector also

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[121] *Id.* at 14.

[122] *See supra* Section II.B.1.

[123] *Id.*

[124] *Id.*

[125] Press Release, Compass Marketing, *supra* note 83.

[126] Supply Change, *Cattle*, http://supply-change.org/commodity/cattle (last visited Feb. 5, 2021).

[127] *See* Press Release, Compass Marketing, *supra* note 83, at 1; World Economic Forum, *supra* note 55, at 5.

[128] IPCC, Mitigation 2014, *supra* note 6, at 743.

[129] *Id.* at 744.

[130] *Id.* at 743.

[131] *Id.*

[132] Dietrich Knorr et al., *Food for an Urban Planet: Challenges and Research Opportunities*, 4 Frontiers Nutrition 1, 3 (2018), https://www.frontiersin.org/articles/10.3389/fnut.2017.00073/full (stating "the rapid rise in number, size, and diversity of megacities make the food chain and supply system, from field to tables, increasingly complex to manage" and arguing "[m]anaging these systems will require a Total System Approach incorporating multiple strategies including blockchain technology, Big Data analytics, computational modeling, the internet of things (IoT), and artificial intelligence (AI)").

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likely provide the manufacturer monetary incentives.[133] In other words, efficiency can yield both lower emissions and higher profits.

Nader Mohamed et al. investigate and promote benefits of "Industry 4.0"—the latest industrial revolution driven by big data, data storage and computing capabilities, and "advanced and efficient methods for analyzing data and transforming it into decisions"—for improving cost and energy efficiency in "smart factories."[134] Specifically, they argue BCTs provide a unique benefit to manufacturers when a particular efficiency optimization method requires or involves multiple business partners.[135] "Blockchain can generally provide . . . better methods for trusted information exchanges, automated and efficient negotiation processes, and efficient smart agreements among enterprises."[136] For example:

> [W]ith the capabilities of blockchain, it is possible to have fast and efficient negotiation processes with both customers and suppliers. With this, a smart factory can know in advance the products that need to be manufactured. It can also use previous knowledge to know the energy needed to manufacture these products. The smart factory can use blockchain to negotiate the required energy with several providers. This negotiation helps reduce the cost of energy needed to produce these products. . . . In addition, rapid and efficient agreements can be conducted with the energy providers that leads to the best price without the need for a third party such as an authoritative body to record this agreement. This can reduce time delays, management costs, and human errors, which will further enhance energy efficiency and reduce total cost.[137]

Thus, BCTs' immutability and trustlessness can be a valuable asset to supply-side industry—providing manufacturers a trusted mechanism to increase both cost and energy efficiency.

2. Demand Side

BCTs also help guide consumer behavior to "[e]xtend[ ] product life and us[e] products more intensively" by incentivizing participation in and creation of circular economies—economies based on unlocking financial value in things that are otherwise considered and disposed of as waste.[138] For one, consumers can use BCT-based apps to retrieve rewards (in the form of cryptocurrency) in return for sustainable actions (e.g., collection of ocean plastic, recycling, or water conservation).[139] Plastic Bank and RecycleToCoin are two examples of such BCT-based apps. The apps exchange cryptocurrency for "depositing collected ocean recyclables such as plastic containers, cans or bottles,"[140] or "return[ing] their used plastic containers to automated machines in Europe and around the world."[141]

BCTs can also help incentivize participation in and creation of circular economies when used in more "traditional systems of waste management."[142] Extended producer responsibility (EPR) systems incentivize consumers to extend product life "by transferring a fee paid at the point of purchase to recyclers in order to subsidize the cost of recycling non-profitable or even toxic materials found in products such as electronic waste."[143] In markets where the costs of implementing EPR systems is prohibitive, smart contracts may be used to help increase scalability and efficiency—making this investment in circular economies more worthwhile.[144]

D. *Transport Sector*

BCTs can be used in the transport sector in three main areas: (1) encouraging and effectuating demand-side changes; (2) assisting in necessary demand-side shifts; and (3) streamlining transportation infrastructure.

Although the transport sector is currently responsible for only 14% of total GHG emissions, it demands specific attention. For one, transport emissions have a high potential rate of increase—faster than the rate of increase "from the other energy end-use sectors."[145] Second, there is robust evidence and high agreement that "emissions in the global transport sector have grown in spite of more efficient vehicles (road, rail, watercraft, and aircraft) and policies being adopted."[146]

The IPCC recommends a combination approach to mitigating passenger and freight emissions within the transport sector.[147] Manufacturers should try to lower vehicle energy intensities, and consumers should use fuels with lower-carbon intensities, avoid unnecessary transport journeys to the best of their abilities, and shift their desired mode of transportation "to lower-carbon passenger and freight transport systems."[148]

Beyond these measures, however, the IPCC warns larger change is necessary. Since transport emissions are causally linked to a rising gross domestic product (GDP), developed countries with strong and growing economies—such as the Organisation for Economic Co-Operation and Development (OECD) participating countries—are primarily responsible for transport emissions.[149] Further, as developing countries rise through the ranks and strengthen their

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[133] Nader Mohamed et al., *Leveraging the Capabilities of Industry 4.0 for Improving Energy Efficiency in Smart Factories*, 7 IEEE Access 18008, 18008 (2019), https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8632912.

[134] *Id.* at 18009.

[135] *Id.* at 18016.

[136] *Id.*

[137] *Id.*

[138] World Economic Forum, *supra* note 55, at 6.

[139] *Id.* at 18.

[140] *Id.*

[141] *Id.*

[142] *Id.*

[143] *Id.* at 18-19.

[144] *Id.* at 19.

[145] IPCC, Mitigation 2014, *supra* note 6, at 603.

[146] *Id.* at 72.

[147] *Id.* at 73.

[148] *Id.*

[149] *Id.* at 606.

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own GDPs, we can expect an accompanying increase in GHG emissions.[150]

The IPCC therefore warns, in combatting global climate change, it is vital to "decouple" transport emissions from such economic growth.[151] This is not to say GHG emission mitigation should focus on non-OECD countries. Although developing countries' emissions are expected to increase in the next few decades,[152] the "decoupling" focus remains on OECD countries, because infrastructure constraints and higher urbanization densities in non-OECD countries will force an emission plateau despite accompanying growing economies.

The IPCC reports, with high confidence, the countries that have implemented carbon taxes "alongside technology and other policies [ ] have contributed to decoupling of emissions from GDP." Beyond this evidence, it is unclear precisely how to execute this decoupling, but it is clear responsibility lies on state and local governments to "invest[ ] in infrastructure and compact urban form," making such lower-carbon passenger and freight transport systems—such as ports, trains, and other high-speed rail systems—available for consumer use.[153]

1. Supply Side

Despite a projected failure when focused on a single stream of entities, scholars argue the road transport sector should be incorporated into the Emissions Trading System (ETS) because of its sheer emission growth potential.[154] Fortunately, some suggest a BCT-based ETS for the road transport sector (ETS-RT) integrating the upstream, midstream, and downstream entities may be more successful.[155] The government would first "determine[ ] the [emissions] cap and allocate[ ] the initial permits."[156] The fuel producers, vehicle manufacturers, and vehicle users are thereafter involved as "regulated entities with tradable permits, who are responsible for the three determinants of the road transport emissions: emission factors of fuels, fuel economy of vehicles and vehicle miles traveled, respectively."[157] BCTs will take care of the trading, monitoring, reporting, and verification of the emission permits, "which can dramatically reduce the costs and eliminate the fraudulent behaviors,"[158] thus improving the mitigation mechanism's implementation feasibility.

2. Demand Side

BCTs can also assist consumers in avoiding unnecessary transport journeys and shifting their desired mode of transportation to lower-carbon passenger and freight transport systems.[159] Salam Khanji and Sameer Assaf propose a semi-decentralized BCT-based app, GreenRide, distributing cryptocurrency called GreenRideTokens (GRT)[160] to users utilizing the app to carpool with their colleagues.[161] The program is semi-decentralized, because it is not an entirely accessible peer-to-peer network. For security and regulatory perspectives, "GreenRide users' information [is] kept in Google Firebase database that can be easily integrated with the corporate database and hence, employees' data is not going to be hosted outside the premises of the corporate."[162] However, Khanji and Assaf foresee their technology evolving into a fully decentralized app open to the public, with GRT being "easily an exchangeable token."[163]

3. Transport Infrastructure

Finally, BCTs can be used, particularly in urban areas, to make public transportation infrastructure more efficient and readily/equitably accessible. One scholar hypothesizes that "[a] permission-based blockchain solution could provide users equitable and open market access to transport services, with cashless, subscription-based and/or subsidi[zed] payment mechanisms, . . . supersed[ing] 'closed-loop' AFC [automated fare collection] technology (e.g., smartcards) on buses and trains,"[164] especially in low-income country cities (LICCs) where it could "provide viable infrastructure to the informal minibus . . . taxi market, which represents circa 70% of all mass transit trips in LICCs."[165]

The development of BCT-assisted mass transit infrastructure can assist cities in feasibly incentivizing and formalizing the shift from highly congested and inefficient to a more streamlined public transit system. In doing so, the city is given a "[p]latform for inward investment into public transport infrastructure," and it becomes "[e]asier to allocate subsidies in line with policy objectives" such as active travel and lower-carbon transport.[166] This mitigation mechanism is especially helpful, because the IPCC finds high confidence that technology policy—such as technology-push (e.g., publicly funded research and development) and demand-pull (e.g., governmental procurement programs)—"address market failures related to innovation

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[150] *Id*. at 603.

[151] *Id*. (stating there is high confidence among the global scientific community that "[r]educing global transport [GHG] emissions will be challenging since the continuing growth in passenger and freight activity could outweigh all mitigation measures unless transport emissions can be strongly decoupled from GDP growth").

[152] *Id*.

[153] *Id*.

[154] Wenxiang Li et al., A *Blockchain-Based Emissions Trading System for Road Transport Sector: Policy Design and Evaluation*, Climate Pol'y (2020), *available at* https://www.researchgate.net/publication/347198544_A_blockchain-based_emissions_trading_system_for_the_road_transport_sector_policy_design_and_evaluation.

[155] *Id*.

[156] *Id*.

[157] *Id*.

[158] *Id*.

[159] Salam Khanji & Sameer Assaf, *Boosting Ridesharing Efficiency Through Blockchain: GreenRide Application Case Study*, 2019 10th Int'l Conf. on Inf. & Commc'n Sys. (ICICS) 227-28 (2019), https://ieeexplore.ieee.org/abstract/document/8809108.

[160] *Id*. at 228.

[161] *Id*. at 224.

[162] *Id*. at 227-28.

[163] *Id*.

[164] Simon Herko, *A Blockchain Infrastructure for Transportation in Low Income Country Cities, and Beyond*, 2 J. Brit. Blockchain Ass'n 1, 3-4 (2019), https://doaj.org/article/b4fc8af6f67f4d4da491e6e6d0c7ff1b.

[165] *Id*.

[166] *Id*. at 4.

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and technology diffusion" and thus complement other mitigation policies.[167]

III. Conclusion

This Article provided a baseline description of BCTs: how they work, why they are gaining popularity, and ways in which they can be used. Clearly, BCTs can be (and to some extent already are) utilized in many ways to reduce GHG emissions in the four most emission-heavy global economic sectors: electricity and energy generation, AFOLU, industry, and transport. The Article addressed the potentially carbon-intensive nature of BCTs, identified different ways to utilize BCTs in a less energy-intensive manner, and, finally, discussed many currently implemented and potentially possible ways in which BCTs can be harnessed as a tool to mitigate the main causes of climate change.

At this point in BCT integration, the successful widespread use of some of the identified methods is inconclusive. However, BCTs are unstoppable and increasingly popular emerging technologies, and it can be encouraging to think of blockchain's possibilities in an environmentally and technologically changing world.

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[167] IPCC, Mitigation 2014, *supra* note 6, at 29.