NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

TDT4501 SPECIALIZATION PROJECT

On The Relation Between Blockchain Technology and Sustainability: A Mapping Study

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Abstract

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Master of Engineering

On The Relation Between Blockchain Technology and Sustainability: A Mapping Study

by Eirik Harald LUND

In this paper we look into the relationship between blockchain technology and sustainability. Looking to the UN goals for sustainability, calling for technological innovations to address the global climate issues, we examine smart grids and supply chain management technologies. We conduct a systematic mapping study to get an overview of the current literature. A lot of proposals already exist for both smart grids and supply chain management, but there is a need for real life implementations. We believe there is potential for companies to utilize these technologies, but further research is necessary to make them more economically beneficial.

Acknowledgements

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List of Abbreviations

RQ	**R**esearch **Q**uestions
PoW	**P**roof **o**f **W**ork
PoS	**P**roof **o**f **S**take
P2P	**P**eer to **P**eer
RFID	**R**adio **F**requency **Id**entification

Chapter 1

Introduction

1.1 Summary

In this paper we conduct a systematic mapping study in order to discover how blockchain technology relates to sustainability, as defined by the UN goals. First we introduce the background of the study, with relevant knowledge and why we believe it important to look at these issues [2]. We then move on to describing the methodology used, and why it is relevant to our topic [3], before presenting the results [4]. We then present the findings [5]. After that comes a discussion of the findings, looking at what we can take away from this study [6], before arriving at the conclusion [7].

1.2 Content

In this section we summarize the contents of each subsequent chapter.

1.2.1 Chapter 2 - Background

Chapter 2 summarizes previous knowledge thought to be necessary or otherwise relevant to understand the following research and discussion. We introduce the Blockchain, with an example through Bitcoin, which was the original implementation of the technology. We describe some of the basic functionalities and features of these technologies, in order to give the reader an understanding of the potential for further innovations in the field.

Secondly we discuss sustainability, specifically in relation to the UN goals for sustainable development. We specifically focus on goal 13, and argue that it is of relevance to the field of computer engineering. To narrow the scope, we describe a set of possible technologies that can be developed, and that will be the focus of this study.

Lastly, the relation between these technologies and blockchain is discussed. We argue that it is possible to utilize blockchain technology in the development of sustainable technologies. A few examples are highlighted to show the relevance of our discussion. Finally we mention the negative influence that the blockchain might have on sustainability, particularly through resource use, as many current applications are very energy intensive.

1.2.2 Chapter 3 - Methodology

Here we outline the methodology used to conduct the study. In this paper, we use the methodology for systematic mapping studies in software engineering proposed by Kai Petersen et al. It involves a series of steps where you have an activity, generating an output.

First off it is necessary to define the research questions. The goal of this step is to define the review scope, as to have a goal in mind to reach.

The second step is to conduct the search. In a systematic mapping study, this involves creating a set of search strings. These include key words for the different topics we are looking at. They are grouped together by specific topics, joined by the boolean operators AND and OR. These strings are then used to search for and gather papers from several online libraries. This process yields a large amount of papers of varying relevance.

Next comes the screening of said papers. To do this, one defines inclusion and exclusion criteria. Going through the whole set of papers, generally looking at the title, abstract and conclusion, one decides on which papers to go along with, and which to ignore. After the process of vetting the papers, one is left with a smaller set of useful articles.

The papers left are then subjected to a more thorough review, gathering keywords used in the abstracts. These are used to create a classification scheme in which we can put the papers. It is normal to base the categories on previous research, resulting in an iterative process. Often there will be several disjoint categories, to look at different dimensions of the research examined, such as research type and contribution type.

Lastly, the papers are put into the different categories. Using the resulting data, the results are visualized in a variety of ways. It is common to look at things like publication frequency over time, but also the distribution of contribution types. This is the final step, and with this one is left with a systematic mapping study.

1.2.3 Chapter 4 - Main research

This chapter summarizes the main points of interest of the mapping study. We go through the steps described in the section above, starting with defining the research questions.

To begin we define the research questions. This is done based on the background information from chapter 2. Well-defined research questions are essential to a study, as they give the direction of research and answering them is the end goal of the paper.

In the second step we decide on which libraries to use. This choice was made as an informed decision, based on the reputation and main focus of different libraries. To aid this choice, we conducted some informal, exploratory searches, to get an impression of whether we would find a reasonable amount of relevant papers.

Next we decided on certain inclusion and exclusion criteria. To do this we did a preliminary overview of some of the papers found. This helped gain an understanding of what we had actually found. After coming up with a set of criteria, we tested how these affected the set of papers. After an initial test, adjustments were made before conducting the actual vetting of the papers.

After removing irrelevant papers, we did a more thorough reading to get the different categories into which we would place them. This was also subject to an iterative process, as it is difficult to be completely accurate. This process was further complicated by the fact that we had not found any similar mapping studies upon which we could base our choices.

For the last step we placed the papers into different categories. This left us with several data sets from which we could extract information. We present the findings as various graphs and plots, to more easily view and discuss the data. Through these visualizations we were able to discuss the state of the art.

This finally left us with a systematic mapping, where we can see how the study of these topics has evolved over time. We can also see what kind of contributions have been more common than others. This shows both what researchers have considered important, but also gives an idea of what might be of future interest to study.

1.2.4 Chapter 5 - Results

In chapter 5, the results of the study are discussed. We look at the statistics of the papers found in the literature review, including but not limited to an analysis of the development of research done over time.

A central part of this discussion is the relation between the research questions and the results found.

1.2.5 Chapter 6 - Discussion

In this chapter we go into more detail for a selection of the papers. We present each sub-topic in turn, analyzing how relevant papers relate to it, as well as to other pieces of research. We also bring up relevant articles, papers and reports not found during the mapping.

1.2.6 Chapter 7 - Conclusion

We conclude with findings and discussions on future work we believe relevant and of interest.

Chapter 2

Background

We will here introduce the background we are basing this paper on. We include technical knowledge we believe necessary or useful in order to understand the details, scope and motivations behind the study.

2.1 Blockchain

Blockchain is described as a distributed or public data ledger, where transactions are stored in a series of joined blocks [89]. The blockchain technology was proposed in a paper authored by a Satoshi Nakamoto in 2008. The technique was suggested as a cryptographically secure solution to security issues regarding online transactions and digital currency, specifically as the technology behind the cryptocurrency Bitcoin [1].

The distribution can be better understood through the example of Bitcoin; in Nakamoto's original proposal, an algorithm generates mathematical problems. The difficulty of these is adjusted through a running average to keep the time it takes to solve each problem at roughly ten minutes. The problem is distributed to every node, i.e. participating computer, in the network through a peer-to-peer process. Each participant then races to solve the problem first. When a solution is found, the computer will create a blockchain block and try to add it to the chain. A timestamp is also included. The other computers will then verify the solution. In the case of more than one participant claiming the solution, the timestamp will decide. An agreement is found through group consensus, meaning that even if there are malicious actors in the network, they would need to take over a significant portion of it to take control. The winner is awarded a set amount of bitcoin to be sent to an address of their choosing. The process of solving a mathematical problem to obtain bitcoins is referred to as bitcoin mining.

As Blockchain was launched along with Bitcoin, cryptocurrencies have been a big focus of research and business. As time has passed, however, more use cases have been discovered, for example smart grids [7] and improved sustainability in manufacturing [33]. There are also many examples in the literature of Blockchain being used in supply chains, including for improved visibility [65] and anti-counterfeit measures [34].

Although the replacement of centralized banks argued for by Nakamoto in their paper has not arrived, there's still a big interest in the blockchain technology. The World Economic Forum claims that "distributed ledger technology promises to have far-reaching economic and social implications" [84]. There is reason to believe we will see Blockchain being used in a lot of different contexts in the coming years.

Given the grand expectations for blockchain technology, we believe it can be useful to conduct a mapping study on a subset of the research available, in order to see what is being done, and how the literature has developed over time.

2.2 Sustainability

The UN has defined a list of 17 goals for sustainable development [73]. They describe global challenges we need to address in order to achieve what they describe as a better and more sustainable future. Goal number 13 is about climate action. That is to say, taking action to prevent further human caused climate change [74].

The UN describes climate change as something affecting all of us; "It is disrupting national economies and affecting lives, costing people, communities and countries dearly today and even more tomorrow" [74]. At the same time, they describe it as a "race we can win", but that it requires international cooperation.

In order to win the race they describe, scalable technological innovations are fundamental [74], but they cannot be implemented without due care. We will be looking at some issues contributing to pollution and climate change, including production and distribution of electricity, food waste, and illegal resource harvesting. In order to do this, related technologies will be explored.

According to a report made by REN21, 10.4% of the world's energy production in 2016 came from renewable sources [92]. This number appears to be increasing, with an estimated 70% of the additions to power production in 2017 coming from renewables. However, a lot of people still don't have access to electricity. Instead of putting additional strain on central grids, an option could be to set up off-grid networks; self-reliant networks producing electricity on a small scale. Having self-reliant networks allows for independent stability, and a reduced reliance on externally generated electricity, which in many cases will come from power plants using fossil fuels. Green energy production is a key concern for UN goal 7, affordable and clean energy [74]. Offering people not only the means to easily purchase green energy, but also safely produce it and even sell it themselves could be a motivating factor for more widespread use.

Goal 2 addresses hunger, and mentions the immense food waste in the world [74]. Improving supply chain management might help avoid some unnecessary waste through traceability. The United States Centers for Disease Control and Prevention, and the Food and Drug Administration reported an outbreak of E. coli during the Spring and early Summer of 2018 [44]. Investigation revealed it was caused by romaine lettuce from the area of Yuma, Arizona. The government agencies had to do traceback investigations to deduce from where the bad product originated [48], as most fruit and vegetables for commercial sale are not adequately tracked from origin to destination. Because of the lack of traceability, possibly safe lettuce also had to be discarded, as there was no way to safely ascertain that it came from a non-infected batch, or whether it had been in contact with contaminated products during transportation.

In a different UN report, released in September 2018, it is reported that environmental crime has become the largest financial driver of conflict, out-sizing even drug trade and human trafficking [75]. Illegal exploitation of natural resources such as lumber and minerals are a big part of the economic activities. Similar to the previous point, the lack of reliable traceability contributes to the issue, as there might be no way to tell an illegally harvested resource from a legitimate one.

As such, we believe it is highly relevant to relate issues of sustainability to technological innovation, in this case to blockchain technology. In order to limit the huge scope, we would like to look at only the two topics mentioned above, namely smart grids and supply chains. The energy expenditure and energy efficiency of blockchain technology is also of interest. It is of the authors' belief that these two topics are well worthy of study, and that doing so will offer some insight into how researchers are trying to address issues of sustainable development, and also into what should be done in the future.

2.3 Implementations in Blockchain

Blockchain is being researched and used by companies and start-ups alike to explore the potential of the technology. The motivation is to improve current practices, which can of course lead to lower production costs and hence more industry and pollution, but it also goes hand in hand with more environmentally friendly approaches.

There has been much research done in the area of microgrids and smart grids. Berkeley Lab defines a microgrid as a "localized group of electricity sources and sinks" that can "disconnect and maintain operation autonomously as physical and/or economic conditions dictate" [91]. A smart grid is a grid capable of offering improved grid-customer interaction, for example by adjusting the price of electricity in real-time. These two concepts can be combined to create self-reliant micro networks, e.g. a neighborhood where some have solar panels and sell off surplus production to other people on the grid. Blockchain has been used to create smart contracts that automatically ensure the validity of such transactions [67]. A smart contract is a digitally signed contract with included pieces of code that execute in case of defined events.

Blockchain has also been used to create supply chain traceability systems [29]. The goal is to have accountability for the whole supply chain, from the farm to the market. With each stop along the way confirming the status of the product, one can in theory guarantee the quality. Having a certainty of where a product comes from can be important to improve food safety, and also prevent unnecessary losses in cases of disease outbreak with limited scope.

In the same vein of tracing the product from start to finish, the techniques have potential for combating illegal exploitation. A current challenge is the whitewashing of illegally procured goods through mixing with legal goods [75]. This so-called green washing happens through corruption, hacking, fake documents and other means. Blockchain has been suggested for solving the issue of trustless interaction [41]. Thus one can to some extent prevent corruption and perhaps ensure the truthful origin of products.

At the same time, one cannot ignore the potential consequences of eagerly implementing new technology. Bitcoin has grown immensely in popularity since its launch, spurring the creation of enormous Bitcoin mines. These are essentially data centers, created for the express purpose of solving the algorithmic problems generated by the Bitcoin algorithm. With increasing popularity, and hence competition, the need for computing power increases. More computing power needs more energy, which has lead to an estimated power consumption of at least 2.55 gigawatts of electricity across the network, according to an estimate made by Alex de Vries in a paper published May 2018 [86]. This is roughly equivalent to the total energy consumption of the country of Austria. It is important to note that this is the network used for a single application of the blockchain technology. There are also estimates available for the energy consumption of the Ethereum network, which places it at a level comparable to Iceland as a whole [43].

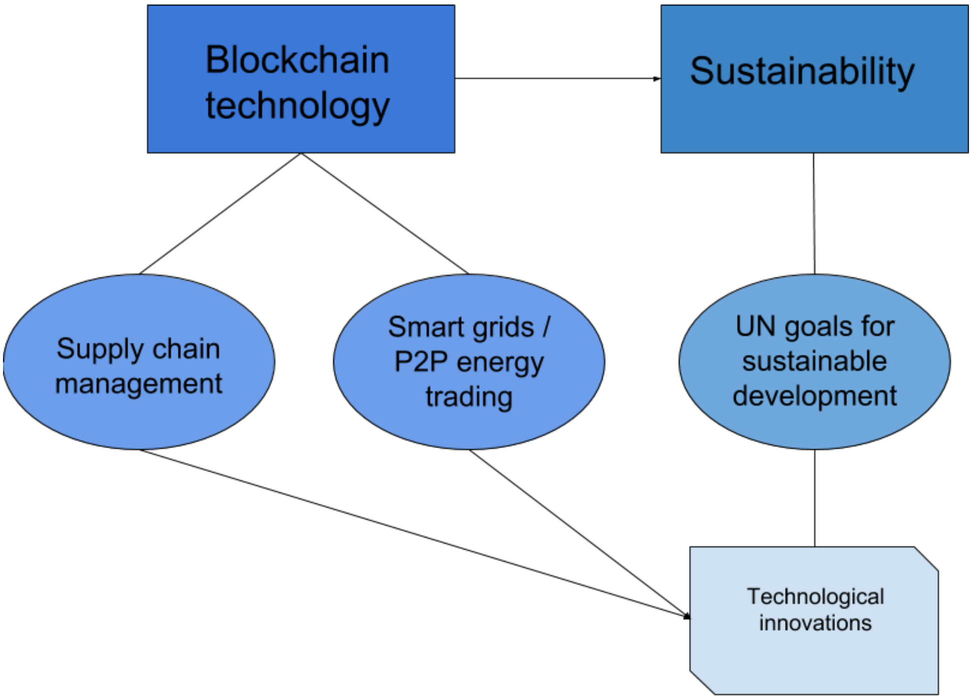


FIGURE 2.1: How the topics of the paper connect.

Figure 2.1 shows how we consider the topics of this paper to be connected. The two main parts are blockchain technology and sustainability. We want to look at how to use blockchain implementations to address issues of sustainability. The specific types of implementations we want to look at are supply chain management systems and smart grid systems made using blockchain technology. We define the sustainability issues through the UN goals for sustainable development [74]. Specifically, goal 13 of the UN goals calls for technological innovations. Goals 2 and 7 also relate to supply chains and smart grids respectively. Improved supply chains can potentially reduce waste in supply chains [13], and smart grids might make it easier to provide green energy to more people [7]. This paper will look at what has been done with regards to the blockchain implementations, and how viable the proposed solutions are for addressing sustainability issues.

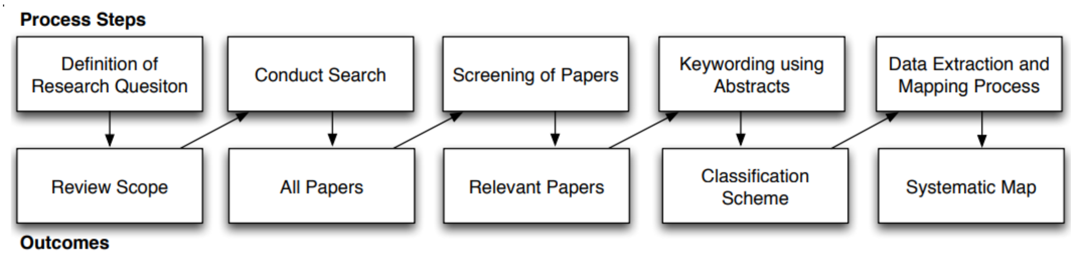
Chapter 3

Methodology

3.1 Systematic mapping study

After considering various options, we decided to use the methodology for systematic mapping studies in software engineering described by Petersen et. al in [2]. We chose this methodology based on two main considerations: 1) It is a good way to get an overview of what already exists in literature, and 2) we found no previous studies of this kind on the topics of blockchain technology and sustainability, so we would have to research the literature regardless in order to study the topics. The methodology consists of several steps, as shown in 3.1. The boxes in the upper row refer to processes or tasks, while the lower refer to the results from carrying out the former.

FIGURE 3.1: The process for systematic mapping studies in software engineering.



We first had to decide on the RQs. This first step is important in order to limit the scope of the study. While it could be possible to review a large amount of literature and decide on a topic from that, it would be a big time sink. It is therefore preferable to limit oneself first, and then look for relevant literature.

For the second step, it is crucial to develop search strings, which are then used to gather all possibly relevant papers. Haphazard searching yields papers, but in an unstructured manner. By carefully constructing the strings, one can be more certain of getting good results, and it also makes it possible for others to retrace your steps.

The search process gathers all papers found in the online libraries using the search strings, without using any judgment, and can easily result in duplicates as well as simply irrelevant papers. These have to be vetted from the pool. Removing duplicates is simple enough, but the next step involves deciding on what qualifies as an irrelevant paper. The decision is made through the use of inclusion and exclusion criteria. The criteria are designed in such a way that one can with a certain amount of accuracy easily rule out the papers that will not contribute to the study. One then goes through the titles and possibly the abstracts of the gathered papers and makes decisions.

After narrowing down the list to a more manageable size, one has to classify the remainder. One should gather keywords from the abstracts, which are then grouped to create categories. The process of going through the papers also helps understanding the context of the works.

Finally, the articles are sorted into suitable categories, which provide a table from which one can calculate frequencies to do analysis. One should also visualize the data and findings, for example using a bubble plot. Visualizations aid quick understanding and make it easier to understand what one is looking at.

3.2 Relevance of methodology

As mentioned at the beginning of this chapter, we want to get an overview of what already exists in literature. Understanding what others have done is an important part of research, as it is wasteful to research a problem that has already been solved satisfyingly.

First we have to decide on the research questions. This study was inspired by reports from the UN on sustainability and environmental crime, so we wanted to have an angle to address these issues. That means formulating research questions in a way that set the scope on sustainability. Technologically, we believe blockchain technology is here to stay, and that it has plenty of potential. These two factors combined helps us set the review scope to the intersection of these topics.

For the search we had to decide on which libraries to use. To decide, we will use libraries mostly aimed at engineering and computer science, as those are the fields within which we are working. It is also important to decide on the search strings. The decision can be made through cursory searches; starting with using keywords related to our topics of interest; blockchain and sustainability, green energy, and so on. The searches then lead to an iterative process where we can find the strings we believe will be the most useful.

Before screening the papers, we should take a quick look at the titles of the papers found. Rather than spending a lot of time doing full readings, skimming the texts will offer some insight into what the authors believe to be the most interesting, i.e. what will catch people's attention. The result of the first readings can then be used in combination with what we are interested in finding out to come up with criteria for including and excluding papers. We can of course not expect the criteria to be perfect from the first attempt, so some time will also be spent further refining them as we come across ideas we might not have considered ourselves.

After being left with a hopefully much smaller amount of papers, it will be more manageable to read them in more detail. We will be looking for more keywords, and in general what the papers have in common. Looking for commonalities is in order to later put them into general categories or groupings. As with the other decisions, this too will have to follow an iterative process, in order to achieve better accuracy.

Lastly we will put the papers into the categories, which will enable us to look at an aggregate of data. Collecting and presenting the data in such a way will offer insight into trends over time, what researchers have focused on, what has not been done much, and so on. Building on that insight, it will hopefully be possible to reach some conclusions, and get ideas of what should be looked into, to aid further research.

To conclude this section, we believe the methodology for systematic mapping studies from Peterson et al. is relevant for the fields we are looking at, as blockchain still is a young technology, and almost no meta-research has been done on how it relates to sustainability. The topic of sustainability is highly relevant for the global society, so we believe insight into how it relates to blockchain technology can be a useful contribution to the literature.

Chapter 4

Main research

4.1 Research questions

This paper revolves around the following research questions (RQs):

Research Question	Explanation
1: How is blockchain technology related to sustainability?	The blockchain technology is being used for a variety of purposes. Some of the use cases might have a net positive effect on climate change, whereas others could cause significant harm.
2: How can blockchain technology be used to develop sustainable technology?	In which direction should further research and development of blockchain technology be headed?

TABLE 4.1: Research questions.

The motivation for these RQs is described in the background, see chapter 2. Sustainability is a major issue that affects the whole global population[73]. There are several factors to addressing the issues, including technological innovation. Blockchain is a fairly novel technology, with both researchers and the industry seeing lots of potential. We want to look into what has been done to relate these two topics.

First we want to explore what relevance there is between the two, building on our belief that certain technological applications can be exploited to the benefit of sustainability. We will look into what research exists, and whether there is any merit to our belief. To answer the second question, we will look at the viability of the solutions we might find. Looking at the literature, we will discuss the potential and difficulties of such solutions.

4.2 Search strings

Working from the RQs, the following search strings were developed:

Initial test searches using the terms "blockchain AND sustainability" and "blockchain AND (sustainability OR sustainable)" yielded a very wide spectrum of results. To get more specific results, we decided to use more specific terms.

Based on the motivation for this study from chapter 2, we wanted to look more into certain use cases, namely smart grids and supply chains, as we believe those to have

Search strings
blockchain AND "climate change"
(blockchain OR cryptocurrency OR bitcoin) AND ("climate change" OR green OR "green energy")
(blockchain OR bitcoin OR cryptocurrency) AND (climate OR green OR "green certificate")
blockchain AND "supply chain"
(blockchain OR bitcoin OR cryptocurrency) AND (climate OR green OR "green certificate") AND ("supply chain")

TABLE 4.2: Search strings.

potential to improve industries. Proof of origin both for products and energy are topics we wanted to look into, which lead to the inclusion of "green energy" and "green certificate".

The term "climate change" was included to look for papers specifically looking into that specific topic, as we would like to look into how these may or may not be related.

4.3 Libraries used

We wanted to look at what is being done with regards to blockchain, smart grids and supply chains, not just on a theoretical level, but also with practical implementations in mind. We therefore decided to use IEEE, ACM and dblp. IEEE has an engineering focus, ACM is for computing and dblp for computer science. Cursory searches also found these to yield relevant results.

Libraries	**Links**
IEEE Xplore	https://ieeexplore.ieee.org/Xplore/home.jsp
ACM Digital Library	https://dl.acm.org
dblp computer science bibliography	https://dblp.uni-trier.de

TABLE 4.3: Online libraries used.

4.4 Papers found

We decided to use the program Mendeley to keep track of the references for all the documents found, and also to facilitate the gathering process.

After conducting the searches in the libraries listed, we ended up with 535 papers. These could be distributed as following:

However, some of the documents found in the libraries were tables of content for conferences and similar, and were automatically excluded by Mendeley simply because they're not meant to be cited. As such, the working set included 486 documents.

Libraries	1st string	2nd string	3rd string	4th string	5th string
IEEE Xplore	17	301	18	35	30
ACM Digital Library	1	4	4	49	0
dblp computer science bibliography	3	28	14	31	0
Total	21	333	36	115	30

TABLE 4.4: Number of papers found using the different search strings in each library.

4.4.1 Filtering

Given the novelty of blockchain technology, there is a lot of change happening quickly. With that in mind, we decided to only look at papers from the last five years, as anything older could very easily be outdated. After removing duplicates, we were left with 318 papers. These were then vetted further through the following inclusion and exclusion criteria:

Inclusion	Exclusion
Studies related to using Blockchain to address sustainability related issues	Study related to the already existing functionality of Blockchain technology
Studies related to improving the energy efficiency of Blockchain services	Studies related to addressing problems with Blockchain technology not related to sustainability
Studies looking at the impact of Blockchain technology	Studies related to offering a service through Blockchain that does not address an environment or climate related topic

TABLE 4.5: Inclusion and exclusion criteria

In the background in chapter 2 describe how smart grids and supply chains tie in with sustainability. Based on that discussion, they were considered related to sustainability for the purpose of these criteria. After going through with the criteria, we were left with 62 papers for further study. Two of the papers were not available for free through our university, but we will consider buying access in the future. As such, the final study was based on 60 papers.

Some papers on smart grids look at how to create a secure network, however papers dealing exclusively with the cryptographic solution were excluded, while those with a more holistic view were included.

4.4.2 Groupings

As we did not find any previous mapping studies on blockchain and sustainability, we were left with the task of deciding the groupings from scratch ourselves.

The papers were put into the following categories:

1. Knowledge area

2. Contribution type
3. Research type

The three categories are further divided into their own groupings. A complete list of these groupings, as well as explanations for them, can be found in Appendix A. At the end of grouping process, we were finally left with categorized data to analyze.

4.4.3 Knowledge areas

We split the papers we found into 6 categories. These categories were decided on through reading the papers and recognizing common topics. The categorization is an important step in the systematic mapping study, and as such requires careful selection. It is common to base the choice on earlier works, as they will have been developed iteratively by several researchers. However, to the best of the authors' knowledge, no similar mapping studies have been done before.

As such, we decided on the grouping by following these steps:

1. Choose a sample of the papers
2. Read the titles, abstracts, conclusions and keywords if included
3. If the paper fits an existing category, put it there. If not, create new category
4. After finishing the sample papers, do the same with the rest of the papers
5. If there is a too big of an overlap between categories, get rid of those categories and return to step 2

The resulting categories can be found in table A.3, in appendix A.

After the first look, most of the categories were already as they are now, but a category named "smart cities" was also included. After some discussion between my supervisors and me, the category was removed. The reasoning was that it is a very broad term, so limiting it only to the topics of interest to us would be too inaccurate.

There was originally a category called "smart grids", which was renamed "P2P energy trading", as the latter was deemed more accurate. Not all of the papers on energy trading between individuals specifically refer to smart grids. However, the category "smart grid security" was kept, as the cases where security was included did deal with smart grids.

Similarly, "smart grid security" was renamed "energy trading security", as the former was found to be too strict. The term "smart grids" refers to a fairly specific scenario, where there is an off-grid network of automated energy trading. "P2P energy trading" is more general, and can cover any kind of situation where individuals are trading energy between each other.

Overall the papers fell fairly neatly into the final knowledge areas. A small amount of papers could potentially fit into more than one, and one was fell slightly outside a strict categorization. The rest were unproblematic.

4.5 Data found

We will here present the data extracted from the papers.

The first graph illustrates the total number of papers published each year. It only includes the papers left after filtering, but no other analysis has been made.

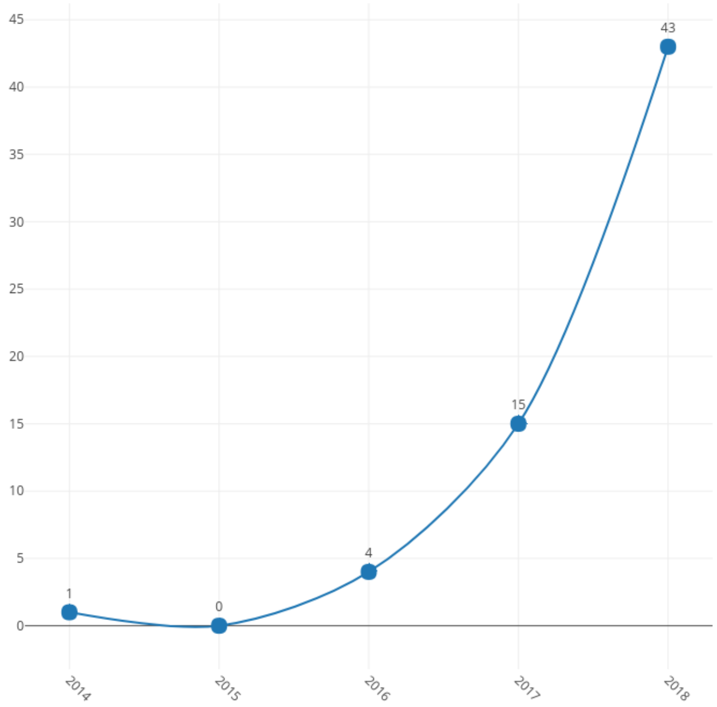


FIGURE 4.1: Publication frequency

In the following graph, we can see what kind of research has been done each year. The different research types are from Peterson et al. [2] and are described in table A.1.

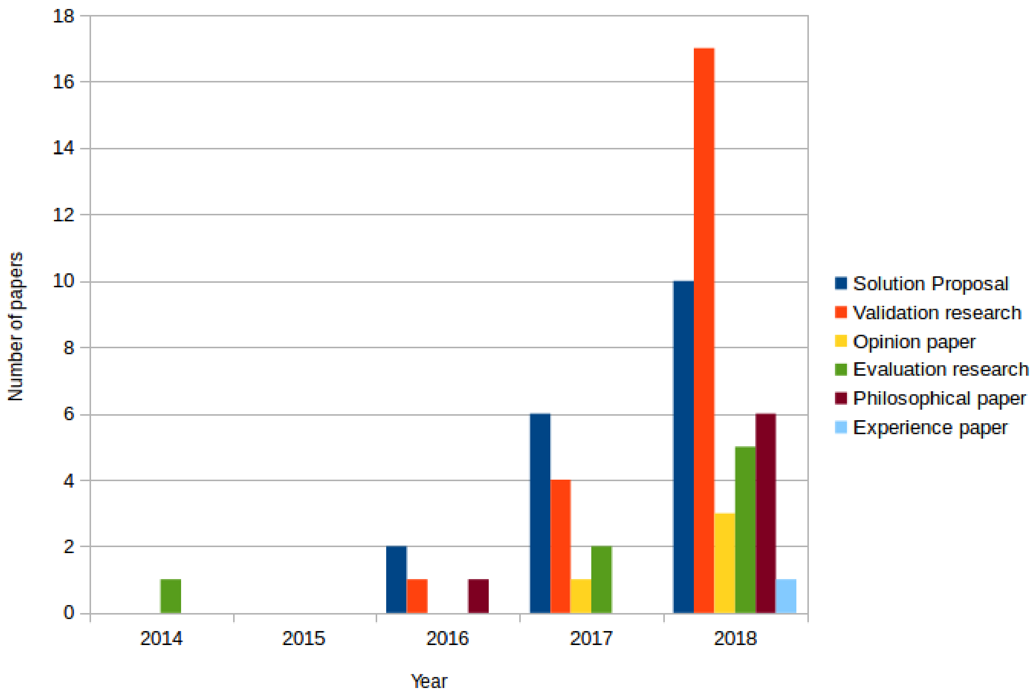


FIGURE 4.2: Research type as frequency per year

Similarly, the next graph shows the contribution types by year.

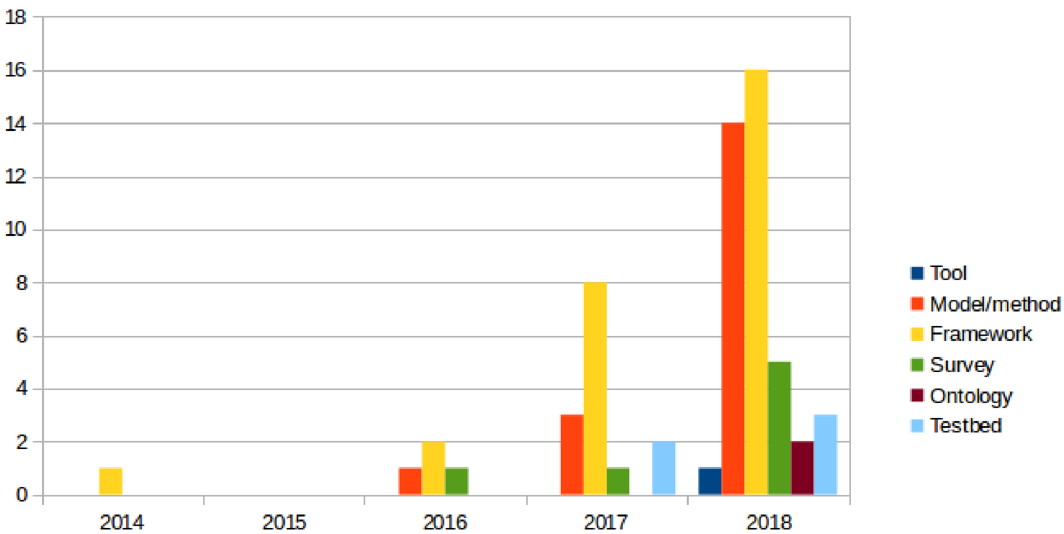


FIGURE 4.3: Contribution type as frequency per year

Finally, the bubble plot below shows the amount of both contribution and research types per knowledge area.

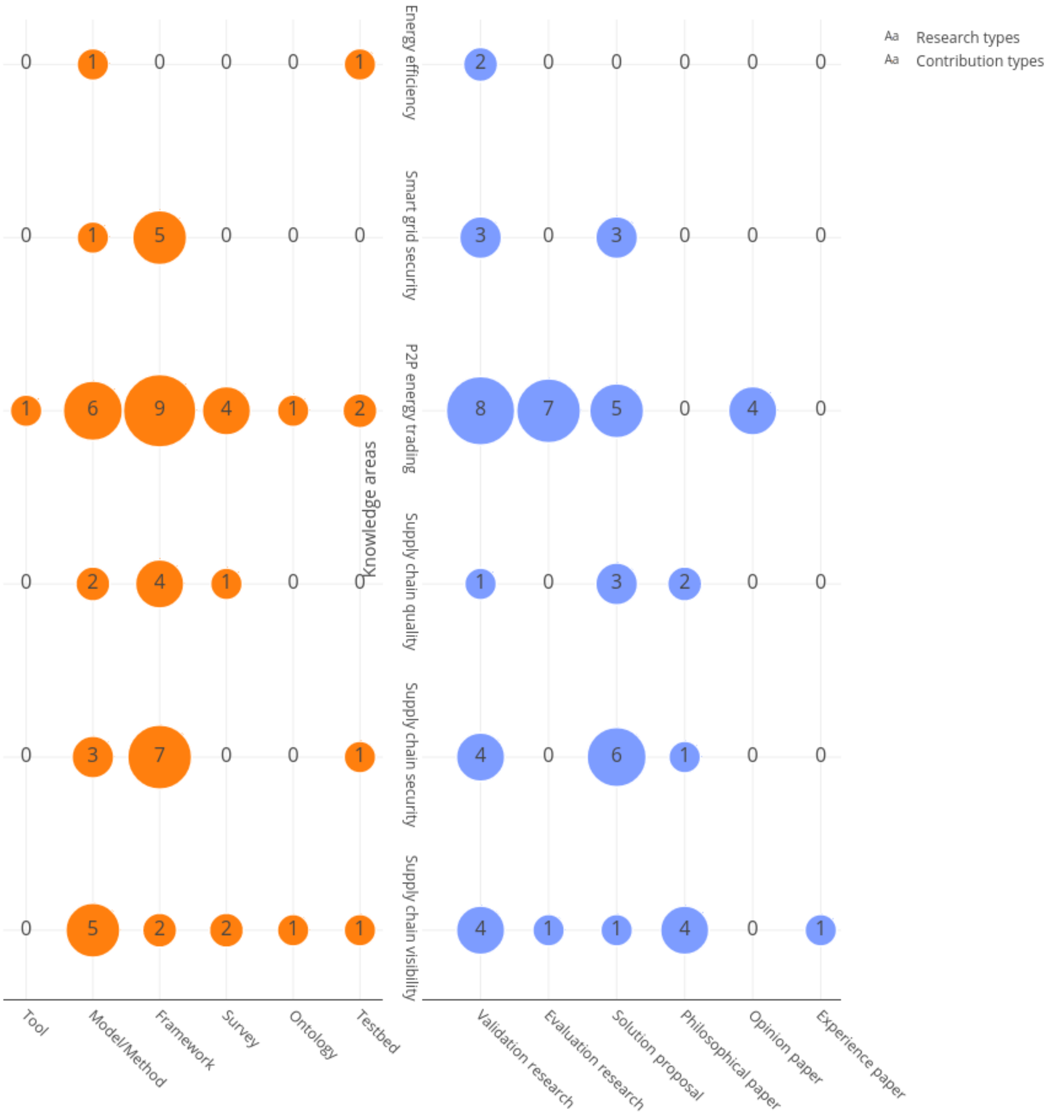


FIGURE 4.4: Publication distribution

Chapter 5

Results

In this chapter we look at the results gained from the literature review and mapping. We present it in the form of answering and discussing each research question in turn.

5.1 RQ1 How is Blockchain technology related to sustainability?

In this paper we have limited the scope of the huge topic of blockchain technology and sustainability, to the fields of smart grids and supply chains, while also looking at the energy expenditure of blockchain implementations. Smart grids were chosen, as we believe they can be helpful in working towards the UN goals for sustainability, and in creating the "smart cities" of the future. We also include supply chains, to see if they can be used for proofs of origin and traceability, as we believe it can be an option to reduce environmental crime and food waste, as well as other use cases. Nevertheless, a significant amount of papers was found, and the data extracted can offer some insight into what is going on in academia.

Figure 4.1 shows how many of the papers found were published each year between 2014 and 2018. We can see a significant increase over the last five years. In fact, 2018 has seen the highest amount of publications by far, despite the year not yet having finished, implying that there is a growing interest in the field.

All of the papers reviewed in this mapping study, relate directly to blockchain technology. Additionally, they relate to one of several topics as discussed earlier, namely energy efficiency, smart grids and supply chains. Based on the background, see chapter 2, we see the increasing amount of papers as an indication that there is more and more research being done on sustainable technology.

In figure 4.2 we can see how different research types were distributed over the last five years. Given the massive increase the last two years, it is difficult to say anything conclusive about the development over time. It can be noted that papers labeled as validation research and solution proposal have become increasingly common over the last three years.

The sudden increase in research interest can be seen in context with an increasing public interest in sustainability and climate issues in general. The UN have also become increasingly persistent on addressing these problems. Additionally, in September 2018 they released a report, naming environmental crime a significant problem

[75]. The UN so clearly pushing for a change, as well as several other parties, contribute to a growing interest in sustainability as a whole, which is reflected in a growing field of research.

5.1.1 Research types

In this section we will discuss what can be understood from 4.2, which shows how many papers there were with different research types over the last five years. Explanations for all the research types can be found in table A.1.

Validation research looks into proposing new possibilities for addressing a given problem A.1. The papers try to prove the validity or viability of some new technique, without actually implementing it. In a similar fashion, solution proposals take it one step further, trying to develop such techniques to a point where they would be suitable for implementation. The increased interest here can be seen as a growing initiative for solving these problems that have caught the public eye.

However, the lack of evaluation research implies that these techniques are still lacking. Researchers have not gotten so far as to implementing them in real life test scenarios. Figure 4.1 supports this view. Prior to 2018, there is very little research into the fields of blockchain and sustainability. It would be overly optimistic to expect full solutions to problems as big as these in such a short period of time.

In 2018 there have been some philosophical papers. These were almost non-existent prior to this year. It might be that there was a conventional understanding of how to utilize blockchain technology for sustainability, which went unquestioned. However, with growing interest comes growing criticism, which could explain why researchers are now trying to propose different ways of understanding and addressing the issues. The same arguments apply for opinion papers.

There has been an almost complete lack of experience papers, hinting at just how new the field is. It carries the implication that not much has actually been tested in the real world.

5.2 RQ2 How can Blockchain technology be used to develop sustainable technology?

The number of solution proposals, validation papers and evaluation research makes it clear that there is potential. Not all the research papers we discovered deal directly with sustainability. In fact, quite a few do not mention sustainability at all, some focusing instead on economic viability. However, economic viability is indeed an important factor for technology adoption. Technological innovation that costs more money than it saves will have a hard time becoming widespread.

5.2.1 Smart grids

As can be seen in figure 4.4, we found many papers on P2P energy trading and security in smart grids. In all the papers, blockchain technology plays a central role.

Hence, it is obvious that researchers believe it is possible to implement these systems. The papers do not discuss whether it is doable, but rather the specific details of implementation.

Again looking at figure 4.4, the categories relating to smart grids, i.e. "P2P energy trading" and "smart grid security", show a similar distribution of research types as the general trend seen in figure 4.2. We see much validation and evaluation research, a fair amount of solution proposals, and little else. Continuing the argument above, the lack of real life tests can be seen as a sign that researchers are still figuring out the best practices for how to implement the smart grid systems.

Looking at the contribution types in figure 4.3, we can see that there are many framework proposals as well as models/methods. There is only one paper contributing a tool for further development. So we have many available variations of implementations, but little in the way of how to use these in real life. The two testbeds might prove useful in achieving that. As research progresses and the field matures, we will see more tools and testbeds, that will make further developments easier.

It should be noted that ensuring consensus on how to implement grids might be crucial. As we are here dealing with infrastructure, compatible solutions can be important. If they are not compatible, each grid will become a separate island, making further development, and perhaps connections over longer distances, much more difficult.

In several papers, there is an emphasis on providing private individuals the means for trading green energy, creating so-called prosumers. It would then allow these prosumers to sell their excess production of energy to consumers in their vicinity. Given that the energy produced is green, e.g. produced with solar panels, consumers are offered the opportunity to replace parts of their energy consumption from a possibly fossil fuelled main grid, to a more sustainable alternative.

Replacing fossil fuel is a key point here. If the system is designed for selling electrical energy in general, the prosumers can use conventional generators, using diesel, gas or non-renewables in general. Alternatively, if the network is not designed with due care, it might be possible to trick the origin check regardless. On a small scale, such as a neighborhood, any attempts at cheating the system would probably be obvious to the individuals buying the energy, but on a larger scale, it would be more difficult. It is therefore of great importance to be sure of the quality of the design and security of the network.

Lombardi et al. claim that blockchain-based smart grids will have limited effects on the industry [66]. Their research shows that certain parts of the industry can be improved through the use of the new technology, such as reducing costs and simplifying transactions, but it will not be disruptive. Chitchyan and Murkin looked at more of the energy sector as a whole [42]. They "remain cautiously optimistic", but similarly do not expect a complete revolution.

There is little doubt that blockchain-based smart grids, or P2P energy trading in general, is a concept with potential. As noted above, due care needs to be taken when designing the system, but it definitely seems doable. There does not, as of yet, appear to be a system that is ready to be deployed in a real life setting. However, with further testing and experimentation on existing proposals, we will hopefully soon see something ready to hit the market.

5.2.2 Supply chains

The papers on supply chains that we found mostly follow the same pattern as the ones on smart grids. However, a key difference is the lack of evaluation research, as witnessed by figure 4.4. Evaluation research has to do with verifying that proposed solutions work. The lack of such research hints that there is still a lot to be done on the use of blockchain technology in supply chains.

As with the papers on energy trading, there are many frameworks and models/methods. Also similarly, it seems that the current issue is to decide on how to go about the real life implementation. Many of the papers look at specific industries or issues. There is as of yet not much focus on agreeing upon a generalized solution. Some companies might want their own specialized supply chain, but as with smart grids, such a system might prove to be problematic when trying to expand.

One technique that has been used is the concept of smart contracts. Smart contracts are in short computer programs that execute automatically when certain conditions have been met [insert ref?]. In the context of supply chain management, a program could consist of a condition such as "product arrives at checkpoint", leading to the execution of "pay sender".

Preventing counterfeit products is another focus of certain papers [30]. Counterfeits have obvious economic effects. Depending on the product, it might also have environmental effects. For example, a company producing furniture might prioritize sourcing timber from a sustainable source. The producers of the fake cannot be expected to do the same, leading to consumers financing deforestation while thinking they are avoiding it.

This brings us to another point: As explained in the World Atlas of Illicit Flows, environmental crime is carried through in part through "green-washing" products [75]. I.e. illegal resources are harvested and then mixed with legit products. If there is no way to tell a legitimate product from a fake, then it is also impossible to know its origin. Proof of origin or Guarantee of origin has been an emphasis of certain supply chain implementations [24][15][20]. Technologies for proof of origin have a wide variety of use cases, several of them possibly benefiting the environment.

Proof of origin and traceability in general has also been proposed as a way to reduce food waste and increase food security [64][13]. Where the food comes from is important information, for example in the case of a disease outbreak. During such an event, it would be possible to discover where the food came from, in order to clear that site. Or, if the farm was not the source of the contaminant, it could be possible to trace every step, and find where the infection did happen. A somewhat less serious issue would be if the food spoils somewhere along the way. If the supply chain is able to track the storage and transportation conditions of the goods, including the time it takes, it would also be possible to discover where errors happen.

Kshetri also notes the food industry to be one of the areas with the biggest potential for using blockchain-based supply chains [63]. For example for discovering supplier dependability and for informing the end customer of the origin of the product. However, they also point out several issues, a central problem being that blockchain only addresses the virtual parts of the supply chain. It cannot inherently stop malicious agents from tampering with a physical product. Sternberg and Baruffaldi also note the physical properties of a product as a problem and limiting factor [37]. They therefore doubt any disruptive changes to any industries due to the introduction of blockchain technology.

It should be clear that the possibilities for using blockchain for supply chain management are there. Many researchers have looked at the issue, from various angles. Hence, the question is not whether it is possible, but rather if it is worth it. Jabbar and Bjørn highlight problems with integrating such a system in an already existing supply chain, but end on an optimistic note [60]. What, then, of the economic advantages? As of now, to the best of the authors' knowledge, no supply chains using blockchain have actually been put into use. Any data on possible savings or profitability in general will therefore be based on experiments and simulations. The literature seems to be cautiously positive with regards to the potential of blockchain-based supply chains, so it would in fact seem possible to address sustainability issues using blockchain technology. However, it might prove difficult to convince companies to actually put existing proposals into use [37].

Chapter 6

Discussion

6.1 Blockchain

A big issue with blockchain that has come to light, is the energy consumption of applications and systems utilizing the technology. Even if we think of Bitcoin as a worst case scenario, popular alternatives such as Ethereum also prove to be problematic [43]. The issue can often be reduced to two factors: scalability when facing a large number of transactions, and which algorithm is used to verify transactions. Bitcoin is neither very scalable, reaching a limit of around seven transactions per second; nor is it energy efficient, with its Proof of Work algorithm resulting in enormous computational expenditure, directly leading to high energy consumption.

Recognizing the wastefulness of PoW, Sunny King and Scott Nadal proposed the concept of Proof of Stake (PoS) in 2012 [4]. Their PPCoin still uses PoW for the initial mining of the currency, but when the minting rate approaches zero, i.e. when a sufficiently low amount of coins are rewarded for mining, the incentive to spend energy on mining also diminishes. The basic idea of PoS involves spending "coin age" for the privilege of generating the next block for the chain. By investing in the currency over time, you are also investing in its stability. By waiting for your coin age to increase, you are staking your money on the value being stable or increasing in value. Hence, virtually no energy is spent on block creation.

However, PoS has faced criticism, its distributed consensus protocol has been claimed to be infeasible in practice [9]. The Ethereum Foundation discussed options for improving it, but ultimately found it too non-trivial to implement [6]. Instead, they ended up opting for their own protocol, named Ethash. The Ethash protocol is also based on PoW, and has unfortunately proven to use a lot of energy, albeit not as much as Bitcoin [43].

Nevertheless, the Ethereum Foundation did not stop trying to improve their consensus protocol. In October 2017, they introduced a soft-fork, laying the groundwork for another soft-fork in the future [17]. The goal is to eventually introduce their new algorithm, Casper. Casper is indeed based on PoS and promises a lot better energy efficiency than before [49]. As such, we will in the near future see if PoS has a viable future, and how it will affect energy expenditure.

As previously mentioned, economic viability plays an important role in the spread of technologies. With that in mind, a limiting factor on Bitcoin and similar implementations, is simply the cost of electricity. With increasing competition, increasing amounts of computational power are also needed, which has lead to a curious form of arms race among miners, as can be seen in the quickly rising energy consumption

[86]. Mining operations have largely been moved to places with cheap electricity, such as Inner Mongolia in China, however new laws might soon cause changes according to news sources [57][56].

The immense energy consumption has multiple effects on sustainability. For one, the energy production in itself might not be green. In certain areas, the energy might come from coal or other fossil fuels. The energy used also contributes to increased demands, that the infrastructure might not be able to meet with green energy. In that regard, NRGCoin offers an elegant alternative, with mining being done through *contributing* electricity rather than *consuming*.

6.2 Smart grids

Smart and micro grids are becoming popular for a variety of use cases. Examples range from setting up off-grid solutions for rural areas, to prosumers selling excess, green energy to their neighbors to replace main-grid energy coming from fossil sources. Two common problems that need to be dealt with are how to incentivize prosumers to produce an excess to sell to others, and how to guarantee the legitimacy of said transaction.

NRGcoin is a proposal by Mihaylov et al., where they set up a virtual market for energy trading in smart grids, with its own cryptocurrency [7]. The currency is generated by supplying energy to the network. Users can also buy energy from others, using the same currency. It would also be possible to exchange the currency for fiat currencies, so one would not be required to sell energy in order to obtain it. Hence, the idea is for participants to balance production and consumption out of self-interest.

They identified two key issues with the methods found in literature. As trading is usually done a day in advance, it requires that you 1) predict the supply and demand ahead of time, and as a result of that you need 2) good knowledge of finance and economy, in order to maximize profits. Their proposal to amend these, involves automating a lot of the activity to have it occur with a much higher frequency. They operate with sub-stations for streets, with each one updating every 15 minutes. The prosumers can also inject energy directly into the grid at any time; they do not have to use batteries for storage, or hope for net consumption to be at a high at the time.

By making buying and selling easier, it becomes possible to adjust prices on the fly, reacting to the market as it changes with highs and lows in consumption. Since the factor of predicting the expenditure of tomorrow is removed, so is the need to predict prices long ahead of time. Buyers and sellers can place bids with various settings, such as whether to wait if there is no immediately available match, or whether they are willing to accept a different price than they have stated.

Questions could be raised regarding the need for a standalone currency for such a system. With the NRGCoin grid, consumers get paid in the currency for a set amount of energy, given conditions of supply and demand. The virtual money can at a later point be exchanged for an equivalent amount of energy, given the same conditions, regardless of any changes in value of the currency, or rises in electricity prices. Moreover, it serves as some proof of origin, as the currency is awarded to producers of green energy. They admit that the project is a work-in-progress, so it remains to be seen if the system works in real life contexts.

An issue avoided by NRGCoin is that of mining. As the currency is generated by generating electricity, the situation is actually reversed. However, the potential positive effects of locally sourced energy require the energy produced to be green. The paper as it stands provides no insight as to how to verify the origin of the energy. Castellanos et al. look into providing green certificates through cryptocurrencies [15]. They point out that it is in Europe possible to buy Guarantees of Origin saying they are providing green energy, while they in fact provide gray energy.

Figure 4.4 shows that there are many more papers in the category of P2P energy trading than in the others. The argument could be made that the category should have been split into more specific sub-categories, like we did for supply chains. However, we did not find it relevant to the discussion, as the papers largely revolve around one of the two energy trading categories we do use.

Nevertheless, a certain amount of papers were left out of the study on the basis of being too focused on security. We concluded that the inclusion of those papers would not contribute meaningfully to the discussion of sustainability, but rather to a discussion of cryptography.

6.3 Supply chain

There is a significant amount of published papers discussing the use of Blockchain technology in supply chains. Researchers have covered fields such as pharmaceuticals and farming, using a variety of different implementations [34] [31]. The goal is to improve the quality of the received product, and to counteract malicious actors who might want to replace a genuine article with a fake. Another benefit, as well as important feature, is supply chain visibility for all parties involved.

An important part of blockchain driven supply chains is that they have to be easy to use. If not, the user experience will be negative, leading to unwillingness to adopt the system. The usability issue comes in addition to the general unwillingness often found in people to adopt new technologies. How to mitigate this unwillingness was studied by Jabbar and Bjørn [60]. They looked at how to introduce blockchain technology to the shipping domain. They describe the domain as being resistant to new technologies, as the existing infrastructure has been built up over a long time.

They bring up two very interesting points. First is the term "infrastructural grind", with which they refer to what occurs when two information infrastructures are converging. They claim the two will rub off on each other, effectively changing each little by little until they fit. The second is the claim that it is necessary to understand the socio-technical infrastructure. In other words, it is not enough to simply offer an industry what you believe is a better solution, you also have to understand how it would fit in with the potential users.

A similar observation was made by Hussain et al., making the case for participatory design in order to create products that truly suit the needs of the users [3]. Participatory design did not come up even once in the papers we looked at. There could be several reasons for this, for example that the proposals simply are not yet at a stage where it is deemed necessary. Another reason could a belief that it is not necessary in the context of infrastructural technology. Such assumptions are almost certainly erroneous, as there will in the end be people using the systems.

As such, the most likely explanation is that these techniques still are at a too early stage. It is more relevant to focus on error testing to get the functionality working correctly, rather than improving the user experience for possible future end users. Naturally, this is research, and any solution proposals can be expected to be heavily modified before being put into use.

A paper of interest is that of Feng Tian, on the agri-food supply chain [13]. Looking at the problem of food safety in China, a system for using blockchain technology in combination with RFID (Radio Frequency Identification) tags is proposed. They conclude that blockchain technology used with RFID has wide application, and can be effectively used to improve quality and safety in agri-food products.

Other researchers have pointed out weaknesses with using RFID for tracing physical products [52]. Indeed, Tian also proposed a different method the following year [29]. Hepp et al. used patterns verifiable by mobile phone cameras to put a unique "stamp" on each unit. The pattern was created using dried lacquer, which creates random patterns of microcracks, referred to as craquelure. Different types of lacquer create different sized fissures, some resulting large enough to be easily identifiable with a normal mobile phone camera.

While there has been substantial research looking into how to apply blockchain technology in order to improve conditions for companies, not much has been done in the way of providing information to consumers. Bettín-Díaz et al. propose a methodology for developing supply chain traceability systems, while also keeping the end customer in mind [39]. Even so, it is only briefly mentioned, and the paper features little in the ways of how to actually present the information to a customer.

An issue with developing such systems to collect and display data, is that current proposals of supply chains are quite proprietary. That is to say, if companies were to adopt the solutions from current literature, they would likely each have their own systems. Similarly, they would also have to develop their own systems for displaying the information.

Granted, the wide variety we are seeing is a recognizable pattern of innovation; a new technology is introduced, followed by a multitude of attempts at utilizing it. This leads to wildly varying solutions, followed by a slow merging, as certain standards are recognized as superior in some way.

Chapter 7

Conclusion

7.1 Findings

While the mapping study did not yield a lot of papers looking at the underlying blockchain technology itself, we found articles and papers through manual searches. Doing so revealed some significant issues with how the technology has been used thus far, the biggest problem most likely being the original Bitcoin, with its enormous energy expenditure. Nevertheless there are also proposals for amending the problems of the energy usage. The Ethereum Foundation is a big actor in the field of cryptocurrencies, and are moving towards improving the energy efficiency of their ecosystem.

While not many researchers have looked directly at the challenge of environmental crimes, we believe it is possible to use current proposals found in the literature for these purposes. Supply chain solutions are often aimed towards specific industries, but the underlying methods are more generic.

A fair amount of research has been done in the field of smart grids. The different papers often emphasize different aspects, some for example looking at how to incentivize prosumers, while others are more focused on how to make the systems resilient towards attacks and exploits.

7.2 Further work

While we have looked at a variety of different implementations for the purpose of sustainability, we have not nearly looked at all. We limited the scope to certain aspects of the issue, primarily supply chain management and smart grids.

We believe it could be possible to apply existing supply chain management methods in the field of environmental crime. Research points to providing visibility to every party involved and avoiding counterfeit products. These relate directly to the issues of malicious actors mixing illicitly procured goods with the genuine products.

When working to ensure the integrity of the supply chain, there is an assumption that there is at least one actor along the supply chain with an interest in the legality of the products being sold. If no one cares, then the battle is lost before it even begins. It could therefore be interesting to look into providing visibility to the end customer as well, as consumers are becoming more interested in organic and sustainable products.

Another issue that has been highlighted as particularly challenging is bridging the gap between the virtual blockchain and the physical products [63][37]. While much research has gone into the virtual part, the physical part has been largely forgotten, which might be due to the difficulty of solving the problem. There are several papers trying to ensure the validity of a container or similar, for example by using RFID tags or lacquer stamps [13][52]. However, while such solutions might offer a unique identifier that is challenging to copy, they do nothing to keep a malicious actor from tampering with the contents of the container.

For both supply chains and smart grids, there is a lack of generalized research. Researchers have mostly been trying to address specific industries or certain problems therein, with a smaller focus on the big picture. In order to unite and further develop the fields, future researchers might want to consider building upon an existing framework, rather than create another one from scratch. Alternatively, they could create more general purpose tools or frameworks, instead of looking to specific industries.

Another issue we have not touched upon is that of other varieties of DLTs. The IOTA Foundation is a good example of this [50]. Instead of a chain of blocks, they use what they call a Tangle, which is a directed acyclic graph. It would be of interest to look at how other implementations of DLTs affect the implementations, both with regards to the specific methods, but also the energy efficiency.

This mapping study has been the first step in a master thesis. The next part will build upon knowledge found here. More specifically, we will be looking further into supply chain management technologies and how to present data to end users. The data found provides a background of what already exists, and what has been considered worth looking into by other researchers. We will build on what previous researchers have found, and use their experiences with implementing supply chain management systems with blockchain technology.

As we have pointed out in this study, there is a significant lack of user involvement in the supply chain traceability, even though the customer has been recognized as a relevant stakeholder [39]. We want to look into how to gather information from a blockchain-based supply chain, and how the information can be presented to an end user, possibly through a web interface or a mobile application. We are hoping to cooperate with industry partners, hearing from them what they would be looking for in a new supply chain management system, and what considerations should be taken when showing supply chain information to a customer.

We have also discovered that there as of now does not exist any kind of standardized methodology or framework for developing supply chain management systems. There are, however, several individual implementations to draw inspiration from, and to see what they have in common. The experience of existing implementations will be used when looking into how to gather the information from the supply chains. Our goal is to provide a general-purpose solution, that can be used as a basis or inspiration for similar efforts in the future, with the goal of gathering and displaying information proving the origin of products.

7.3 Conclusion

We conducted a systematic mapping study, looking at the relationship between sustainability, as defined through the UN goals, and blockchain technology. More specifically, we focused on the use cases supply chains and smart grids. By doing this, we got an overview of what has been published, and what the researchers have tried to achieve.

We found that certain implementations of blockchain technology have severe effects on energy consumption on a global scale. Work is being done to address this issue, but it is far from done. Additionally, systems like the Bitcoin network will need either a significant rework to justify continued use.

There is research being done on the fields of blockchain-driven P2P energy trading and supply chains. The research has not yet reached the point of being implemented in real life. What does exist appears to be positive to the possibilities in the future. However, care needs to be taken when bridging the gap between experiments and real life, to avoid potential gains to be lost.

For both the main topics in this study, namely smart grids and supply chains, the literature appears to be cautiously optimistic, but doubts any huge changes to industry practice. There is potential to improve the industries, but more definite advantages must be discovered and proven in order to incentivize companies to put the technologies into use.

Appendix A

Categories

A.1 Research types

Research type	Description
Validation research	Techniques investigated are novel and have not yet been implemented in practice. Techniques used are for example experiments, i.e., work done in the lab.
Evaluation research	Techniques are implemented in practice and an evaluation of the technique is conducted. That means, it is shown how the technique is implemented in practice (solution implementation) and what are the consequences of the implementation in terms of benefits and drawbacks (implementation evaluation). This also includes to identify problems in industry.
Solution proposal	A solution for a problem is proposed, the solution can be either novel or a significant extension of an existing technique. The potential benefits and the applicability of the solution is shown by a small example or a good line of argumentation.
Philosophical paper	These papers sketch a new way of looking at existing things by structuring the field in form of a taxonomy or conceptual framework.
Opinion paper	These papers express the personal opinion of somebody whether a certain technique is good or bad, or how things should been done. They do not rely on related work and research methodologies.
Experience paper	Experience papers explain on what and how something has been done in practice. It has to be the personal experience of the author.

TABLE A.1: Research types, from Peterson et al. [2]

A.2 Contribution types

Emphasis	**Description**
Tool	Papers proposing a tool to aid further development
Model/method	Papers introducing new models or methods for addressing a problem
Framework	Papers proposing frameworks for development
Survey	Papers presenting data on what already exists, but do not propose a solution in themselves
Ontology	Papers proposing an ontology for identifying and discussing issues
Testbed	Papers proposing a testbed to aid further development

TABLE A.2: Table of contribution types [2]

A.3 Knowledge areas

Knowledge area	**Description**
Supply chain for visibility	Making supply chains more transparent to the actors involved, to keep track of each step along the way
Supply chain for security	Improving the resilience of supply chains against malicious actors, including counterfeit protection
Supply chain for quality	Improving supply chains to ensure the quality of the end product, reducing spoilage and product loss
P2P energy trading	How to make Peer-to-peer (P2P) energy trading available to the public
Energy trading security	Discussing the security of using smart grids, or P2P energy trading in general
Blockchain energy efficiency	Proposals to improve the energy efficiency of future blockchain implementations

TABLE A.3: Table of knowledge areas

Appendix B

Papers found

On the next page is a table listing all the papers used in the systematic mapping study. The table includes the title of the paper, the knowledge area, the research type, the contribution type and the publication year.

Title	Knowledge area	Research type	Contribution type	Publication year
NRGcoin: Virtual Currency for Trading of Renewable Energy in Smart Grids	P2P energy trading	Evaluation research	Framework	2014
An Agri-food Supply Chain Traceability System for China Based on RFID & Blockchain Technology	Supply chain quality	Solution proposal	Framework	2016
Blockchain – A Financial Technology For Future Sustainable Development	Supply chain visibility	Philosophical paper	Survey	2016
Envisioning Cloud of Energy	P2P Energy trading	Validation research	Model/method	2016
ARTA: An Economic Middleware to Exchange Pervasive Energy and Computing Resources	P2P energy trading	Solution proposal	Framework	2016
Cryptocurrency as Guarantees of Origin: Simulating a Green Certificate Market with the Ethereum Blockchain	P2P energy trading	Validation research	Model/method	2017
A Blockchain-based Supply Chain Quality Management Framework	Supply chain quality	Solution proposal	Framework	2017
A Novel Blockchain-Based Product Ownership Management System (POMS) for Anti-Counterfeits in the Post Supply Chain	Supply chain security	Solution proposal	Framework	2017
A Supply Chain Traceability System for Food Safety Based on HACCP, Blockchain & Internet of Things	Supply chain quality	Solution proposal	Framework	2017
The green blockchain - Managing decentralized energy production and consumption	P2P energy trading	Evaluation research	Framework	2017
Supply Chain Object Discovery with Semantic-enhanced Blockchain	Supply chain security	Validation research	Framework	2017
Blockchain Applications In Microgrids - An overview of current projects and concepts	P2P energy trading	Opinion paper	Survey	2017
Intelligent Resource Management in Blockchain-Based Cloud Datacenters	Blockchain energy efficiency	Validation research	Model/method	2017
A Method to Assess the Economic Feasibility of New Commercial Services in the Smart Grid	P2P energy trading	Solution proposal	Model/method	2017
On the integration of event-based and transaction-based architectures for supply chains	Supply chain visibility	Solution proposal	Framework	2017
Novel market approach for locally balancing renewable energy production and flexible demand	P2P energy trading	Validation research	Framework	2017
Democratisation of the SmartGrid and the Active Participation of Prosumers	P2P energy trading	Validation research	Testbed	2017
Information Sharing for Supply Chain Management based on Block Chain Technology	Supply chain security	Solution proposal	Framework	2017
Securing Physical Assets on the Blockchain	Supply chain security	Solution proposal	Framework	2018
Blockchain Application in Food Supply Information Security	Supply chain quality	Philosophical paper	Model/method	2018
Feather forking as a positive force: incentivising green energy production in a blockchain-based smart grid	Energy trading security	Solution proposal	Framework	2018
Agent-based model of sand supply governance employing blockchain technology	Supply chain visibility	Validation research	Testbed	2018
Intellectual Property Protection of 3D Print Supply Chain with Blockchain Technology	Supply chain security	Solution proposal	Model/method	2018
Block-Supply Chain: A New Anti-Counterfeiting Supply Chain Using NFC and Blockchain	Supply chain security	Solution proposal	Framework	2018
RFID Security, Verification, and Blockchain: Vulnerabilities within the Supply Chain for Food Security	Supply chain security	Solution proposal	Framework	2018
Towards an Ontology-Driven Blockchain Design for Supply Chain Provenance	Supply chain visibility	Experience paper	Model/method	2018
Methodological Approach to the Definition of a Blockchain System for the Food Industry Supply Chain Traceability	Supply chain visibily	Validation research	Model/method	2018
Blockchain-based Traceability in Agri-Food Supply Chain Management: A Practical Implementation	Supply chain visibility	Evaluation research	Framework	2018
When Trust Saves Energy: A Reference Framework for Proof of Trust (PoT) Blockchains	Energy trading security	Validation research	Framework	2018
Research on agricultural supply chain system with double chain architecture based on blockchain technology	Supply chain visibility	Validation research	Model/method	2018
Consortium Blockchain for Secure Energy Trading in Industrial Internet of Things	Energy trading security	Validation research	Model/method	2018
The Blockchain in Microgrids for Transacting Energy and Attributing Losses	P2P energy trading	Validation research	Framework	2018
Infrastructural Grind: Introducing Blockchain Technology in the Shipping Domain	Supply chain visibility	Philosophical paper	Ontology	2018
Blockchain for peer-to-peer energy exchanges: design and recommendations	P2P energy trading	Evaluation research	Model/method	2018
Applying blockchain technology to decentralized operation in future energy internet	P2P energy trading	Solution proposal	Framework	2018
On the applicability of the GRIDNET protocol to Smart Grid environments	Energy trading security	Solution proposal	Framework	2018
Bit-energy: An innovative bitcoin-style distributed transactional model for a competitive electricity market	P2P energy trading	Solution proposal	Framework	2018
Review of Blockchain Technology and its Expectations: Case of the Energy Sector	P2P energy trading	Opinion paper	Survey	2018
A Blockchain-based Infrastructure for Reliable and Cost-effective IoT-aided Smart Grids	P2P energy trading	Opinion paper	survey	2018
The security and traceability of shared information in the process of transportation of dangerous goods	Supply chain security	Validation research	Model/method	2018
Establishing a Secure, Transparent, and Autonomous Blockchain of Custody for Renewable Energy Credits and Carbon Credits	P2P energy trading	Opinion paper	Survey	2018
Blockchain-Assisted Crowdsourced Energy Systems	P2P energy trading	Evaluation research	Framework	2018
Towards Realistic Energy Profiling of Blockchains for securing Internet of Things	Blockchain energy efficiency	Validation research	Testbed	2018
Exchange of Renewable Energy among Prosumers using Blockchain with Dynamic Pricing	P2P energy trading	Validation research	Tool	2018
Spatial services for decentralised smart green energy management	P2P energy trading	Evaluation research	Framework	2018
A Technical Approach to the Energy Blockchain in Microgrids	P2P energy trading	Validation research	Model/method	2018
Merging Supply Chain and Blockchain Technologies	Supply chain visibility	Philosophical paper	Model/method	2018
Chains in Chains – Logic and Challenges of Blockchains in Supply Chains	Supply chain visibility	Philosophical paper	Survey	2018
Modeling in Support of Multi-Perspective Valuation of Smart Grid Initiatives	P2P energy trading	Evaluation research	Ontology	2018
Big Data and Blockchain Basis for Operating a New Archetype of Supply Chain	Supply chain security	Philosophical paper	Model/method	2018
Blockchain's roles in meeting key supply chain management objectives	Supply chain quality	Philosophical paper	Survey	2018
Fostering Consumers' Energy Market through Smart Contracts	P2P energy trading	Evaluation research	Testbed	2018
On IC Traceability via Blockchain	Supply chain security	Solution proposal	Framework	2018
How blockchain improves the supply chain: case study alimentary	Supply chain visibility	Validation research	Model/method	2018
A blockchain-based smart grid: towards sustainable local energy markets	P2P energy trading	Validation research	Framework	2018
Blockchain Based Decentralized Management of Demand Response Programs in Smart Energy Grids	P2P energy trading	Validation research	Framework	2018
Multi-Class Energy Management for Peer-to-Peer Energy Trading Driven by Prosumer Preferences	P2P energy trading	Solution proposal	Model/method	2018
SPB: A Secure Private Blockchain- based Solution for Energy Trading	Smart grid security	Solution proposal	Framework	2018
Blockchain for Supply Chain Cybersecurity, Optimization and Compliance	Supply chain security	Validation research	Testbed	2018
Exploring the applicability of blockchain technology to enhance manufacturing supply chains in the composite materials industry	Supply chain quality	Validation research	Model/method	2018

TABLE B.1: Papers found, listed by publication year

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