Blockchain, Double Counting, and the Paris Agreement

Working paper by Henrique Schneider, h.schneider@sgv-usam.ch

This essay explores possibilities and limitations of applying the blockchain technology to select aspects of the Paris Agreement (PA, or, Agreement), especially to issues under Article 6 (and 4, and 13). While this essay identifies several areas in which the blockchain technology could ease the implementation of the articles just mentioned, it will also highlight limitations to this approach. Some limits to blockchain are imposed by the technology itself. The most important, however, arise from the context in which it could be employed. Blockchain cannot substitute Party-negotiations, which determine the set-up of a system to which blockchain could be applied. Blockchain is a form of implementation, and not an institutional set-up. It is quite the inverse: blockchain can only implement a pre-arranged institutional set-up. On the other hand, the decision for using blockchain has implications for the institutional set up.

The main thesis of this essay is: through the application of the blockchain, double counting (and similar concerns) can be mitigated while making reporting, tracking and managing corresponding adjustments efficient. Blockchain enables accounting for nationally determined contributions (NDCs) and increases the transparency of Paris Agreement's implementation. This, on the other hand, depends on a careful institutional set-up.

In a first section, this paper explains the idea of blockchain and its core, the distributed ledger. The second section explains how blockchain relates to issues of the Article 6, and subsequently 4 and 13, of the Paris Agreement. The third discusses the limitations of this approach. A brief conclusion ends the paper.

1. The Blockchain Technology

The blockchain is a digital, public, permanent, append-only distributed ledger (Idelberger et al. 2016). A ledger is a list of transactions. This list is chronologically structured, i.e. every new transaction is added to the list immediately after the one before it. It is not possible to change earlier entries as it is not possible to switch their place or delete them, therefore permanent and append-only.

While these attributes are common to most or all types of ledgers, the blockchain's ledger has further characteristics. It is digital, existing as a mathematical structure. It is distributed, i.e. it is not centrally managed, but maintained by a group of dispersed managers, or, nodes. The mathematical structure of the ledger exists in all nodes at the same time and in the same form. The management of the blockchain does not allow for the nodes to split the ledger nor for division of labor. Every node performs the exact same task and every ledger in all nodes of a system is identical. System stands for a group of nodes and agents using a specific algorithm based on blockchain.

The ledgers can change by adding an entry to them (all). This occurs, when a majority – over 50% – of the nodes of that system agree to add an entry to the ledger. Once they do so, all nodes add the entry to their respective ledgers creating isomorphism among the ledgers in the nodes. The blockchain-system relies on all nodes being isomorphic as a sign of robustness. The ledger as a mathematical structure exists at the same time in a potentially unlimited number of nodes. A transaction can only be added if most nodes process the exact same transaction, validating it.

At regular intervals, the program creates a block that contains all of the transactions in that period. There is a group of nodes called "miners" who compete to validate the transactions in the block. Once a block is validated, it gets connected to the previous block to create a chain of validated blocks. If a block cannot be validated, it does not become part of the chain and all transactions therein are lost. (In cryptocurrencies, the mining nodes compete against each other for validating the block. The first to succeed, receives a unit of cryptocurrency.) Records cannot be altered retroactively without the alteration of all subsequent blocks and the collusion of the network. Therefore, to hack a validated block an agent would need to hack the entire chain simultaneously.

In addition to these requirements, the isomorphic ledgers distributed among nodes are public. Any interested entity – even a non-node-running-entity or not-transaction-party-entity – is able to view them and identify the transactions as well as the agents of the transactions. Often, blockchain is wrongly understood as an anonymous system. It allows anonymity and it allows full transparency. By default, however, it is a pseudonymous system.

While the previous paragraphs sketch the core of the logic behind blockchain, additional background could foster its understanding. One important issue, for example, is establishing the relationship of blockchain to Bitcoin. While the cryptocurrency Bitcoin is the first application of the blockchain, not all blockchain is necessarily Bitcoin – nor cryptocurrency. Blockchain is a technology applicable to all matters of governance, for example to smart contracts, to record keeping, or to bookkeeping (Catalini & Gans 2016).

Satoshi Nakamoto, the pseudonymous creator of the blockchain and Bitcoin, wrote in a message sent to a cryptography-focused mailing list in October 2008. "I've been working on a new electronic cash system that's fully peer-to-peer, with no trusted third party." As he wrote these words about Bitcoin, he attached a white paper in which he developed the blockchain. Nakamoto thought the blockchain as a new way of answering an old question: how can there be enough trust between peers to exchange something of value.

His answer: neither through force nor through central institutions but through networks. Combining established cryptography tools with computer science research, the blockchain operationalizes trust in tying it to the transactions. Peers might continue to distrust each other, but they will trust a transaction if it is robust, verified, unique (i.e. without a possibility for double counting), shown transparently and isomorphic on all data points, or nodes. In other words, Nakamoto (2018) intended to create a system in which it is costly to create value but cheap to guarantee property as well as costly to rig the system but cheap to verify the transactions of that system.

How does a transaction in blockchain work? Let it be explained using Bitcoin as an example. In Bitcoin, a transaction is the transfer of cryptocurrency from one person to another. One person can send cryptocurrency to the other person. To do so, the first person creates a transaction on her computer that must reference a past transaction on the blockchain in which she received sufficient funds, as well as her private key to the funds and the other person's address. That transaction is then sent out to the nodes in the network. The nodes will validate the transaction as long as it has followed the appropriate rules. If most nodes accept the transaction – i.e. the deduction from the first person, the authentication of the key, and the addition to the second person – all nodes will add the entry into a data-block and the transaction is completed.

In Bitcoin and other cryptocurrencies, a subset of nodes, called miners, organize valid transactions into lists called blocks. A block in progress contains a list of recent valid transactions and a cryptographic reference to the previous block. In blockchain systems like Bitcoin and Ethereum, miners race to complete new blocks, a process that requires solving a labor-intensive mathematical puzzle, which is unique to each new block. The first miner to solve the puzzle will earn some cryptocurrency as a reward. The math puzzle involves randomly guessing at a number called a nonce. The nonce is combined with the other data in the block to create an encrypted digital fingerprint, called a hash.

The hash must meet certain conditions; if it doesn't, the miner tries another random nonce and calculates the hash again. It takes an enormous number of tries to find a valid hash. This process deters hackers by making it hard to modify the ledger. While some blockchain entities use other systems to secure their chains, this approach, called "proof of work", is the most thoroughly tested.

This is the final step in securing the ledger. When a mining node becomes the first to maintain a block, it sends the block to the rest of the network for approval, earning digital tokens in reward. Mining difficulty is encoded in the blockchain's protocol; Bitcoin and Ethereum are designed to make it increasingly hard to solve a block over time. Since each block also contains a reference to the previous one, the blocks are mathematically chained together. Tampering with an earlier block would require repeating the proof of work for all the subsequent blocks in the chain.

Which of these attributes are important for implementing or operationalizing the Paris Agreement? First, blockchain is a system among peers. Second, it creates trust by identifying trust with transactional clarity. Third, it has no central institutions but allocates responsibility to all peers at the same time. Fourth, different specific systems can emerge while adopting the same blockchain principle. Fifth, the blockchain is public; in other words, transactions are transparent.

Trust is a risk judgement between different parties. In blockchain, determining trust is a function of *proving identity (authentication)* and *proving permissions (authorization)*. Put more simply, the blockchain wants to know, "Are you who you say you are?" and "Should you be able to do what you are trying to do?” In the case of blockchain technology, private key cryptography provides a powerful ownership tool that fulfills authentication requirements. Possession of a private key is ownership. In the context of Paris, each Party would be required to have its own key, giving them ownership but also identifying them to the system. Authentication is not enough. Authorization – having enough money, broadcasting the correct transaction type, etc. – needs a distributed, peer-to-peer network as a starting point. A distributed network reduces the risk of centralized corruption or failure. This distributed network must also be committed to the transaction network's recordkeeping and security. Authorizing transactions is a result of the entire network applying the rules upon which it was designed (the blockchain's protocol).

There is plenty of research on applying blockchain to accounting, for example: Sarkar (2018) provides a broad overview on blockchain, governance and the management of accounting processes. Faning & Centers (2016) as well as Kokina et al. (2017) show how accounting has increasingly been incorporating blockchain in order to keep records, clear transactions, and consolidate reports. Kiviat (2015) explores risks and limitations of applying blockchain to accounting and smart contracts. The next section explores how to apply blockchain specifically to accounting under the Paris Agreement.

2. The Paris Agreement and Blockchain

This section operationalizes the former by identifying select topics of the Paris Agreement that could profit from the blockchain technology. Here, the focus is Article 6 (, and 4 and 13). It is going to explain, first, the general issues concerning the topic; second, to summarize the system requirements; and finally, to discuss the application of the blockchain.

2.1 Technical Issues of the Paris Agreement

While there are many areas in which the blockchain could be applied to the implementation of the Paris Agreement, focusing on one, Article 6, makes its possibilities and limitations as well as its interactions with the institutional set-up clearer. By directing its attention to Article 6.1-7, this section will also discuss direct implications for Articles 4 and 13 as well as for the relevant paragraphs in Decision 1/CP.21 (Decision) and subsequent decisions. This section will be following the outline of expert discussions and negotiations as in Umweltbundesamt (2017), OECD/IEA (2017), and Marcu et al. (2017) as well as in the numerous presentations made in preparation for the COP 24 (2018).

At a first glance, the Paris Agreement seems to contain enough provisions on counting, accounting and accounting for a Nationally Determined Contribution (NDC). With a grain of salt, they are (Umweltbundesamt 2017):

- Definition of targets, methods and accounting approaches in Article 4.8 PA and para 28 Decision (Formulating NDC), Article 4.10 PA (timeframe for NDC), Article 4.12 and para 29 Decision (public registration of NDC), as well as Article 4.13 PA and para 31 Decision (accounting for NDC).

- Tracking progress in Article 13.7 PA and para 91-98 Decision.
- Accounting for international transfers in Article 6.2 PA and para 33 Decision (corresponding adjustments), as well as Article 6.5 PA and para 37-38 Decision (emission reductions).
- Final assessment in Article 4.13 PA and para 31 Decision (accounting for NDCs).
- Review and compliance in Article 13.11 PA and para 91-98 Decision (technical expectations), as well as Article 15 PA and para 104 Decision (mechanism to promote compliance).

These provisions, however, need operationalization. With operationalization comes interpretation which leads to many still unanswered questions, even in the already specialized realm of accounting. Examples of such questions with consequences for counting and accounting are:

- How to deal with differently formulated NDCs – intensity goals, CO2-equivalents, NDCs based on target, NDCs based on investments, etc.?
- How to deal with NDCs formulated on different basis – emissions, budget, target, intensity, measures, etc.?
- How to handle multi-year versus single-year NDCs?
- How to differentiate NDCs covering whole economies, some sectors of an economy, subsectors, programs of activities or projects?
- What does count as a reduction in the sense of a climate-action unit, i.e. mitigation outcome – as stipulated in 6.2 – or an emission reduction – as stipulated in 6.4? Factual reductions of CO2 equivalents, removals, sinks, avoidance, or even capacity building?
- How to change a NDC?
- How to count and account for domestic transfers?
- How to generate climate-action units and relate them to NDCs? For example, by quantifying mitigation targets and progress, quantifying mitigation outcomes, avoiding double counting (and similar concerns), accommodating different metrics, dealing with different vintages, adjusting for additionality and non-permanence.
- In addition, some Parties think that units, especially internationally transferable mitigation outcomes ITMOs, should bear a serial number to be clearly identifiable. This would help identifying their vintage, the history of their transferences, and their use or cancellation. More robust suggestions want ITMOs to be identifiable by what, when, by whom, to what extent, and in which quality they attest. For one of the most robust information on ITMOs, refer to Umweltbundesamt (2017, 62-63).

For the aims of this paper, there are two pivotal technical questions with systemic relevance: How to adjust correspondingly when transacting climate-action units and how to avoid double counting (and issuing, crediting, claiming, using, etc.) when engaging in cooperative approaches – those under Article 6 PA?

A corresponding adjustment is the method by which transferring Parties and acquiring Parties participating in cooperative approaches (help) avoid double counting. From the accounting point of view, adjusting correspondingly seems to denote a method for settling accounts. The Paris Agreement and related decisions do not specify (yet) the technical rules for settling accounts. They also leave open whether the settlement occurs at a given point of time, typically the end of a pre-defined period, or continuously, i.e. immediately after or even as the transaction occurs. In addition, the official documents do not explain what constitutes double counting. Instead, they often refer to the statement of Article 4.13 of the Paris Agreement, “Parties shall avoid double counting in accounting for their NDCs”. In expert panels, a consensus seems to emerge understanding double counting as arising, when the same unit is used by more than one Party or for more than one purpose, e.g. achieving an NDC and achieving some other aim.

So far, two different approaches for operationalizing the corresponding adjustments and the subsequent usage or cancellation of units seem to have emerged. The first is the introduction of a – global-centrally maintained (?) – buffer registry. This buffer registry records transactions between Parties and, at the end of a pre-determined period, allows for clearing and balancing the respective Parties’ accounts for use and cancellation. The second approach counts and accounts with a greenhouse-gas GHG inventory and a balance sheet. Departing from a Party’s GHG inventory, acquired units would be subtracted from and transferred units would be added to a balance sheet. At the end of a pre-determined period, the initial inventory as well as a balance sheet are reported and balanced. What is adjusted is the balance sheet, and not the inventory. Netting them is at the same time a report as well as the proof of work whether a Party has achieved its aims under the Agreement. While the first approach is more flexible allowing for differently formulated NDCs, the second approach is clearer in the sense of accounting but presupposes metricized GHG inventories in each Party.

2.2 Desiderata for a System of Accounting

From the point of view of accounting strictly speaking, three system-requirements are necessary: the unit, the transaction, and its logging.

Within a system of accounting, the accounting *unit* must be measurable, clear, and stable. Formulating the unit in a mathematical structure leads to measurability and clarity. When the mathematical structure for measuring the unit remains unchanged and is unchangeable by single agents, the unit becomes stable. If more than one unit coexist at the same time, the accounting system needs to define one as a base-unit into which the others are transformed, at least for reporting reasons.

For example, most accounting systems choose the currency of the sovereign entity as base-unit of accounting. It may incorporate transactions in other currencies, but at some point, it transforms these other currencies into its default currency, or, unit. This has a threefold consequence for its application to the Paris Agreement. First, every Party needs to define its respective measurable, clear and stable base-unit, supposedly, the unit in which the NDC is formulated, ideally, a ton-equivalent of CO2. Second, it is possible for Parties to entertain different units as long as they define their respective the base-unit. Third, each Party that entertains different units will have to convert all units to its respective base-unit – at least at some point.

A *transaction* denotes an exchange. Independently from the context of the exchanged goods, a transaction leads to changes in the ledgers of the parties involved in the transaction. Taking the simplest transaction there is, a one-to-one exchange, as an example: this transaction leads to two changes in each of the two ledgers. The first party notes what is subtracted from its ledger and what is added to it. The second party notes what is subtracted from its ledger and what is added to it.

If party one sells chocolate to party two at 5 GBP, the changes to the ledger are as follows: Party one, minus chocolate, plus 5 GBP. Party two, minus 5 GBP, plus chocolate. The correspondingly adjusted ledgers, in accounting, are maintained separately, each party maintaining its own. While parties could, after each transaction, consolidate the ledger by compiling the balance sheet, usually they only do so after a pre-determined amount of time elapses, for example, a quarter or a year. This has a twofold consequence for its application to the Paris Agreement. First, if there is exchange of units among Parties, the exchange should be accounted for in the manner of a set of subtraction and addition for each party involved in a transaction. Second, there is need to clarify how often the ledger is consolidated and reported to those entities not involved in this transaction. The possibilities are immediately or after a pre-determined period.

An aspect of transaction, negotiations usually ask how to treat the use of a climate-action unit against the fulfillment of an NDC or its voluntary cancellation. From the point of view of accounting, the solution to both is not different from the system explained above. The use for NDC or cancellation of a unit is a transaction. On one side, on the account of how many units a Party has, the unit is subtracted. On the other side, a use for NDC or cancellation account, the used or cancelled unit is added. The two accounts balance each other, and the ledger is thus settled.

In accounting, each accounting party *logs* all its transactions in a log. Usually, this log is permanent, append-only, central and private. Permanent means that entries cannot be changed and deleted but by new entries which are recorded as new entries at the bottom of the old ledger, therefore appendant. Central logs are those that exist only in one instantiation; therefore, whoever maintains the log controls it and its entries. Outsiders or unauthorized parties cannot view the private log. The conversion of centrality of management and privacy of the log is especially valuable for private entities, such as companies.

This has a twofold consequence for its application to the Paris Agreement. First, there is the question whether the log is central or not. Note that from the point of view of accounting, a private log maintained by one or each Party and a central log maintained by the UNFCCC, for example, are both examples of central logs. They are central because the log exists in one instantiation only, i.e. there is just one log or one main log. Maintaining isomorphic logs at the same time is the contrary to central, thus, decentral. The second question is whether the log (or the logs) are private or open to public or other-Party viewing.

One overarching theme concerns whether corresponding adjustments only apply to instruments under 6.2 or also under 6.4. While the discussion must remain open in this paper, it is worthwhile noting that from the point of view of accounting, nothing prevents applying the logic discussed here to 6.2 as well as 6.4. And in any case, blockchain can equally be applied to both.

2.3 Applying Blockchain to Accounting in the Paris Agreement

When exploring how and to what extend to apply blockchain to select aspects of the Paris Agreement, there is need to differentiate two sets of questions. The first is, how the system should be set-up in order for blockchain to work. The second is, once the system has been set-up and the blockchain applied to it, what consequences it bears. The first questions will be discussed using the three elements identified above – unit, transaction, and log. The second questions will then lead to a more general review.

For the blockchain technology to be applicable to some aspects of Article 6 of the Paris Agreement, climate-action units, emission reductions or ITMOs, need a metric. From the point of view of blockchain, it is not important how the metric is generated – whether by actual emissions reductions, co-benefit, adaptation plans, economic diversification, etc. –; it matters that the metric and the generation of units is a rule-following procedure that can be expressed by a mathematical structure. This mathematical structure would, then, be the primary algorithm for a blockchain system under Paris. Each Party can have an algorithm of their own, or there could be different Parties adopting or subscribing to a common algorithm. Under Paris, a potential unlimited number of algorithms can be established. A system denotes here a specific algorithm. Each system needs to have a base-unit.

It especially matters that the metric of the unit does not change. The base-unit for a Party should be clear and stable. This, however, does not mean that there cannot be different types of units, or that a Party cannot entertain different types of units at the same type. On the other hand, each type would be governed by a different algorithm. If tokens of different types are traded and exchanged, a separate algorithm might determine their “exchange rate”. Therefore, the blockchain would establish different systems with each a different unit, and it could also establish a methodology of conversion.

As for the transactions, the same algorithm that manages the units would manage the transactions. As mentioned above, the algorithm is the determinant in a system of blockchain. It connects the nodes, generates the time-interval in which blocks must be maintained, and serves as an objective anchor for the creation of units. In principle, there are two variants of how far-reaching the algorithm should be:

The first (“thin”) variant is establishing one or more algorithms clearing either each Party’s balance sheet or buffer account. This algorithm would, at the same time, track and settle transactions as well as adjust additions and subtractions to the balance sheet or buffer account correspondingly. While this kind of algorithm can be used in both cases, it would work better with the balance sheet approach, since by adding or subtracting units to a ledger its logic is already subscribed to the balance sheet. Note, however, that this application of the blockchain, even if relying on the balance-sheet-approach, does not presuppose a GHG inventory. The results the algorithm produces, i.e. the up-to-date-ledger, can also be used to account for transfers under any other type of base and NDC, if appropriate mathematical conversions are made.

The first variant does not use the algorithm to its full extend. A possible second ("thick") variant is more ambitious in applying the blockchain to Article 6 PA. It presupposes that Parties exchanging units adopt the same algorithm. This can best be explained using an example. Imagine that there is a central mechanism managed by the UNFCCC and imagine there is a multilateral mechanism between some Parties. In this more ambitious variant, there would be one single algorithm for all Parties engaged in the central mechanism managed by the UNFCCC and there would be one single algorithm used by all Parties to the multilateral mechanism. If one Party used both, it will use both algorithm and a third-one, a conversion algorithm – maybe, this conversion algorithm can even be global, a central facility of the UNFCCC.

At a first glance, this might seem complicated and prone to double counting (and similar concerns). But it is not. The algorithms cannot transact without the nodes; it is the nodes that "certify" a transaction. There is no transaction without "proof of work" and there is no addition without subtraction. The algorithms can also be programmed to only allow into their systems units created in that system. E.g. even if a Party uses the conversion algorithm to convert units from the UNFCCC managed mechanism into those of the multilateral mechanism, the multilateral mechanism's algorithm can be programmed not to allow converted units to be further transferred. With the blockchain, a Party can be part of multiple algorithm, without risking double counting (and similar) or losing a unit. Furthermore, the blockchain's algorithm(s) can ensure an identification of each unit, if so programmed.

Independently from either variant, the blockchain has the additional advantage that its users can always know the state of transactions and the whereabouts of units. This, by the way, seems to imply that there isn't need for a pre-determined timeframe in which to report and consolidate adjustments, balance sheets or buffer accounts, since the algorithm itself always establishes each Party's and the system's balance. Also, it is worthwhile recalling that the blockchain system, by default, is one transparency. The state of transactions and whereabouts of units are in principle known to all, Parties and non-Parties.

This means that the algorithm does not only fulfill the role as technical standard for a transaction. As it manages transactions, it also is a log. By the definition of the blockchain, this log is decentralized and public. In this context, it would make sense to turn each participating Party of a system of crediting and transferring, i.e. of a blockchain or of an algorithm, into a node. Each Party should have its own authorization and identification code.

This dual structure of Parties as nodes and users of the system corresponds with certain set-up requirements: As nodes, Parties are active in the governance of the system validating each transaction – a transaction can only be added to the general ledger if more than 50% of nodes clear it. This also means that Parties always have access to the ledger and to the logs, leading, thus, to more transparency and accountability. As users, Parties to a system can use the system's blockchain in counting their climate-action units, their engagement in international cooperation, accounting for their own NDCs as well as multi-Party benchmarking. As users, Parties can rely on the blockchain as a fast, clear, secure, and cheap technology.

This outline shows that applying blockchain to Article 6 of the Paris Agreement – with obvious consequences for Articles 4 and 13 – has not only technical but more importantly systemic consequences. On the one hand, it can mitigate and even eliminate the problem of double counting (and similar issues) while solving the problem of adjusting correspondingly. This is a feature of the Blockchain sharing the logical pre-requisites of any accounting system – unit, transaction, and log – while relying on the decentral management of isomorphic ledgers and on nodal verification. These aspects are clear desiderata of the Paris Agreement.

On the other hand, applying the blockchain leads to other consequences that are not expressly foreseen in the Agreement. Among these consequences are transparency, instantaneous clearing and settling of accounts, instantaneous reporting, and constant verification (in the accounting sense). These consequences arise because of the features of the blockchain as a distributed ledger. They are not necessarily unavoidable. An algorithm can be programmed to mask the Parties' identity as it can be programed to not to settle accounts or only to reveal the results after a certain time or on predetermined timeframes. The algorithm can accommodate non-consolidation of blocks until a defined point in time; it would keep record of all transactions but neither disclose nor verify them (in the accounting sense) until the adequate command is given. While the Blockchain can accommodate as such, it would seem inefficient to curb so many of the advantages of that technology. There are some aspects that cannot be changed. These are: decentralization, distribution of ledgers, append-only ledgers, and nodal verification.

3. Limitations of the Blockchain

After the review of the technical set-up and its consequences when applying Blockchain to Article 6 PA, it seems important to discuss its limitations. There are technical limitations lying in the conception of blockchain as a technology itself. And then, there are limitations given the nature of the Paris Agreement. Finally, there are some things the Blockchain cannot do – on its own.

3.1 Limitations due to technology

The blockchain is a remarkably robust system. As per current knowledge, among all its different applications that have been running since 2008, not once has a system with a properly programmed algorithm broken down. On the other hand, the algorithm has not only to be properly programmed, it must remain unchanged. A change of rules would probably lead to a new algorithm. This raises the issue of how to treat or incorporate units of different algorithms. While the systemic security of a system of blockchain seems not to be an issue, there is the problem of physical security of hacking. Many party-agents and nodes of blockchain have been targeted by cybercrime. While the attacks, even if successful, could not influence the system per se due to its multi-nodal nature, they could successfully harm the attacked party-agents and nodes.

In a system in which the total amount of nodes is limited, there is the risk of collusion. If more than half of all nodes agree to set prices, divide markets, or on any other form of detrimental coordination, the whole system is affected. In a system with potentially unlimited number of nodes, this threat is mitigated by the rate of creation of new nodes being higher than the incentives to collude. In a system with a limited number of nodes, however, the incentives to collude are not counter-balanced by the increase of nodes.

Finally, the application of blockchain can be complex. While the management of the system as well as its use are simple, its setting-up and especially the programming of the algorithm presuppose knowledge and commitment.

3.2 Limitations due to the Nature of PA

Some limitations in the application of the blockchain to Article 6 – the focus of this essay – arise due to the nature of the Paris Agreement as a fruit of negotiation between sovereign Parties. These limitations are not absolute; Parties can address them. In minimum, however, negotiations do not become easier by having to treat more technical issues in a more definite way.

The application of the blockchain presupposes a pre-defined institutional set-up, i.e. stable rules, modalities, and procedures. This potentially burdens negotiations in two ways. First, experience has shown that the more rules, modalities, and procedures are negotiated, the more time-intensive and difficult negotiations become. Second, defining an overarching system in the sense of the blockchain means setting-up this system in its entirety, i.e. negotiations cannot settle some issues while leaving others open. Once the system is set-up and the algorithm programmed, changing it is almost impossible – at least, strongly discouraged. Foreseeing all the necessary details is, generally and in Party-negotiations, a difficult task.

While the blockchain eases the implementation of technical aspects of the Paris Agreement as well as compliance and reporting, its technical specificities might impose a higher entry-barrier to some Parties and non-Party entities interested in the select Articles of the Agreement to which it is applied. Examples of these barriers are the understanding of the blockchain, programming of a specific algorithm, hardware and software requirements to run a node, especially a mining node, or software requirements to use the system, to mention some.

From a negotiations point of view, blockchain's limitations arise because the application of the blockchain pre-judges negotiations' outcomes. For example, applying the blockchain necessitates the definition of unit, transactions, and logs. While addressing these issues is not controversial per se, they ought to be addressed because of the Agreement and the Parties' decision and not because they must be addressed to implement a technology. Similarly, the implementation of the blockchain combines otherwise separate layers of the Paris Agreement. The example of this essay being Article 6, 4, and 13. Again: while it is not controversial to harmonize the requirements of these articles, it is controversial to do it because of a technology in their implementation.

3.3 Final caveats

In addition to the limitations to blockchain due to its technology or due to the nature of the Paris Agreement, there are decisions that cannot be delegated to the implementation phase or to the implementation with blockchain as wells as there are processes that cannot be implemented by blockchain itself. Among the first are decisions relating to the unit and its metric of to units and their metrics as well as to rules, modalities, and procedures. Furthermore, the criteria for qualification and participation in the instrument(s) or mechanism(s) under Article 6.2 and 6.4 are not part of the blockchain. While the technology can accommodate for either, both, and different instantiations of them, it is a question of principle whether the technology should do so.

Examples of processes that cannot be delegated to the blockchain are real verification and how to deal with the share of proceeds. While the blockchain robustly verifies the accounting side of each transaction, the real, or climate-impact, side still needs "on the ground" verification. While the blockchain eases transactions in climate-unit between Parties, the monetary transactions are outside its scope.

4. Conclusions

This essay has shown that through the application of the blockchain, double counting (and similar concerns) can be mitigated while making reporting, tracking and managing corresponding adjustments in transacting climate-action units efficient. Blockchain enables accounting for nationally determined contributions (NDCs) and increases the transparency of Paris Agreement's implementation. This, on the other hand, depends on a careful institutional set-up.

The application of the blockchain to select aspects of the Paris Agreement – this essay focused on Article 6 (, 4, and 13) – faces, however, limitations. The careful institutional set-up it presupposes is one of its most important limitations because it burdens negotiations. In addition, there are technical limitations to what a blockchain can deliver.

In lieu of an overall conclusion, a practical suggestion is to apply the blockchain to a pilot program under Article 6.4 of the Paris Agreement, to establish learnings, and to decide whether to scale it at a later point in time.

References

Catalini, C., & Gans, J. S. (2016). Some simple economics of the blockchain. *National Bureau of Economic Research*. White Paper No. w22952.

Kiviat, T. I. (2015). Beyond bitcoin: Issues in regulating blockchain tranactions. *Duke Law Joural*, *65*, 569-611.

Kokina, J., Mancha, R., & Pachamanova, D. (2017). Blockchain: Emergent industry adoption and implications for accounting. *Journal of Emerging Technologies in Accounting*, *14*(2), 91-100.

Idelberger, F., Governatori, G., Riveret, R., & Sartor, G. (2016). Evaluation of logic-based smart contracts for blockchain systems. *International Symposium on Rules and Rule Markup Languages for the Semantic Web* (pp. 167-183). Springer, Cham.

Fanning, K., & Centers, D. P. (2016). Blockchain and its coming impact on financial services. *Journal of Corporate Accounting & Finance*, *27*(5), 53-57.

Marcu, A., Vangenechten, D., Martin-Harvey, O. & González Holguera, S. (2017). Paris Agreement Issues and Options: Elements for Text under Article 6. *ICTSD Working Paper*. https://www.ictsd.org/sites/default/files/research/20171020_andrei_marcu_-_issues_and_option_in_article_6_pa_0.pdf

Marcu, A. & Zaman, P. (2018). Paris Agreement 'Straw Man': Guidance on Cooperative Approaches Referred to in Article 6, Paragraph 2 of the Paris Agreement. *ICTSD Brief*. https://www.ictsd.org/sites/default/files/research/20180212_article_6.2_guidance_skeleton.pdf

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system*.

OECD/IEA Project for the Climate Change Expert Group (2017). *Workshop Summary Workshop on "Corresponding Adjustment" as part of Article 6 accounting.* Ottawa, Canada, 20 February 2017

Sarkar, S. (2018). Blockchain Accounting, The Disruption Ahead. *The Management Accountant Journal*, *53*(6), 73-78.

Umweltbundesamt (2017). *Robust Accounting of International Transfers under Article 6 of the Paris Agreement*. Discussion Paper

UNFCCC (2015). *Paris Agreement*. FCCC/CP/2015/10/Add.1

UNFCCC (2015). *Decision 1/CP21*. FCCC/CP/2015/10/Add.1