Digital Sustainability

Master‘s thesis

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submitted to

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Summary

Content

Digital Sustainability wants to generate, develop, sustain and ensure access to digital artifacts in a way that digital artifacts provide the highest possible benefit for society. Digital artifacts are data, information, knowledge and source code. In contrary to natural resources, where the use of resources has to be limited by a cap (point of maximal use) to ensure environmental sustainability, digital artifacts benefit society by its wide distribution and accessibility. Therefore, digital sustainability is not a question of a cap which limits the use of digital artifacts, digital sustainability is fulfilled by providing digital artifacts under basic conditions (floor), allowing the largest possible distribution and accessibility of digital artifacts.

Methodology

This master's thesis is based on a broad literature review on 120 sources to provide a theoretical foundation for digital sustainability. Based on the literature review, the concept of the floor model is built. The floor model enlarges theory by contributing the favorable basic conditions for digital artifacts to reach digital sustainability.

Findings

Digital artifacts have to fulfill technological, legal, organizational and financial basic conditions (the floor) to be digital sustainable. The composition of the floor depends whether the resource is a personal digital artifact (e.g. personal health data about a disease) or a non-personal artifact (e.g. geological data or source code source code of a web-platform). The basic conditions for non-personal artifacts are: open data, open license with copyleft, neutrality of infrastructure provider, cooperation, software quality, open format, open standard, modularity, distributed knowledge, documentation, affordability, open access and business models on additional value. Different than for non-personal digital artifacts, for personal artifacts the favorable basic condition of privacy replaces open data.

Zusammenfassung

Inhalt

Digitale Nachhaltigkeit zielt auf die Erstellung, Weiterentwicklung, Erhaltung und die Zugänglichkeit von digitalen Artefakten in einer Weise, dass der grösstmögliche gesellschaftliche Nutzen daraus entsteht. Digitale Artefakte sind Daten, Informationen, Wissen und Source Code. Im Gegensatz zu natürlichen Ressourcen, wo die Nutzung von einer Obergrenze (Punkt der maximalen Nutzung) limitiert werden muss um ökologische Nachhaltigkeit zu erreichen, profitiert die Gesellschaft durch die breite Verteilung und Zugänglichkeit von digitalen Artefakten. Somit geht es bei der digitalen Nachhaltigkeit nicht um eine Obergrenze der Ressourcennutzung, sondern um die Zurverfügungstellung unter begünstigenden Grundvoraussetzungen (Untergrenze), welche eine grösstmögliche Verteilung und Zugänglichkeit von digitalen Artefakten ermöglicht.

Methodik

Die Masterarbeit basiert auf einer breit durchgeführten Literaturanalyse von 120 Quellen, um die digitale Nachhaltigkeit mit theoretischen Grundlagen zu fundieren. Basierend auf der Literaturanalyse wird das Konzept der Untergrenze erarbeitet. Das Modell der Untergrenze erweitert die Theorie, indem es begünstigende Grundvoraussetzungen für digitale Artefakte definiert.

Resultate

Digitale Artefakte müssen technische, rechtliche, organisatorische und finanzielle Grundvoraussetzungen erfüllen, um digital nachhaltig zu sein. Die Zusammensetzung der Grundvoraussetzungen hängt von der Art des digitalen Artefakts ab. Es werden zwei Arten von digitalen Artefakten unterschieden: Persönliche digitale Artefakte (bspw. persönliche Daten zur eigenen Krankheitsakte beim Arzt) und nicht-persönliche Artefakte (bspw. Meteorologische Daten oder Quellcode einer Webplattform). Die begünstigenden Grundvoraussetzungen zu einer digitalen Nachhaltigkeit für nicht-persönliche Daten sind offene Daten, eine offene Lizenz mit Copyleft, Neutralität des Providers,

Kooperation, Softwarequalität, offene Formate, offene Standards, Modularität, verteiltes Wissen, Dokumentation, finanzielle Erschwinglichkeit, offener Zugang und Geschäftsmodelle, die auf zusätzlichen ökonomischen Nutzen basieren. Persönliche digitale Artefakte müssen andere Grundvoraussetzungen als nicht-persönliche Artefakte erfüllen. Die begünstigende Grundvoraussetzung von offenen Daten wird mit der Notwendigkeit von Privatsphäre ersetzt.

Table of Contents

1 Introduction

1.1 Background

Many scholars define our society as a knowledge society, where knowledge is the most important resource (Drucker, 2001; Probst et al., 2012). Simultaneously, knowledge is getting more digital where earlier in time knowledge was stored analog (Hilbert and Lopez, 2011). If knowledge has such an important status and it is simultaneously available almost exclusively digital, we have to be aware how digital knowledge is produced, developed, sustained and accessible to the benefit of the society. It is important to ask who has access to knowledge and how knowledge can be generated and sustained. In a second step, we have to ask how we can develop our knowledge to face societal challenges.

1.2 Problem Description

Intellectual property rights should incentive organizations to be innovative, because property rights allow innovators returns on the invested resources and guarantee a monopoly control over the generated knowledge (Arrow, 1962; Dam, 1995). On the one hand this has a positive effect for society, as it encourages people and organizations to investments in innovations. On the other hand, society experiences a relative loss to the whole amount of available knowledge, if knowledge is protected by intellectual property rights. The available public knowledge, compared to the overall knowledge is relatively smaller by protecting it with intellectual property rights (von Hippel and von Krogh, 2003). At first glance it does not matter whether knowledge is available as a common property or as a private good, as long as it is affordable and accessible to the people who are in need of the specific knowledge.

At least in three use cases the **accessibility** is not ensured, if knowledge is solely available as a private good. First, if we allow firms to treat knowledge as a property and allow to sell knowledge as a private commodity (e.g. the composition of medications) on the market, where only demand and supply decides over access and distribution, only people who are able to **afford the goods** will be able to profit from its benefits. Pearce (2012) illustrates this problem by the case of millions of children under the age of five die from preventable causes in developing countries. He arguments that patent laws in combination with the financial interest of companies hinder the spread of HIV medication or access to articles on renewable electricity generation to the people who need it in the third world. In conclusion intellectual property rights do incentivize people and organizations to innovate, but not the whole society profits from the generated knowledge, even if everybody is legally obliged to accept the mechanisms of intellectual property rights.

The second problem is a potential **coordination breakdown** among patent holders and potential future innovators, as goods are usually consisting of various fragments and need to be assembled to provide value. Patents on required fragments can lead to a coordination breakdown of the development process due to the high costs of negotiating with every patent holder or the impossibility of reinventing every fragment from scratch in a different way than it is already patented. This coordination breakdown can be described as the tragedy of the anticommons (Heller and Eisenberg, 1998). Heller and Eisenberg (1998) underpin the tragedy with an example from biomedical research: Receptors evaluating pharmaceuticals for side effects are often patented, therefore researchers are not allowed to test with existing receptors if a new medication has side effects without the permission (and obviously correlated to payments) from the patent-holders on the receptors. Receptors are illustrative for one fragment which is necessary for the development of new medication. If the process of developing new medication is fragmented in too many patented components (which is often the case), property rights make the development of new medication very complicated or even impossible. Another innovation breakdown can also be illustrated within the smartphone industry, where around 300’000 patents are active (Reidenberg et al., 2015). A new innovative manufacturer of smartphones would be faced with that many patents that it may hinders to put his /her idea into practice.

Another well-known problem faces **lock-in effects** from providers and vendors. Digital artifacts are initially often provided at low rates, which leads to low costs of purchasing. With additional required complementary goods and storing data in proprietary formats (which usually leads to high switching costs), total costs may exceed the initially assumed costs and data is locked to a specific proprietary software and/or proprietary format (Shapiro and Varian, 1999). Therefore, it is important to ask before procuring a software solution several questions: What happens if the software company which developed the system is no more providing support? What happens with data stored in a system if the system is no more usable? Do we lose all data if the software-company no more has the product in the range of products (or goes bankrupt)?

1.3 Aims of the Thesis

The thesis aims to evaluate, what favorable framework conditions are required to not be confronted with the three abovementioned accessibility-problems (affordability, coordination breakdowns and lock-in effects). The evaluation follows a three-stage approach. First, it is aimed to provide an **overview** over the different research streams focusing on the accessibility-problems related to digital artifacts. The second goal is to formulate a **definition** which is concrete enough to be able to introduce measures for digital artifacts. Finally the third step builds a summary and categorization of **favorable framework conditions for digital artifacts** for digital sustainability. Where the first step is descriptive, the second and the third step are prescriptive-normative.

1.4 Structure of the Thesis, Methodological Approach

The thesis is based on a broad literature review (approximately 120 academic papers and a small number of books) on information ethics, the commons and sustainability. Due to the fact that immaterial artifacts (such as digital artifacts) need to be threaten different than natural artifacts (such as wood or oil) to reach sustainability, a conceptual model is developed. The conceptual model helps to understand the characteristics of digital artifacts. Understanding the characteristics is essential to answer the research question of this master's thesis, which is the following:

What are the favorable framework conditions for digital artifacts to provide the greatest possible benefit to society?

A conceptual research method is used due to the fact that digital sustainability is not established in scientific research yet. Therefore, before empirically testing the predictions of digital sustainability, the concept itself has to be raised. Sustainability is a normative concept focusing on global impacts of human behavior (Kläy et al., 2015). Different to research which is independent from moral values, research in sustainability should focus on the societal and natural benefits.

After this introduction in part 1, part 2 provides an overview on sustainability, digital artifacts, knowledge, the commons and socio-technical systems. Part 3 explains different understandings of digital sustainability and concludes with a definition comprising the understanding of digital sustainability at the University of Bern and the associated Research Center of Digital Sustainability. Part 4 develops the concept of the floor model to explain differences in sustainability between the treatments of digital goods compared to material resources. The conclusion in part 5 summarizes the findings in a table, before discussing the limitations and suggestions for further research.

2 Theory

To get an understanding of digital sustainability, theory of the five basic terms have to be introduced. The evaluation of which terms are relevant was done based on the state of research in information ethics, the commons and sustainability research. In many articles, they are required as prior knowledge. These basic terms are sustainability (2.1), digital artifacts (2.2), knowledge (2.3), commons (2.4) and socio-technical systems (2.5).

2.1 Sustainability

The most popular definition for sustainability provides the Brundtland Report from 1987. The Report was published from the United Nations World Commission on Environment and Development (1987). Originally the term comes from forest industry, where a tax accountant and mining administrator von Carlowitz (1713) stated that only as much trees could be taken, as the logging does not exceed the rate at which trees grow. While von Carlowitz introduced the concept of sustainability in the forest industry, Malthus (1798) focused on the growth rate between human population and food supply. He remarked that the population was growing much faster than the supply of food is developing its output. Therefore, Malthus applied the concept of sustainability for the first time to another field than forest industry.

Mill (1848) was the first who expanded the concept to all finite resources. He was afraid of the fact, that the aim of the industrial economy is constant growth. This would automatically result in the destruction of the environment. Therefore, he argued that after reaching the goal of well-being for everybody, the society should change in a stationary state, where the accumulation of capital is no more the dominant logic. It is important to remark, that human well-being could be used as a synonym to sustainability in its anthropocentric meaning (Stiglitz et al., 2009). In the stationary state, people would be aware, that the increase of fortune does not increase the happiness or the well-being of people. Due to the awareness, that after a certain amount of wealth the well-being cannot be increased, finite resources could be secured from exploitation in the concept of Mill. The brief historical context of von Carlowitz, Malthus and Mill was important to explain the evolvement of the concept of sustainability from a sector-specific towards a concept to natural resources in general.

Meadows et al. (1972) showed in an explorative analysis, what Mill stated 200 years ago: The world has a limit for growth. Additionally to Mill, Meadows et al. (1972) determined the five basic factors, which ultimately limit the growth: Population, agricultural production, natural resources, industrial production and pollution. Dennis and Donella Meadows were both scientists of the Massachusetts Institute of Technology and were writing in the name of the think tank “Club of Rome”. Maybe for the first time sustainability raised global attention with the before-mentioned book, called “The Limits to Growth” (Meadows et al. 1972).

The breakthrough of the concept was reached with the Brundtland Report (World Commission on Environment and Development, 1987). It provides the most popular definition for sustainable development (World Commission on Environment and Development 1987: 43): "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The principle of a limit for growth was revived from Meadows et al. (1972). The accumulation of knowledge and the development of technology were seen as vehicles to enhance the carrying capacity of resources (World Commission on Environment and Development 1987: 44).

Besides the stream of sustainable development, capital theory was of high importance for sustainability. Irvin Fisher made an important distinction between capital and income (Fisher, 1906): “A stock of wealth existing at an instant of time is called capital. A flow of services through a period of time is called income.” Boulding (1966) expanded the capital theory to a multi-capital theory, where not only economic or natural stocks of capital were in the focus, but generally resources could be divided into capital and income. Hicks et al. (1974) found out, that the capitals, Fisher and Boulding were researching on, are the source for generating new valuable goods. Nowadays usually four or five types of capitals build the base for capital theory. According to Ekins (1992) these are environmental capital, human capital, physically produced capital and social capital. Porrit (2007) defines five: natural capital, human capital, social capital, manufactured capital and financial capital.

Later on Elkington (1997) provided one of the most important metaphors for sustainability with the Triple Bottom Line. The Triple Bottom Line simplifies sustainability into three dimension: these are financial, ecological and social sustainability. The book explains, that enterprises gain more relevance compared to governments. Therefore, capitalism has to be to done in a sustainable manner as governments do not have any more full power over resource consumption. He provides six key indicators for the shift from the classical capitalism towards a sustainable capitalism.

1. Markets – From Compliance to Competition: Innovative strategies toward sustainability have to be built by incorporating the criteria of the triple bottom line.
2. Values – From Hard to Soft: Soft Factors (impacts on the stakeholders) have to be considered besides the already measured hard-facts.
3. Transparency – From Closed to Open: Thanks to the possibilities of information systems, sustainability reporting can help to make sustainability efforts more visible and therefore more transparent.
4. Life-Cycle Technology – From Product to Function: Companies have to consider the whole life-cycle of their products. For this, government-industry-NGO symbiosis gaining importance.
5. Partnerships – From Subversion to Symbiosis: Scenario-based tools can provide foresights for the future and therefore enables companies to include worst case scenarios into their calculations, such as big disasters.

6. Time – From Wider to Longer: The inclusion for stakeholders is seen as very important. Not only considering them after decision but involving them in the decision making process.

Further on, Elkington (1997) addresses the responsibility for politicians within the regulatory framework. In a way that taxes should include economic, environmental and social aspects. In general he cautioned politicians to act towards a prospective vision instead of shortsighted view on their own political gains.

As the next important step of the evolvement of the concept of sustainability, the millennium goals have to be considered (“United Nations Millennium Development Goals,” 2000). The millennium goals covers merely the reduction of social & health problems. These are poverty, education, gender equality, child mortality, maternal health, HIV/AIDS and partnerships for development. Exceptionally goal seven regards environmental sustainability (“United Nations Millennium Development Goals,” 2000).

In contrary to the social focus of the millennium goals, Rockström et al. (2009) focused on to the influence of humans endangering the stable ecosystem of earth and put the focus of sustainability back on environmental issues. They defined nine essential variables on which human behavior should not exceed a threshold. The boundaries defined by the thresholds describe the safe operating space for humanity. Therefore, it is assumed, that by controlling these factors, earths stability is no more endangered by human behavior. The red wedges within the graphic (see figure 1) symbolizes the current state, whereas the green circle visualizes the safe operating space. As one can notice, climate change (consisting of atmospheric carbon dioxide concentration and change in radiative forcing), the rate of biodiversity loss and the nitrogen cycle are already over the limit of the safe operating space. The boundaries represent biophysical preconditions that cannot outbalance each other. It is not possible to ignore one of them by contributing to another of the nine relevant preconditions.

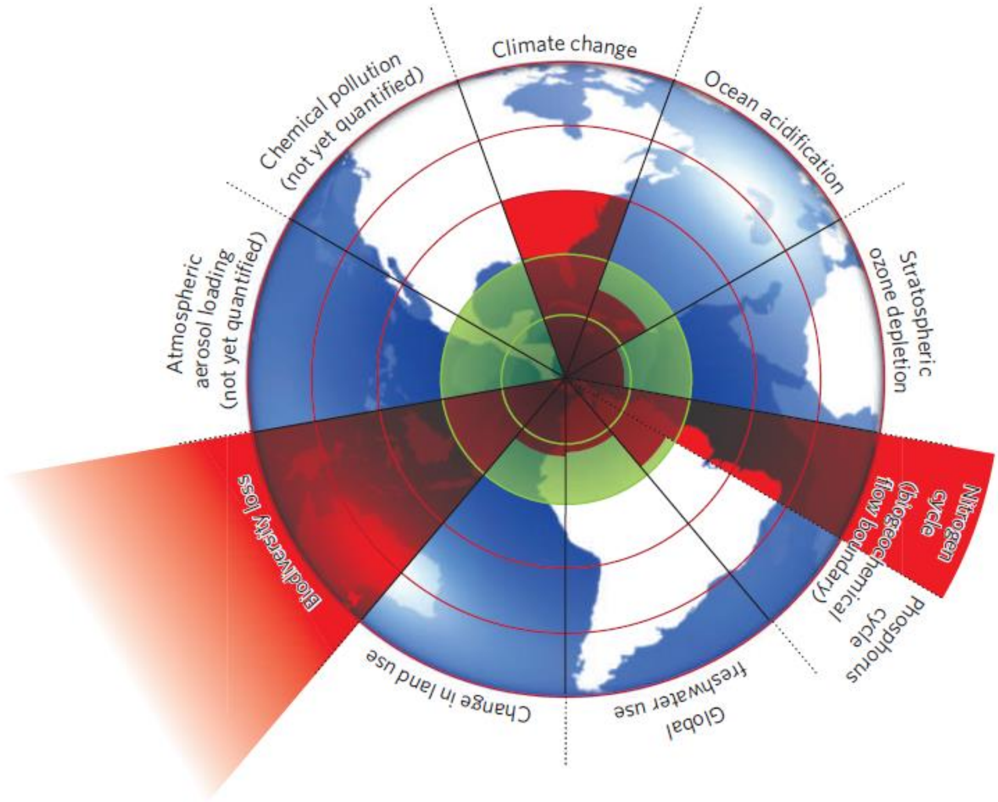

Figure 1: Nine ecological variables for earth stability (Rockström et al., 2009)

Raworth (2012) evolved the work of Rockström et al. (2009) by including social foundations of human life. This results in a space called "the safe and just space for humanity". The inner boundary consists of the social foundations and the outer boundary of environmental limitations according to Rockström (2009). Because the model (see figure 2) looks like a doughnut, the framework is also called the "doughnut model". The doughnut model visualizes that we should aim to live within the boundaries of environmental and social boundaries.

According to Raworth (2012) it is possible to build sustainable economic development within this space. Within this space human well-being can be reached. As one of the main problems she observed the current growth paradigm of economy. If we assume, that today's economy may operate in "the safe and just space for humanity", we are misunderstanding the way economy works. If decisions are made according to the monetary driven return on investment, sustainable behavior is never more than a side-effect that sometimes is profitable and therefore executed. But actions are also executed as non-sustainable behavior if such a project is more profitable than a sustainable approach. The growth paradigm is not only seen on an enterprise level, but also on the state level. As long as GDP is the main indicator of a national economy, economic actions will not act towards sustainability. If the aim of our society is the well-being of humans, we have to change the growth paradigm towards a more sustainable paradigm.

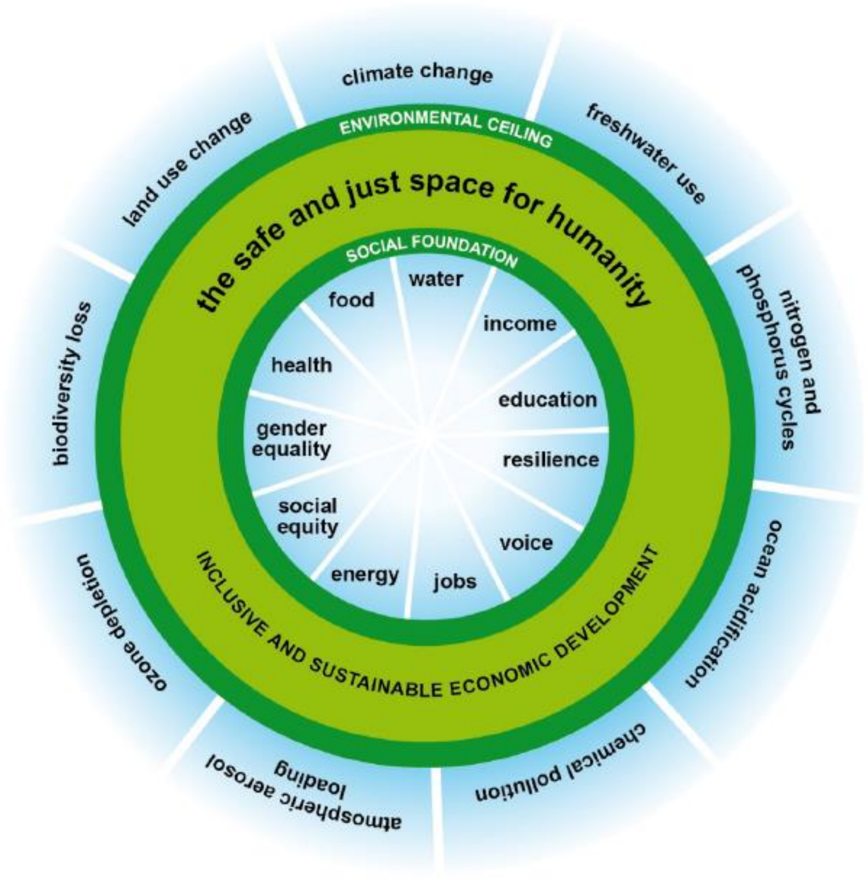

Figure 2: The safe and just space for humanity (Raworth, 2012)

The most recent evolution of the sustainability concept provide the Sustainable Development Goals (United Nations Department of Economic and Social Affairs, 2015) present the new global agenda by the United Nations for the next 15 years. To reach these goals the action plan lists 169 targets, each linked to one of the 17 goals. These goals are the continuation of the Millennium Development Goals mentioned above. While the Millennium Development Goals were merely focused on social and health issues, the Sustainable Development goals are integrative. Figure 3 lists them (United Nations Department of Economic and Social Affairs, 2015):

- Goal 1. End poverty in all its forms everywhere
- Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Goal 3. Ensure healthy lives and promote well-being for all at all ages
- Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
- Goal 5. Achieve gender equality and empower all women and girls
- Goal 6. Ensure availability and sustainable management of water and sanitation for all
- Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all
- Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- Goal 10. Reduce inequality within and among countries
- Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
- Goal 12. Ensure sustainable consumption and production patterns
- Goal 13. Take urgent action to combat climate change and its impacts*
- Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
- Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
- Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

Figure 3: Sustainable Development Goals (United Nations Department of Economic and Social Affairs, 2015)

It is important to understand that not all addressed resources within the sustainable development goals have to be treated the same way. Many times technologies are considered as an enabler for sustainability. As digital digital have some differences to physical goods, digital goods are explained in the following section.

2.2 Digital goods and artifacts

Digital goods and digital artifacts are closely related to each other. Digital goods consist of source code and non-personal data. Artifacts do not specifically ask for exchange (and therefore also include personal data), where goods are usually combined with exchange and economic value like in the following definition: “Digital goods are bitstrings, sequences of 0s and 1s, that have economic value. They are distinguished from other goods by five characteristics: digital goods are nonrival, infinitely expansible, discrete, aspatial, and recombinant." (Quah, 2003) The following taxonomy (see figure 4) briefly explains the terminology used within this thesis. Digital artifacts is the overall construct, where personal data builds an exception within this concept. Personal data has to be threaten different than other digital artifacts. Within this thesis, digital sustainability focus on non-personal artifacts and source code (which are the components of digital goods).

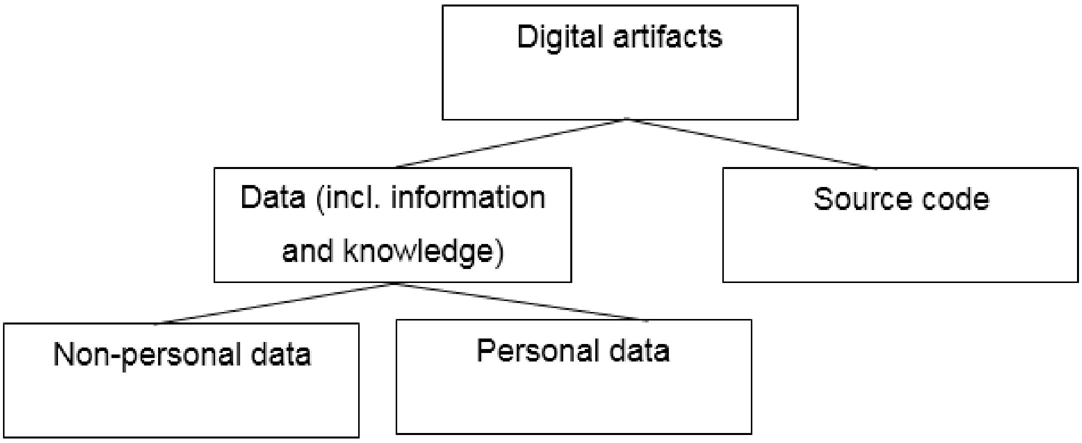

Figure 4: Taxonomy of digital artifacts

Characteristically for digital goods is the difference of production costs compared to traditional economic cost structures of physical goods (see figure 5). While the marginal cost structure of digital goods stagnates on a certain level above zero, in the lower part of figure 5, some authors even claim that digital goods reach almost zero marginal costs during their lifetime (Rifkin, 2014). Kogut and Metiu (2001) describe that in fact digital information has originally the properties of a public good as it can be transported and being replicated at almost zero marginal costs.

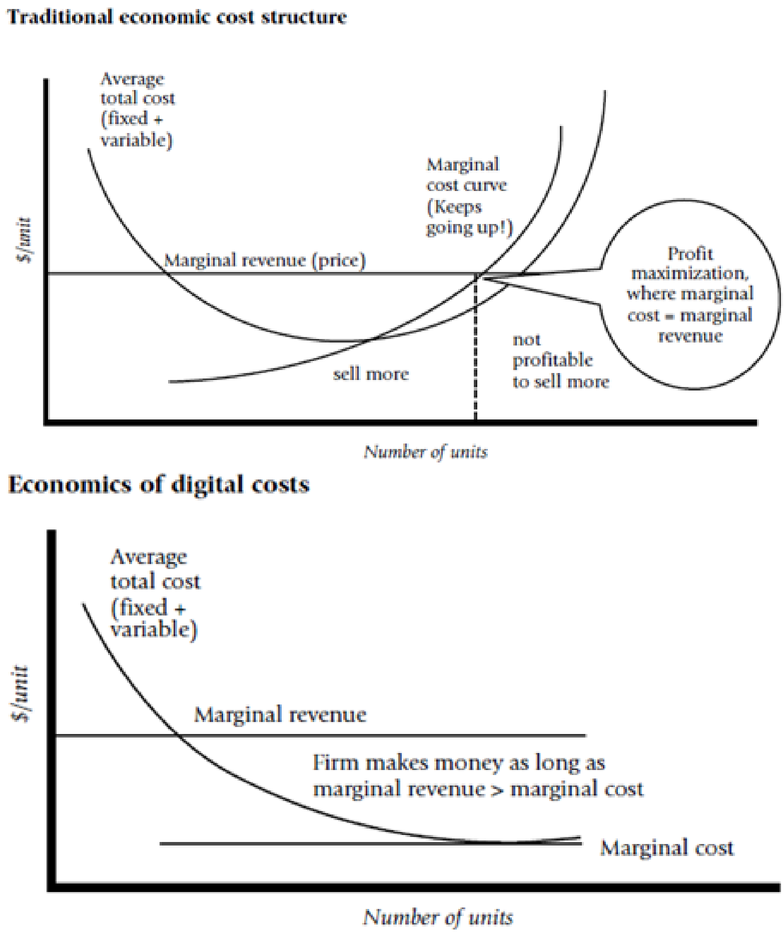

Figure 5: Cost structure of physical vs. digital goods

But it is not easy to distinguish what a digital good exactly is. Where the attribution as a digital good is easy for internet, protocols (e.g. TCP/IP), markup languages (e.g. HTML), free libre and open source software (FLOSS) or web applications (e.g. Wikipedia), for other goods the distinction is not clear. Choi et al. (1997) defined three dimensions which lead to the digitalization of a good. The most obvious layer builds the product itself: if the product is a virtual or a physical good. But the attribution of digital to a certain good is also made if only agents or processes (e.g. reservation or distribution) are digital. Goods where only agents or processes are digital could be called mixed forms (see figure 6).

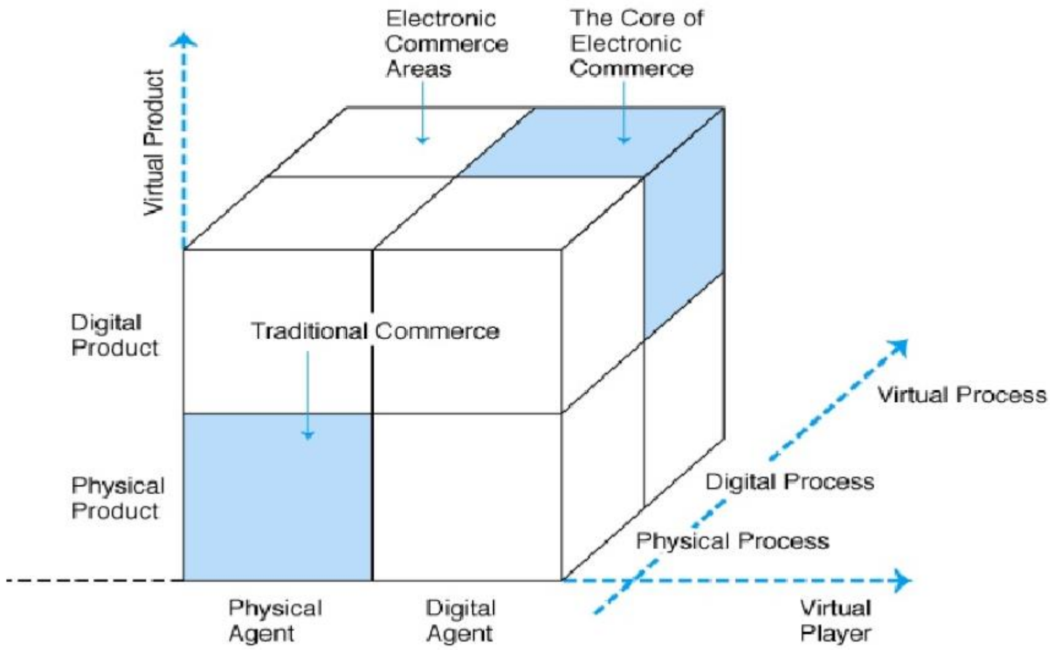

Figure 6: Various forms of digital goods (Choi et al., 1997)

The explanation of the mixed forms is therefore important, as digital innovation is more and more influencing the physical world. On the hand this is the case due to the change in data storing behavior. Where earlier in time most of data was stored analog, a shift towards digital storage was executed. Nowadays information is almost exclusively stored digital (Hilbert and Lopez, 2011). On the other hand processes getting more and more digital, where exemplary the taxi business was rather a physical business, nowadays with companies like Uber the taxi business is no longer a typical physical business as reservations are made digital (“Uber,” 2016). Another mixture are firms opening specifications for physical products and provide products as open source products. Exemplarily for this development is Thingiverse, which provides instruction for 3D-Printing objects or WikihHouse which is an open source building system for houses (Thingiverse.com, 2016; “Wikihouse,” 2016).

2.3 Knowledge

The interest for digital goods lies in the fact, that digital goods carry, process, manipulate or lose data. Data itself lies on the base of information and knowledge.

First it is important to question if a differentiation of data, information and knowledge is necessary for digital sustainability. This will be done according to Rowley (2007) who made a critical literature review over the hierarchical structure of data, information and knowledge. Most of the scholars do not go beyond knowledge which is manifested in the data-information-knowledge pyramid (DIK-pyramid; see figure 7). Data are observable properties, either automatically collected or self-evaluated. The common sense of definitions of data is on what data lacks: It has no meaning, is unprocessed and not organized. Information is usually seen as structured data, where data is made relevant in a certain context what makes it to information in the specific purpose. Knowledge has to be differentiated between tacit knowledge, which is embedded in individuals and explicit knowledge which is resided in documents, databases code or verbalized. As the distinction between data, information and knowledge is hardly to find anyway, the difference of explicit knowledge and information is even more intertwined. This could be the reason that a lot of academics mention knowledge as one entity including tacit and explicit knowledge.

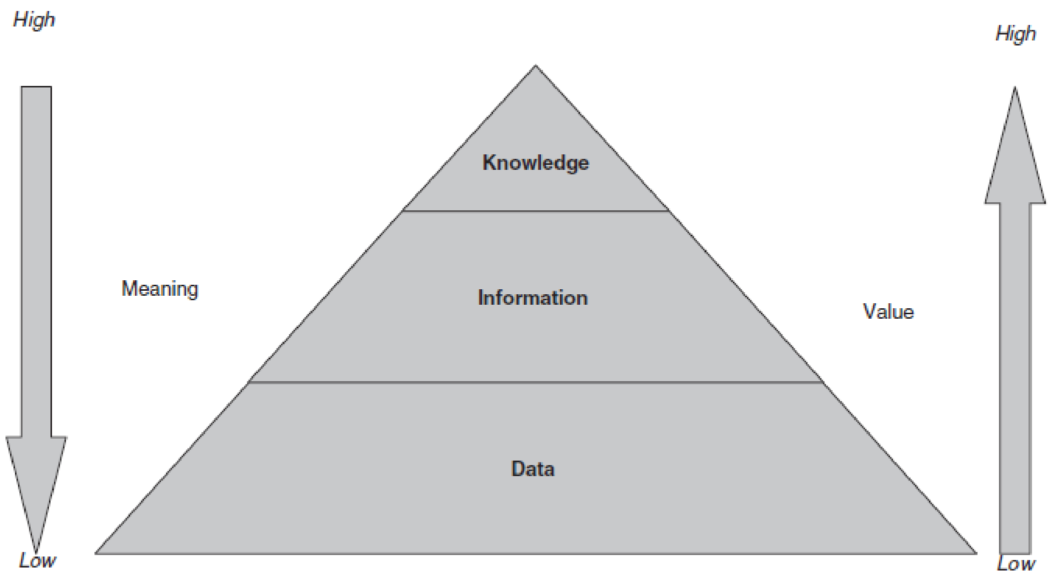

Figure 7: Data - information - knowledge pyramid (Chaffey and Wood, 2005)

Some scholars expand the DIK pyramid with a fifth level with the extension of wisdom or enlightenment, depending on the author (e.g. Ackoff, 1989; Zeleny, 1987). But in the end every model has to fulfill three quality criteria, the model has to have syntactic quality, semantic quality and pragmatic quality. The applied quality requirement in a specific contextual setting may change (Lindland et al., 1994). Therefore, the author of this thesis state that the differentiation whether a bitstring of 0s and 1s is data, information or knowledge may change and as everything is based on data (which is again a digital good or a digital artifact), the concept of digital sustainability does not require a distinction between the elements of the DIK-pyramid.

Wenger (2004) realized, that knowledge (which from now on is used as a synonym to data) is not based on individuals, it is the community of practice where individuals belong to, decide what is right or wrong. He believes that knowledge is related to the practitioners, the people who apply knowledge to their actions. The practitioners who make the dough for the doughnut (see figure 8), do rely on their community of practice: “Communities of practice are groups of people who share a passion for something that they know how to do, and who interact regularly in order to learn how to do it better.” (Wenger, 2004). Only within the community of practice, people understand the difficulties and insights to a sufficient amount to improve learning. A community of practice is based on three factors (see figure 8):

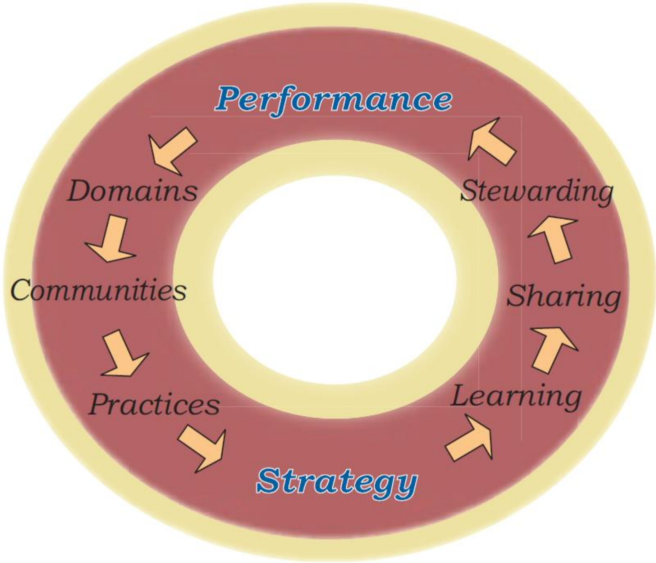

Figure 8: Community of practice (Wenger, 2004)

1. Domain: The area of knowledge on what learning and development is fulfilled.
2. Community: The quality of the relationships and the boundaries of the community.
3. Practice: “the body of knowledge, methods, tools, stories, cases documents, which members share and develop together” (Wenger, 2004).

“Rather than assuming that knowledge is the property of management and the workers are the implementers of this knowledge, it assumes that knowledge is the property of the practitioners, and the role of management is to make it possible for practitioners to act as managers of their knowledge.” (Wenger, 2004, p.6). For a prospering community of practice it is important that knowledge is not horded; the sharing and stewarding of the knowledge can be applied by other practitioners and therefore they can increase the performance of the whole community (Wenger, 2004). Sharing and exchange knowledge among communities is explained to the best as knowledge commons (Frischmann et al., 2014). But to describe knowledge commons, basic understanding about the commons in general is essential as well.

2.4 Commons

Commons are a constitutional arrangement among common pool-resources, where sharing of the resources among the community is institutionalized (Frischmann et al., 2014). In specific, knowledge commons are an “institutionalized community governance of the sharing and, in some cases, creation, of information, science, knowledge, data, and other types of intellectual and cultural resources.” (Frischmann et al., 2014, p.3) It is important to distinguish between “open commons” where basically no one has the right to exclude another person and “property regimes” where the commoners have the ability to exclude others, to access the resource, to manage (by making transformations or improvements) and to obtain units of the resource (Hess and Ostrom, 2003). This thesis follows the assumption that ideally private digital goods (private data) should be treated as a property of the owner, where digital goods should be treated as open commons with symmetric access and user rules for everybody. The openness of digital goods enables spillovers (positives externalities Frischmann and Lemley, 2007) which are “social benefits that flow from uses and reuses of information resources and sustain the dynamic character of the information environment.” (Madison et al., 2010, p. 668; Frischmann and Lemley, 2007)

Important for digital sustainability is not solely the concept of the definition of the knowledge commons, but also the definition of digital commons: Digital commons could be defined “as an information and knowledge resources that are collectively created and owned or shared between or among a community and that tend to be non-exclusivedible, that is, be (generally freely) available to third parties. Thus, they are oriented to favor use and reuse, rather than to exchange as a commodity. Additionally, the community of people building them can intervene in the governing of their interaction processes and of their shared resources.” (Fuster Morell, 2010, p.5) It seems obvious that different terms of commons do overlap.

To shed light on the darkness Hess (2008) mapped a taxonomy on fields of the commons (see figure 9). It is important to acknowledge the difference of commons among scarce resources and on the other side nonrival resources such as knowledge/information (Benkler, eds.). It is obvious that among scarce resources, such as pastors in the Alps, group commons are more reasonable, where for digital/knowledge commons such as the World Wide Web the existence as an open common does not negatively influence the sustainability and even supports our private and economical ecosystem.

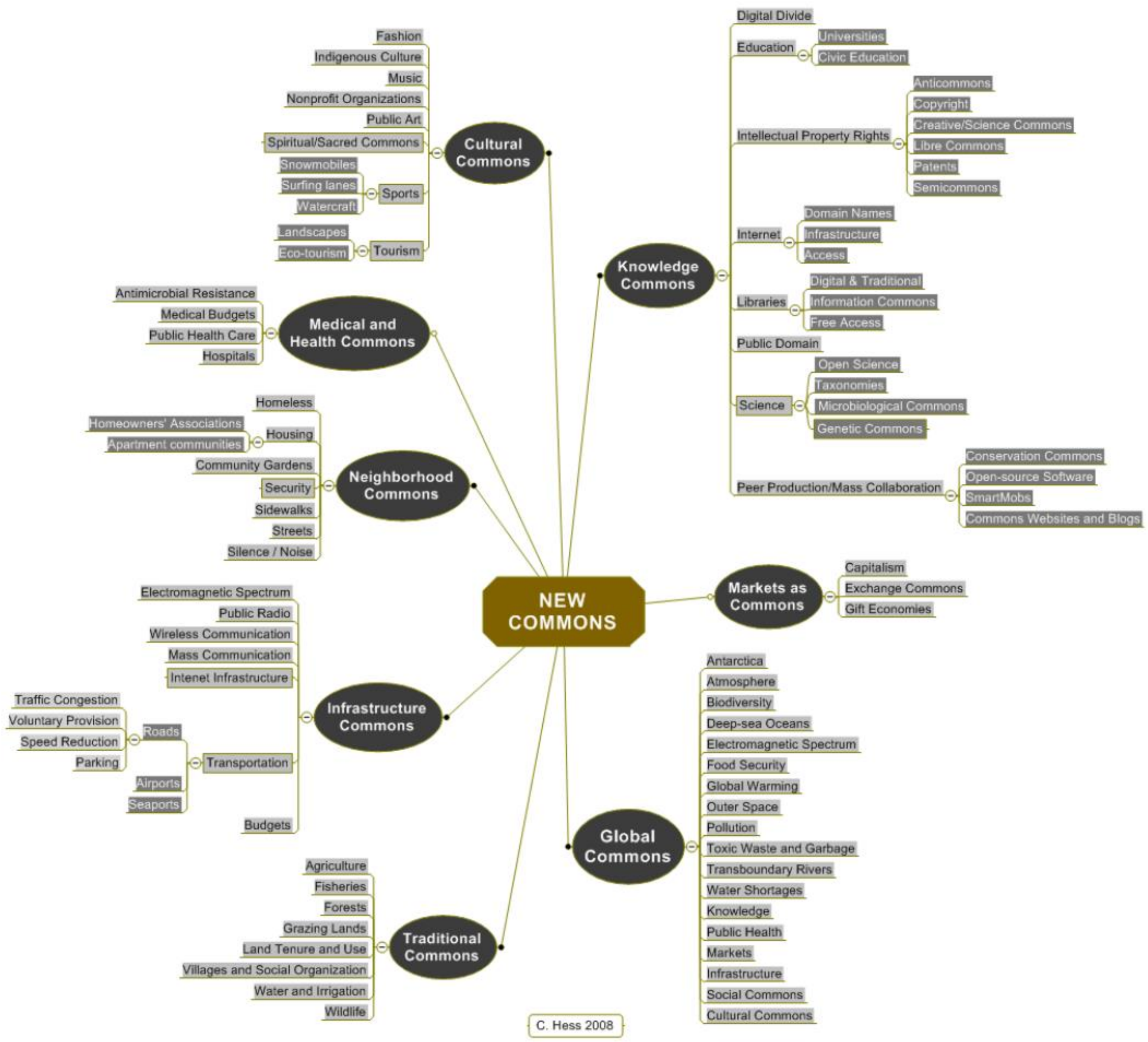

Figure 9: Taxonomy of the commons (Hess, 2008)

The commons provide three relevant conceptualizations, which are important for digital sustainability: The tragedy of the commons, the tragedy of the anti-commons and the comedy of the commons.

2.4.1 Tragedy of the commons

For a long time it was assumed, that people would exploit resources if resources are not privatized or served as public goods from the state. The effect of self-interested individuals depleting resources against the interest of the community is called the tragedy of the commons (Hardin, 1968). Although Elinor Ostrom found out that under certain conditions the exploitation of natural resources is not a necessary consequence (Ostrom, 1990), privatization is still seen as an effective way of enabling resources to sustain (Heller, 2008). Property rights regulate the use of resources due to the owners’ self-interest.

2.4.2 Tragedy of the anticommons

Whereas privatization may be in some cases an effective way for natural resources, the consequences of privatization for knowledge resources have to be considered. Isaac Newton mentioned in 1676: “If I have seen further, it is by standing on the shoulders of giants.” New Knowledge is usually based on already existing knowledge. If existing knowledge is extensively protected with property rights, new knowledge cannot be developed. If a newly researched medication has patents on various components by other firms, the effort is too high to continue the development. This coordination breakdown is described in theory of the “tragedy of the anticommons” from Heller (Heller and Eisenberg, 1998; Heller, 2008). The similarity to the term “tragedy of the commons” from Hardin (Hardin, 1968) is on purpose, to mention that the contrary results in a tragedy as well. In the case of “the tragedy of the commons” due to an over-consumption, whereas in the case of “the tragedy of the anti-commons” due to an under-production and therefore an under-consumption.

2.4.3 Comedy of the commons

Rose (1986) describes, that property is usually made either private or public. Automatically economic theory assumes, that governments are able to govern public property. But there are four caveats regarding the success of government to handle public property.

(1) The state is able to identify instances, where market failure occurs
(2) The state is able to reduce the market inefficiency
(3) The intervention does not generate new inefficiencies
(4) The costs of the intervention are not higher than the generated value of the intervention

She argues that, besides the usual understanding of a duality between private property and governmental controlled public property, there is a third category called “inherently public property”. The inherently public property is “owned” and “managed” by the whole society. In contrast to the tragedy of the commons, some inherent public property is comedic (and not tragic). Comedic in a sense as two outcomes are positive: On the one hand due to the increased human wealth and on the other hand, it expands sociability. In the comedy, people contribute knowledge to the public, rather than hording for their personal gain. Rose (1986) described the comedy of the commons insofar, as she describes the goods which are not exhaustible, noncompetitive and non-excludable as anti-rival. They are not only non-rival, they are anti-rival as in the sense of the more people use it, the more value provides the good.

Contributing knowledge to the public means in regard of the topic of digital sustainability, contributing data with the vehicle of an information system to the public domain. To describe the interplay between humans and information systems theory of socio technical systems is appropriate. Therefore, the following part describes the theory in general and in a second step, the socioeconomic production regarding the commons.

2.5 Socio Technical Systems

2.5.1 General theory

In socio-technical systems theory, organizations are divided into two subsystems. On the one hand a technical subsystem which incorporates tasks and technologies to transform input into output and on the other hand the social subsystem which comprises knowledge, skills and values of the people, the relationships among them and the authority structure (Leavitt, 1965; Bostrom and Heinen, 1977).

Seidel et al. (2013) used theory of socio-technical systems (STS) to describe affordances of information systems contributing to a transformation towards environmental sustainability in organizations. Interestingly the material properties of information systems which positively influence a transformation towards sustainability are monitoring, analyzing, transparency, sharing, providing access, enabling dissemination of knowledge from internal and external resources (Seidel et al., 2013). They interestingly rely on the openness of data that could potentially be collected and provided. Openness in the term of access to resources is defined as “our capacity to relate to a resource by accessing and using it” (Madison et al., 2010, p. 695).

The abovementioned research streams of the commons mainly refer to the socio-technical system of commons-based peer production to describe the relevant framework for the production of common-property digital goods (Benkler, 2006). In contrary to the research of Seidel et al. (2013) commons-based peer production describes inter-organizational production and also to a great extent non-formal collaboration among individuals and groups.

2.5.2 Commons-based peer production

The concept of commons-based peer production was developed by Benkler (2006). Commons-based peer production describes a socio-technical system based on a large amount of individuals collaborating without market prices and managerial hierarchies. An important reason for the lack of managerial hierarchies is the fact, that products developed with commons-based peer production are not owned by an individual or an organization (Benkler and Nissenbaum, 2006). Therefore, nobody is excluded from contributing or using the product (e.g. software).

Commons-based peer production is a modality of collective intelligence. Different to other modalities of collective intelligence, commons-based peer production does not involve centralized control (e.g. for goal-setting and task prioritization). Contributors have a broad range of motivation by contributing to the common good and it usually exists without obligations of contracts resource restriction by property rights (Benkler et al., 2013).

Artifacts enabling to be built with commons-based peer production need to have the following basic conditions:

(1) Ability to be built modular
(2) A fine granularity among the modules
(3) The possibility to integrate new modules in the end-product
(4) The new modules need to be integrated at low-cost
(5) Mechanism for excluding qualitative poor contribution has to be include.

The most visible manifestation of commons-based peer production is in free and open source software. Famous examples therefore are Linux and Apache. Nevertheless commons-based peer production is less visible in other domains, it holds various examples in information, knowledge and cultural production in the internet. “The effort is sustained by a combination of volunteerism and good will, technology, some law—mostly licensing like the GNU General Public License that governs most free software development—and a good bit of self-serving participation.” (Benkler and Nissenbaum 2006, p. 396).

3 A definition of digital sustainability

3.1 Functional and discrete digital sustainability

Digital sustainability can be considered in two different ways. On the one hand, how digital artifacts are sustainable themselves and therefore how to create sustainable digital commons. On the other hand, how digital artifacts can contribute to a sustainable development. In this second way, digital artifacts are seen as vehicles to reach sustainability. The author of this thesis calls the first meaning discrete digital sustainability, where the latter is called functional digital sustainability. The term Green IT can be contributed to environmental sustainability. Pamlin and Mingay (2008) found out that 2% of the overall greenhouse gas emission are caused by digital technologies. The reduction of this 2% is attributed to Green IT.

Functional digital sustainability has to be reached by a transdisciplinary approach. The research discipline of information system is able to elaborate the requirements for sustainable digital commons, but the achievement of a sustainable development is only possible in a cooperation of all disciplines. Already a glance on the sustainable development goals (United Nations Department of Economic and Social Affairs, 2015) provides proof, that they cover to many disciplines.

The discrete view on digital sustainability is based on research from legal academics (e.g. Lessig, 2001; Benkler, 2006), the knowledge commons (Hess and Ostrom, 2005; Frischmann et al., 2014), information ethics (Busch, 2010; Kuhlen, 2013) and from the open source research (e.g. von Hippel and von Krogh, 2003; Stürmer, 2014). They all examine, how (digital) goods in the public domain can be sustained. (Discrete) Digital sustainability therefore are the framework conditions, how digital goods optimize the societal benefit. The framework of discrete digital sustainability is the way, how immaterial digital goods, such as information and knowledge should be treated to lead to digital commons.

Exemplarily the difference between functional and discrete digital sustainability will be explained according to goal 6 of the sustainable development goals. Goal 6 aims to ensure availability and sustainable management of water and sanitation for all (United Nations Department of Economic and Social Affairs, 2015). The functional role of digital sustainability regarding to goal 6 would be to collect data on water wells and flows and store them in a database. The discrete role of digital sustainability would be a regularly updated platform, where collaboratively knowledge about the actual situation is shared and exchanged. The openness of the platform guarantees spillovers to other regions, where the system only has to be adapted to the local conditions and profits from the already available experiences of the initial platform.

Of Course both dimensions of digital sustainability (discrete and functional) are relevant. If only the functional role is followed, an enterprise could collect water data (which is functional digital sustainable) but sell it for hardly affordable fees to the community. The system itself is able to provide sustainability to the community, but as there is no access on the gathered knowledge it is not a digital common and therefore not discrete digital sustainable. The other way around it is possible that discrete digital sustainability is fulfilled on a platform to get access to illegal weapon markets, but of course the criteria of functional sustainability are not fulfilled, because the platform is not a vehicle for sustainability as weapon are a threat to society.

In the previous example about water management the author examined that the two different dimensions (functional and discrete) of digital sustainability do not exclude each other. In an ideal world both concepts are combined increasing their impact of digital artifacts.

Another example of the combination of functional and discrete digital sustainability shows how environmental sustainability supporting information systems capture, process and store data from assessments (Melville, 2010). The software indicates the functional digital sustainability perspective, as the Life Cycle Assessment (LCA) is able to assess the effects of a product through-out its life-cycle (Shaft et al., 1997) and is therefore a vehicle to reach environmental sustainability. Analyzing how the software could be reused by other companies when developing an open source LCA and considering public available standards to make comparisons among captured assessment-data from LCA, the discrete digital sustainability perspective is included (Ciroth, 2007; Zhang et al., 2015).

3.2 Definition of discrete digital sustainability

The understanding of discrete digital sustainability is not that simple. Principally it is the availability of digital sustainable commons. The differentiation between digital commons and digital sustainable commons lies in the fact, that it is important to maintain the digital artifacts to sustain the knowledge from digital commons. To remember the definition of the digital commons, it is hereby mentioned for a second time "as an information and knowledge resources that are collectively created and owned or shared between or among a community and that tend to be non-exclusivedible, that is, be (generally freely) available to third parties. Thus, they are oriented to favor use and reuse, rather than to exchange as a commodity. Additionally, the community of people building them can intervene in the governing of their interaction processes and of their shared resources." (Fuster Morell, 2010).

To the understanding of the author, the definition of the digital commons does not mention the problem that motivation to provide knowledge as a common property to the digital commons could be weak due to the lack of financial incentives for contributors. Therefore, the accessibility of knowledge is endangered. To overcome the weak motivation through monetary incentives, contributors (e.g. firms) of knowledge do not provide their knowledge in digital commons, but proprietary to get direct compensation. Direct compensation could be high licensing costs and patenting to sell knowledge at high costs. The closeness of knowledge can lead to the three problems mentioned in the problem description of this thesis in part 1: (1) knowledge is not affordable (2) coordination breakdowns and (3) lock-in effects.

Of course in some cases it is appropriate not to follow the mantra of openness (e.g. for private data, see chapter 2.2). To overcome that every kind of digital artifact has to be open and the abovementioned problem, that the definition of digital commons is not sufficiently incorporating the necessity of sustaining the common, a new definition of discrete digital sustainability is built: (*Discrete) Digital Sustainability wants to generate, develop, sustain and ensure access to digital artifacts in a way that digital artifacts provide the highest possible benefit for society.*

To underline the importance of sustainability of the digital commons, the following chapter explains the need for sustainability science and the differentiation between the constitution of artifacts, whether they are immaterial or material. Afterwards the basic conditions for digital goods are evaluated, how digital goods could be accessible, generated, developed and sustained. The basic conditions will be divided in organizational, legal, technical and financial layers.

4 Results of the literature review

4.1 The need for sustainability science

Digital sustainability follows a normative approach, where sustainability is the most important concept. This is in contradiction with economic research, which often valuate welfare or growth as the most important drivers. Kläy (Kläy et al., 2015) argues that not only economic research has the logic of providing value insofar as a lot of research “only” maintains the competiveness of the individual researcher, the institution or the country. Of course maintaining attractiveness of the institutional or national science also contributes to the society. Kläy (2015) proposes therefore a sustainability validation for future research. The point of requiring a sustainability validation in research is merely a top-down approach.

Another possibility to promote a transformation in research is the alignment of individual research towards a validation of sustainability science form bottom-up. In the bottom up approach, members from various disciplines need to introduce their own discipline to build a thought-collective towards a sustainable development. This thesis is an attempt to build a bottom-up approach from information systems research towards sustainability science among digital artifacts which play a pivotal role in the knowledge society (Hilbert and Lopez, 2011). To understand what framework conditions attribute goods as sustainable, two simplified models support the understanding. On the one hand the cap model, which limits natural resources from overconsumption and on the other hand the floor model which requires basic conditions for digital artifacts.

4.2 Cap Model

The Cap model is explained by a visualization from Wackernagel and Rees (1998).

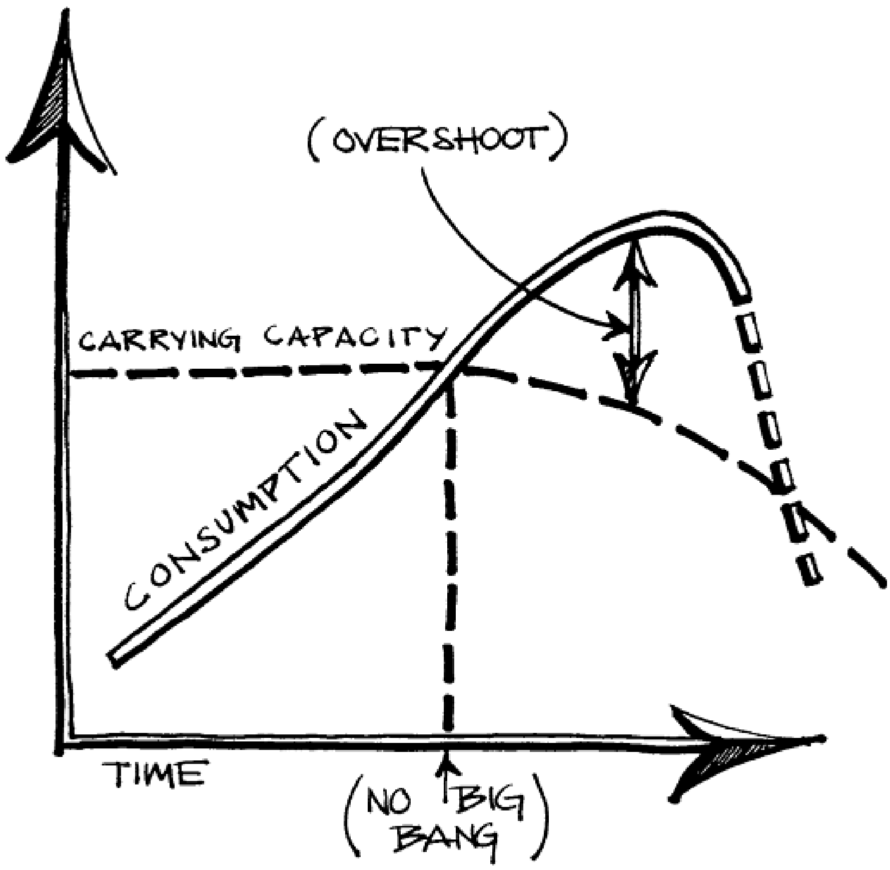

Figure 10: Carrying capacity (Wackernagel and Rees, 1998)

Figure 10 shows that consumption of natural resources by humans is constrained by a carrying capacity. Of course this carrying capacity is flexible due to economical, natural or social innovations.

In general we can observe a growing per capita consumption towards a carrying capacity. The carrying capacity can be called a maximum load which the ecosystem can hold. This leads to the consequence that consumption which exceeds the carrying capacity of our ecosystem asks for a smaller population or less exploitation of natural resources. As the ecosphere is too complex to observe regions independently, a global view has to be conducted by studying the abovementioned figure 10.

Of course the model is too simplistic as there has to be a differentiation between renewable resources and non-renewable resources, but it clearly signals that environmental sustainability is mostly related to a maximum use (the so called cap) of natural resources (Heller, 2012).

4.3 Floor Model

In contrary digital resources do not benefit society sustainably before not providing the resource under certain basic conditions. Of course also proprietary artifacts do benefit society but not in a sustainable way, as they create vendor dependencies, especially sole-source providers do provide high dependencies (Benkler, eds.). The vendor dependencies lead to the already mentioned accessibility problems (affordability, coordination breakdowns and lock-in effects).

Digital Sustainability faces two challenges. Up to the point of the intersection (see figure 11; point B) of production between digital goods and the basic conditions for digital sustainability, digital goods are endangered by underproduction and are not protected from a big loss (point A). A big loss could occur, if only one person or one firm has knowledge about a digital good and the person/firm is no more able or no more willing to provide the good. In such a case the gathered knowledge within the digital good is lost. Another possibility for a loss is defective hardware for sources only stored on the defective hardware.

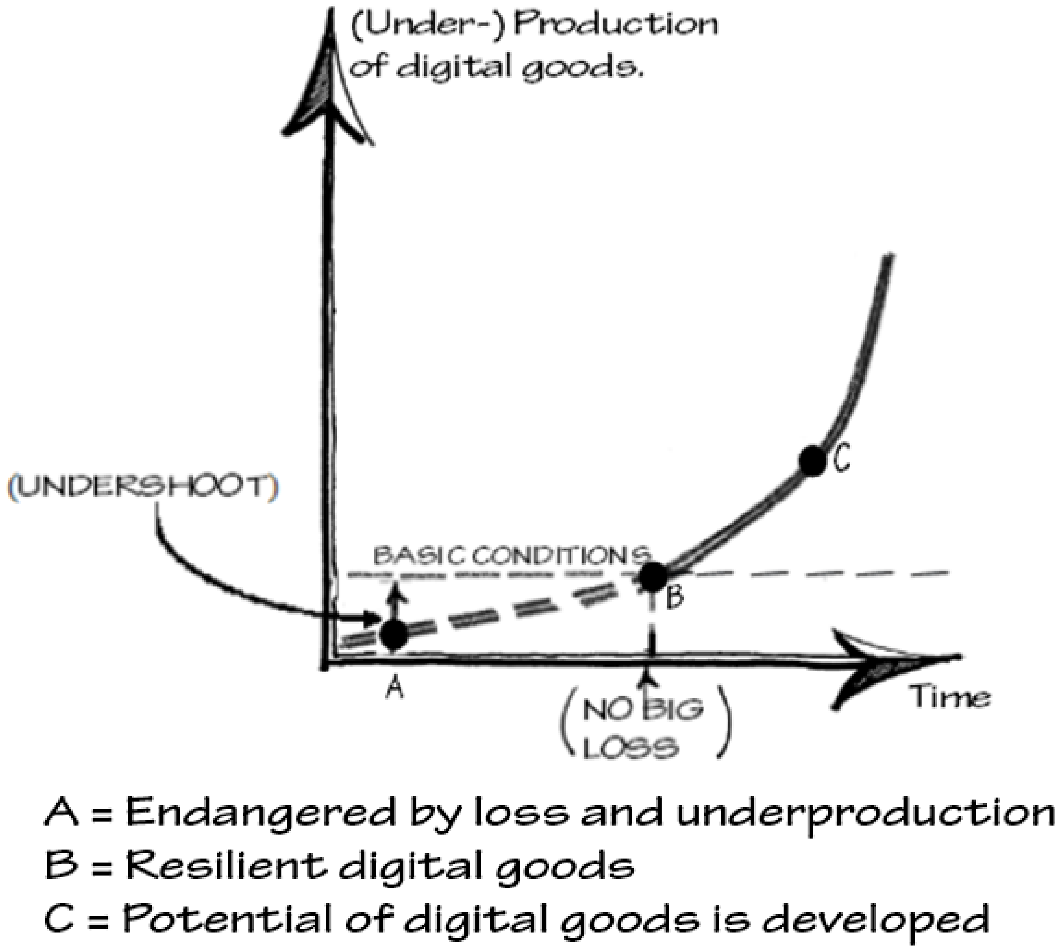

Figure 11: Floor model for digital artifacts

Underproduction occurs, when (i) it is not known that certain digital goods already exist, (ii) people cannot find the digital good (iii) the good is protected with property laws or (iv) technical barriers hinders the access to the digital good. Digital goods do not exist per se and are therefore created by humans. After basic conditions are met, the potential of knowledge can be developed (point C). To make this more understandable two cases for each point (A, B and C) should contribute to the comprehensibility. The first case is a mix of two examples from natural sciences, where case 2 is an adapted case from the author’s personal experience.

Case 1 for point A: A medical researcher from university discovered a new medication against cancer. As the receptor tests to evaluate the medication for side effects are patented from companies, the researcher is not allowed to test if the medication has side effects. Either she/he pays the patent-holder of the receptor test or the researcher has to develop the receptor test from scratch or does not further evaluate the medication. As the process of developing new medication is fragmented in lots of different parts, too many parties who claim property rights on one of the fragments make the development very complicated or even impossible (Heller and Eisenberg, 1998).

Case 1 for point B: Hampton et al. (2013) describe that biologist should publish their data public, well documented, discoverable online, complete, machine readable, standardized and integrated into big data streams. If ecologists provide their data as proposed from Hampton, ecologists could profit from each other's research. Exemplarily data can be stored in GenBanks or data networks. An example for a data network is DataOne which provides "sustainable cyberinfrastructure that meets the needs of science and society for open, persistent, robust, and secure access to well-described and easily discovered Earth observational data." (DataOne, 2015).

Case 1 for point C: Researchers will be able to analyze a huge amount of ecological and medical data. The aim of data repositories like DataNet is that researcher can profit from a huge amount of data to conduct new research (e.g. to go up from point B to point C). The researchers are obliged to bring the results back to the common-pool. Like this, knowledge can be expanded in favor of society. The most important part of this reciprocal behavior is the provision of biological data with creative commons licenses instead of restricting the access for further studies by patents or other intellectual property laws.

Case 2 for point A: A government collects day time road traffic noise. This data can be downloaded in a proprietary format (a format which is protected by property rights and without a public available specification) which is not convertible. A software developer who would like to visualize the noise data in a mobile app is not able to process data, because data is not convertible to a standardized format. As there is no specification of the proprietary format, the software developer is not able to visualize the noise data. The mobile app would have helped potential tenants to evaluate housing offers.

Case 2 for point B: Now the structured data of day time traffic noise is made available (e.g. by the government) on the internet in a non-proprietary format like CSV, the description of the source is available and data is linked to other data which is in context to day time traffic noise data. Additionally the data structure is filled with metadata and the non-proprietary data format is publicly available. Contextual data could be coordinates. If traffic noise data is related to coordinates it would be interesting to link this coordinates to addresses which represents another dataset.

Case 2 for point C: The application connects addresses and day time traffic noise data. Potential tenants are able to evaluate housing offers according to noise data. Lessors will know, which windows are required at a specific site and government knows the best, where new action against noise have to be introduced. The app develops new knowledge for tenants, lesser and government only due to the fact that government provided address data and noise data meeting the basic conditions of point B. Point B are the basic conditions for digital sustainability.

The broad literature review conducted for this thesis leads to the finding, that the favorable basic conditions could be divided into four layers: An organizational, a technical, a legal and a financial layer. Only the combination of the layers are able to provide digital sustainable artifacts. First an overview of the literature review is provided (see table 1), secondly important elaborations are followed in the sub-chapters 4.3.1 to 4.3.2.

The literature review explains the important terms for knowledge commons and why they benefit digital sustainability. In chapter 2, the author of this thesis explained the difference between digital goods (data and source code) and personal data. The term “privacy” is used for the exception of personal data and replaces “open data” which is a benefit for digital goods.

Open Data (incl. information/ knowledge)	Opening data provides benefits for the society as it leads to transparency, efficiency, effectiveness and participation. Additionally new business models may evolve from revealed data.	(Klessmann et al., 2012; Bürgi-Schmelz, 2013; Hampton et al., 2013; Kuhlen, 2013; Davies, 2014; Ubaldi, 2013; Carrara et al., 2015)
Copyleft (Open Source, Open License)	Open Licenses are at the core of digital sustainability as the licenses legally guarantee the free use and re-use. The addition of copyleft aims to not lose the option to profit from data (e.g. source code) enhancements.	(von Hippel and von Krogh, 2003; Madison et al., 2010; Frischmann et al., 2014; Stürmer, 2014)
Neutrality of infrastructure provider	Governance is highly influenced by the software (e.g. web platform) provider and/or vendor. The source code determines the possible actions for users and contributors.	(Fuster Morell, 2014, 2010; Wright and De Filippi, 2015; Scholz, 2016)
Cooperation/ Co-opetiton	Instead of harmful competition among organizations, a huge amount of synergies are possible. Competition is not necessarily the best strategy and especially learning is more effective if it results from various sources.	(Axelrod and Hamilton, 1981; Siemens, 2005; Brandenburger and Nalebuff, 2011; Bouncken et al., 2015)
Software quality	Software quality is based on reliability, suitability, security, usability, compatibility, efficiency and maintainability. These factors are	(Stamelos et al., 2002; Heitlager et al., 2007; ISO, 2011)

	relevant for a sustainable existence of the underlying data.	
Open Format/ Standard	Open formats and open standards prevent data holders from lock-in effects and vendor dependencies.	(Smith Rumsey, 2010; Huemer, 2013; Stürmer, 2014)
Modularity	Modularity and granularity facilitate the contribution from various sources and the simultaneously evolvement of the underlying digital artifact.	(Stamelos et al., 2002; Benkler, 2006; Stürmer, 2014)
Blockchain	The blockchain is able to avoid centralized control of the software provider/vendor as every interaction is decentralized stored among all participants of the network.	(Swan, 2015; Wright and De Filippi, 2015; Scholz, 2016)
Distributed Knowledge / Documentation	Metadata and documentation are essential to not make users dependent on individuals or firms. Additionally the knowledge has to be distributed among various individuals or/and organizations.	(Hess and Ostrom, 2005; Stuermer et al., 2009; Busch, 2010; Hampton et al., 2013)
Affordability (to use and to contribute)	If the only the market plays on data protected by intellectual property high inefficiencies, market failure and inequality occurs.	(Benkler, 2002; Shantharam, 2005; Pearce, 2012)
Business models on additional value, not on intellectual property rights	Business models should be done on additional value and not on intellectual property rights. Therefore, payments from users can be aimed for additional value and not for already created property. Typ-	(Bonaccorsi and Rossi, 2003; Krishnamurthy, 2005; Bonina, 2013; Henkel, 2006; Dahlander and

	ically individualization, maintenance and subscriptions among many others possibilities guarantee additional value.	Gann, 2010; Lindman and Nyman, 2014)
Open Access	To enable people (e.g. researchers) to know, what is already done within the field of interest. This leads to less inefficiencies and unproductivity.	(Lessig, 2001; Antelman, 2004; Harnad et al., 2008; Kuhlen, 2013)
Privacy	Personal data should not be threaten as open data. Therefore, free choice of data dissemination, collection and processing is necessary. Data invasion is only accepted in case of higher interest.	(Solove, 2002; Malhotra et al., 2004; Solove, 2006)

Table 1: Summary of Literature Review

The author of the thesis examined, that privacy and open data are interchanged, depending whether the object of digital sustainability are digital goods (open data) or personal data (privacy). A second observation lies in the categorization of the evaluated important terms for digital sustainability. The categorization clusters the following for layers: An organizational (4.3.1), a technological (4.3.2), a legal (4.3.3) and a financial (4.3.4).

4.3.1 Organizational Layer

We have to question whether organizational or individual cooperation is utopian. Usually firm strategies are driven by a competitive strategy. A manifestation of the competitive logic are the five forces from Porter (1980). The model of the five forces allows evaluating the industry a firm is operating. The evaluation is conducted by competitive lenses on five components: These components are (1) internal rivalry, (2) supplier power, (3) buyer power, (3) ease of entry, (4) substitutes and (5) complements. Complements boost demand, where the other forces are negatively correlated to the potential of the industry. Therefore, the five forces examine the threats to the industry. Porter (1980) generally ignores that firms within and industry can also cooperate in a form, that profits can increase. Brandenburger and Nalebuff (2011) pointed on examples positively influencing the interactions between “competitors” (according to Porter), suppliers and buyers. Such examples could be: Common technological standards, promoting favorable legislation, collaboration with suppliers to develop products with higher quality or to establish processes that increase the efficiency of the production process (Besanko, 2013).

The additional invention of the Value Net as a measurement for opportunities among suppliers, customers, competitors and complements supports the concept of coopetition (Brandenburger and Nalebuff, 2011). The profit of the value net can be described as the “overall value of the net when firm X participates minus overall value of net when it does not participate” (Besanko, 2013, p.266).

An important strategy to facilitate a cooperative equilibrium is tit-for-tat. Tit-for-tat is a reciprocal strategy. Usually competitions leading in price wars endanger the existence of all competitors, where cooperation can lead in mutual existence where both are better off. A lot of research has been conducted on price mechanisms among competitors. Research has shown that tit-for-tat strategy can lead to an equilibrium where all the parties are profiting. Tit-for-tat is facilitated by a long-term thinking. If points of contact between the firms are only once, tit-for-tat is not possible to follow due to its reciprocal character. Tit-for-tat aims to answer to the other parties’ behavior in the same way as it treated me. If the other organization is acting cooperative, I am responding cooperative. If the other organization is acting competitive I react competitive. If both parties are better off in the cooperative stage and both parties use tit-for-tat then the equilibrium will be at a cooperative level which is higher than the competitive level (Besanko, 2013).

Cooperation in the development process for digital goods is not limited to organizations. The already mentioned production process of commons-based peer production can be crucial for the development of sustainable digital commons as well. Commons-based peer production could be delimitated according to four categories (Fuster Morell et al., 2014):

(1) Collaboration and production of value that did not exist before the production
(2) Peers relate in autonomous and decentralized structure to each other
(3) The outcome is driven by general interest and is therefore common based
(4) The outcomes are forkable, which means the common products can be reproduced and derivated

Most of the empirical commons-based peer production projects are based on FLOSS Communities, even if recently some research on Wikipedia has been conducted as well (Fuster Morell et al., 2014). Commons-based peer production had the starting point in 1999/2000. Usually the cases are digitally based. A sample taken in 2014, evaluated 73% are digitally based, where digitally supported commons-based peer production only counted for 27% (Fuster Morell et al., 2014). Most of the commons-based peer production is based on people writing something together (such as software code), followed by albums of multimedia archives and then followed by exchange platforms. Among 90% of the cases have different types of roles and according to the role a set of permissions. Commons-based peer production projects are characterized by a broad range of generated value and outcomes. The plurality of the outcomes is institutionalized by a plurality of licenses, standards and norms. Projects are partly built on own platforms, but often on external social networks or external provided interaction providers (e.g. chats, mailing lists and forums).

4.3.2 Technological Layer

Standards can reduce the transaction costs between the stakeholders if formats and interfaces are based on standards. Standards should be based on four essential principles which are (Huemer, 2013):

(1) Transparency and Openness: The development of standards should be open for all stakeholders. Drafts (Draft Standards) should be evaluated by public (Public Enquiry) bevor implementing the standard
(2) Coherence and Consistency: Standards should not contradict existing standards. Additionally the standards have to be coherent by themselves.
(3) Consensus: A work draft should be accepted by a high amount of relevant stakeholders before evaluating the modifications in the Public Enquiry.
(4) Publicity: New standards have to be published.

Open Standards are relevant to reduce dependency to infrastructure providers which is often the case. Fuster Morell (2010) conducted a quantitative analysis of fifty cases that observed dependencies of platform suppliers. Fuster Morell (2014) examined online creating communities (OCCs). OCCs are platforms where the aim of communities is knowledge creating and knowledge sharing. Typically in OCCs, contributors are participating on a voluntarily base, even if some contributors use the infrastructure for paid work outside the community. Fuster Morell (2014) questioned the neutrality of the infrastructure provider. The neutrality of an infrastructure is determined by the people who govern the platform. Importantly therefore is who governs the platform in which manner (how). Fuster Morell found eight criteria which are relevant for the governance of OCCs. These are (Fuster Morell, 2014):

(1) Collective mission of goal of the process
(2) Cultural principles and social norms. This could be openness, freedom to operate, meritocracy (valuing people on quantity and quality of their

contribution) and Do-acracy (who does something has authority about it).

(3) The design of the platform (the code) defines the degree of participation of the users. The (i) level of openness regarding the licenses, access to content and technological/requirements burdens to contribute. (ii) Modularity leads two more decentralization and empowers people to participate. (iii) Asynchronous and online participation possibilities. (iv)

(4) Self-management of contributions, even if most of the users do not contribute at all. Non-contributors have four positive external benefits: (1) Network effects (2) Digital threads show what is relevant (3) Free riders are an audience (4) Restrictions to outsiders are costly.

(5) How formal rules are harvested: (i) Community decides if there are rules/tasks (ii) Roles are determined by the infrastructure provider

(6) The license contributes to the common-pool resource and the software code

(7) Decision-Making and Conflict Resolution Systems

(8) Infrastructure Provision

(1) *Collective mission or goal of the process.*
(2) Cultural principles/Social norms.
(3) *Design of the platform of participation (where regulation is embedded in the code).*
(4) Self-management of contributions: autonomous condition of participants in allocating her or his contribution to the building process.
(5) *Formal rules or policies applied to community interaction.*
(6) *License.*
(7) *Decision-making and conflict resolution system with regard to community interaction.*
(8) *Infrastructure provision.*

Legend: In *italics* the dimensions that might be controlled by infrastructure provider.

Figure 12: Dependency on infrastructure provider (Fuster Morell, 2014)

Fuster Morell found out, that six out of eight criteria for governance of OCCs are determined by the platform provider. Figure 12 shows all the influenced dimensions by platform providers in italics. This leads to the need of business models, not depending on platforms (Fuster Morell, 2010; Wright and De Filippi, 2015).

Blockchain technology can shift the power from centralized organizations towards decentralized networks. The blockchain technology enables people to agree on a transaction without an authorization party through the existence of an encrypted database. It can be assumed that the blockchain technology will be as revolutionary as the Internet (Swan, 2015).

Based on the blockchain technology, decentralized organizations (DOs) can be built. It is even possible to create decentralized autonomous organizations (DAOs), which do no more need human intervention (Wright and De Filippi, 2015). Without blockchain technology it is not possible to secure that nobody has tampered data if not governed by a trustful authority. The important part of the blockchain is that after new data is added to the blockchain, the dataset can no more be deleted. It is not possible to delete as data is stored in every participating computer of the network.

Various applications of the blockchain are possible and not yet fully known the potential for new types of applications. An already programmed example are encrypted communication protocols that could replace centralized cloud storages. This could be done with renting space on a hard drive of another participant within the decentralized network. Other applications are e-voting and smart contracts. As long as these organizations are open-sourced organizations, everybody able to read source code, can proof the foundation of the autonomous organization.

It is important to mention, that the main advantage of decentralization has two sides of the coin. The decentralization could be a thriving business for illegal activities. Secondly, as DAOs are autonomous, it is hard to stop the execution of the programmed software. We recognize that Blockchain technology can be used manipulative, but for exactly this reason it is even more important to understand the technology.

4.3.3 Legal Layer

The legal layer for digital sustainability is important, as legal systems harmonize different interests, such as interests of the public sphere and the private (mainly economic growth), by simultaneously enabling individual autonomy and rights (Wright and De Filippi, 2015). National law becomes less important, as providers and communities decide their own rules. These are for example licensing agreements, terms of use, open source licenses or the creative commons (Wright and De Filippi, 2015).

There exist a huge variety of free and open source licenses (GNU, 2016). Fuster Morell et al. (2014) examined which license is in use for the special case of commons-based peer production. A survey of 60 commons-peer based production showed that CC-BY-Sa, GPL and BSD/MIT/Apache are equally used.

It is important to differentiate between ownership and property. Property means how others can be excluded from the source code or the common-pool resource. Ownership is dependent on who the infrastructure governs. If a firm has ownership over an infrastructure, but the property is open to fork and reuse, the criteria from commons-based peer production are fulfilled (Benkler, eds.).

The above mentioned (chapter 4.3.2) possible emergence of the blockchain would lead to a transformation in legal work. No more the execution of a contract had to be evaluated as the source code is binding. In contrary to centralized contracts, where contracts could be successfully breached, this is impossible with smart contracts. Therefore, law and source code would melt together (Wright and De Filippi, 2015). Technological norms and standards reflect existing value in communities.

Also copyrights would become less relevant, as with smart contracts creators of work could track reproduction, sharing and displaying at their own conditions. This could harm the principle of digital sustainability where knowledge should be a common good.

If blockchain technology is not going where governments wants technology to be, they have four opportunities to stop the evolvement of blockchain technology (Wright and De Filippi, 2015):

(1) Internet providers are obliged to block encrypted data
(2) Search engines are not allowed to index blockchain-based applications
(3) Prosecute software developers or blockchain users
(4) Modify hardware to prevent encryption techniques

If government is preventing the potential of the blockchain technology, the control will be similar to the surveillance within internet happens. But if laws are not directly embedded into code, nor ethical algorithms are programmed, drastic reactions of governments can occur.

4.3.4 Financial Layer

Independent how ethical the code is, or which technology is used, every project needs somehow a (financial) commitment. Where programmers are able to contribute code for a digital good, users are optimally willing to pay the development of digital goods. But due to the collective-action problem, it is often assumed, that users are not willing to contribute for goods in the public domain (Hardin, 1982).

Public good games are important experiments of behavioral economics to question the assumed market failure in the provision of public goods (goods that are non-rival and non-excludable). Rational theory assumes that in the case of public goods, people are not willing to contribute to the production of public goods due to free riders which are able to profit from public goods without contributing. Therefore, in the lenses of rational theory, only the state can provide public goods.

In contrary experiments from behavioral economics do emphasize under which conditions people are willing to contribute despite the “problem” of free riders. A typical experiment can be conducted as follows (Beck, 2014): Every participant receives 5$. The participant can take the 5$ or contribute it to a public good. All the contributions to the public good are multiplied by a multiplicator k bigger than 1 but smaller than the amount of all participants n.

At the end every participant receives (k*n)/n independent if he contributed to the public good or not. If every person contributes to the public good, everybody would be better off to the same amount. As soon as one person is not contributing, this person is better off even if everybody profits. As the free rider profits even more, the rational theory suggests not to contribute. In an extreme case it could be that one contributor does have less than the initial amount of 5$ (e.g. if n=4, k=2 and only 1 person contributes to the public good. The contributor ends with 2.5$ and the free riders with 7.5$). Therefore, a self-interested person should never contribute to the public good.

Social psychology theories explain, that some people will contribute part of their money to the public good due to altruism, group dynamics and social norms (Beck, 2014). Dawes and Thaler (1988) found that 40-60% contribute to the public good in experiments and Ledyard (1995) described in his book, that the amount of contributors decrease the more rounds are played. But if the game is restarted with the same players, contributions are again on a similar amount than in game 1 (Andreoni, 1987). Fehr and Gächter (1999) found out, that participants are contributing much more if participants could be punished for not-contributing. Contributors even invest money to punish non-contributors. Therefore, the conclusion of Ledyard (Ledyard, 1995) makes sense that public good games can be designed in a way that almost nobody contributes to the public good, but in contrary they can be also designed that almost everybody contributes. The latter makes it very interesting for the financial layer of digital sustainability. If public good games can be designed that almost everybody contributes, we “only” have to transfer such experiment “designs” to reality in the production of common digital artifacts.

Beck (2014) explains that besides the amount of rounds and the social psychological motivations other factors are relevant: The gender, if it is played among humans or in front of a computer, if the results are getting public etc. But not to forget, that also the personal value for the underlying good is essential whether people contribute or not.

4.4 Private-Collective Innovation Model

Where earlier in time the production was usually industrial, the production was very costly and only firms or government were able to finance production. But four attributes of the information network community are nowadays significantly different (Benkler, 2002).

(1) Information is purely nonrival
(2) Physical capital costs of information production have declined
(3) Input from humans are highly variable in motivation and background
(4) The communication and information exchange is much cheaper

Benkler (2002) therefore differentiated the optimal production of goods according to the opportunity costs between implementation costs of property rights and cost of property and the efficiency of market exchange, organizing and peering. He defined six different forms of organizational production, but the most important finding from Benkler for the theory of digital sustainability is the fact, that the implementation of property rights is in some cases more expensive than the opportunity costs. The private-collective innovation model (which will be explained below) confirmed this finding (Benkler, 2002; von Hippel and von Krogh, 2003).

Still it is assumed, that opening data, information and knowledge leads to harmful free-riding. About the occurrence of free-riding there is broad consensus. But if free-riding is harmful depends. Von Hippel and von Krogh (von Hippel and von Krogh, 2003) provided evidence from the field of open-source that free-riding not necessarily harms a company.

Von Hippel and von Krogh (2003) start with explaining the two common known models for innovation. One the one hand this is the private model of innovation. The private model of innovation is driven by the incentive of intellectual property rights of firms. In return to be innovative, firms can protect their property with copyrights and patents and therefore decide the licensing costs or the selling price of their products. This model is coupled to a societal loss in knowledge. The loss of knowledge occurs due to the constant amount of absolute knowledge of the society, while the innovative firm was able to enlarge its knowledge but did not make the knowledge available to society. Therefore, the society loses relatively to the total amount of knowledge existing.

$$\frac{\text{proprietary knowledge in } t_0}{\text{knowledge in the public domain in } t_0} < \frac{\text{proprietary knowledge in } t_1}{\text{knowledge in the public domain in } t_1}$$

On the other hand the Collective Action Model is explained, where innovation is provided as a public good. In such a constellation, society does not experience a loss in knowledge, not absolutely nor relatively. In contrary there is no direct incentive like in the private model of innovation to support the creation of a good, as goods in the collective action model do relate to the public and are therefore public goods, also called a common-pool resources. Therefore, the private-collective innovation model may lead to a collective action problem, because nobody wants to take responsibility for the creation and maintenance of the public good.

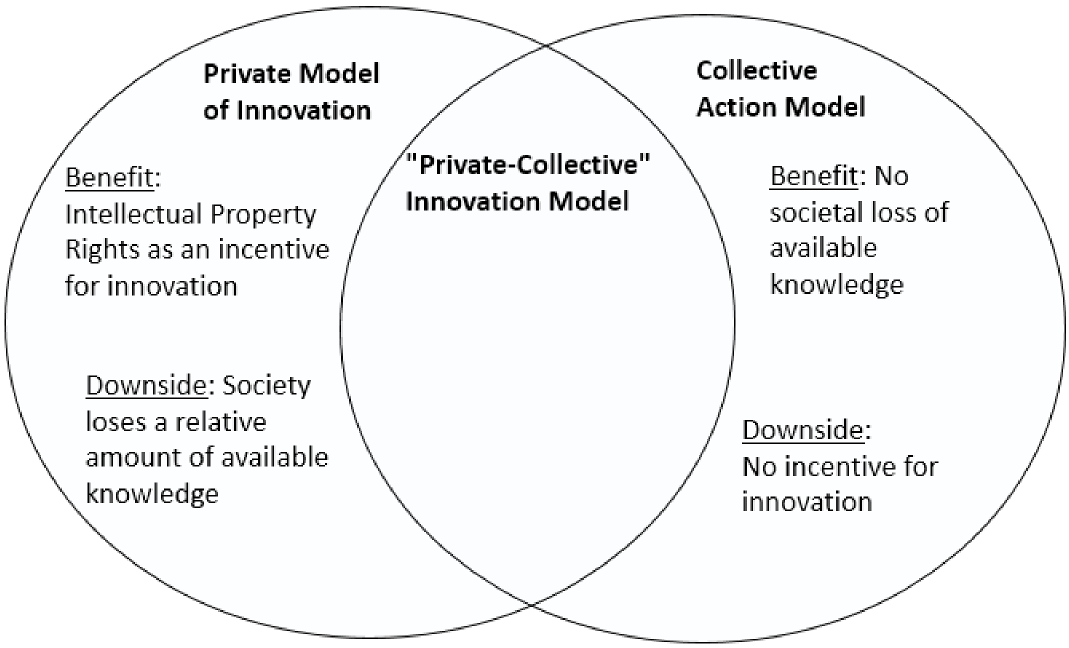

Figure 13: Benefits and downsides of private/collective action

Where the private model of innovation (Arrow, 1962; Dam, 1995) and the collective action model (Hardin, 1982) were already known, the introduction of the private-collective innovation model is new by von Hippel and von Krogh (2003). The private-collective innovation model assumes that there are incentives for firms and individuals to develop common-pool resources without being incentivized by property rights. In the "Private-Collective Innovation Model" innovators benefit from advantages different than property rights. According to Stuermer et al. (Stuermer et al., 2009) these are:

(1) Low knowledge protection costs
(2) Learning effects
(3) Reputation gain
(4) Adoption of innovation
(5) Increase Innovation of lower costs
(6) Lower manufacturing costs
(7) Faster time-to-market

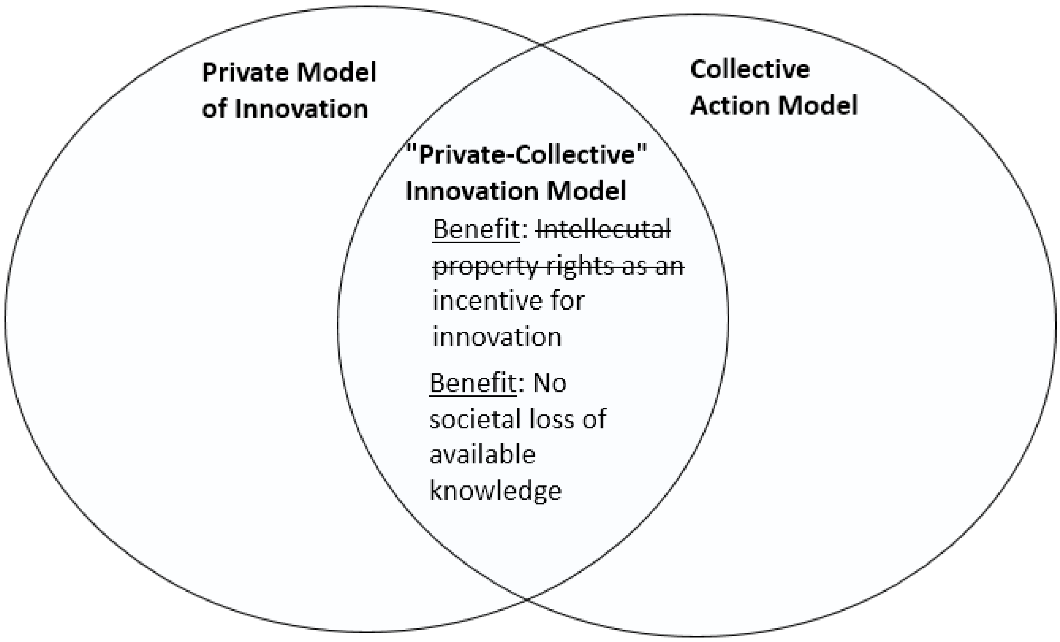

Figure 14: Intersection of private and collective action

Figure 14 illustrates the intersection of the private model of innovation and the collective action model. The favorable basic conditions (the floor) of digital goods should lead the production at the intersection of. Therefore, it is assumed that the floor aims for a production as it is discussed within the private-collective innovation model.

5 Conclusion

5.1 Findings and Implications

This master thesis examined the framework condition for digital artifacts to provide the greatest possible benefit to society. First of all the difference between natural and digital resources is essential. Two dimensions are critically therefore. On the hand it is the creation, maintenance and development of the resources and on the other hand it is the use of the resources. Where natural resources already exist by nature, digital goods have to be created. In contrary the use of natural resources has to be regulated to not consume non-renewable resources and to not over-consume renewable resources (Wackernagel and Rees, 1998; Porritt, 2007). The following table (see table 2) summarizes this finding:

	Natural Resources	Digital Resources
Creation Maintenance Development	Natural resources are provided by nature	Need for **digital sustainability**
Use	Need for **environmental sustainability**	No depletion through use

Table 2: Create and use-dimension of natural and digital resources (goods)

This splitting of the two dimensions leads to the conclusion that a sustainable development of natural resources (environmental sustainability) challenges the use-dimension, where a sustainable development of digital resources (digital sustainability) challenges the creation-dimension. A metaphor was built within this master thesis, where the limitation of the use for natural resources is called the “cap” and the need for favorable conditions is called the “floor”.

The favorable basic conditions are necessary for digital goods, as per default digital goods are often not accessible. They are not accessible due to the fact that potential users (1) do not know that the good exists, (2) do not find them (3) are not able to open the digital good because of proprietary formats without specifications (Stürmer, 2014) (4) due to technical obsolescence (Smith Rumsey, 2010) or (5) because of the protection with intellectual property rights (Lessig, 2001).

The fact that digital artifacts are not always accessible lead in some cases to inefficiencies, market failure and inequality. Such undesirable outcomes are (1) non-affordability of goods (Shantharam, 2005; Pearce, 2012), (2) coordination breakdowns as to many fragments of a new good are patented and therefore innovation is hindered (Heller, 1998; Heller and Eisenberg, 1998) and (3) lock-in effects of vendors (Shapiro and Varian, 1999), where vendors initially provide a digital good at a low rate (or for free) but then binding the user with proprietary formats (which leads to high switching costs), expansive fees on additional components and other barriers.

Apart from the negative aspects, of course intellectual property rights do also have positive aspects, as they incentivize people to innovate and to maintain resources (Hardin, 1968). But (Benkler, 2002) found out, that for some goods the implementation costs of intellectual property rights are higher than the opportunity costs. Especially information (which I used synonymous to knowledge and data) profit from low production and exchange costs. Von Hippel and von Krogh (2003) also examined one year later, that especially open source software profits from the non-existing of implementing costs for intellectual property rights and the low diffusion costs. Due to the low cost of protecting and diffusion, rapidly a net profit due to contributions and network effects results (Stuermer et al., 2009).

The findings from Benkler, von Hippel and von Krogh lead to the assumption that digital goods in general may overcome the collective action problem in case they follow certain favorable basic conditions (“the floor”). With a broad literature review of 120 sources, favorable basic conditions for digital sustainability could have been evaluated and clustered into four categories. The four categories build an organizational, a legal, a technological and a financial layer (table 3). Where open source and open data (in bolt letters) are at the core of the knowledge/digital commons, other favorable conditions benefit digital sustainability as well.

Domain	Legal Layer	Organizational Layer	Technological Layer	Financial Layer
Personal artifacts	Privacy		Software Quality Open Formats Open Standards Open Source Distributed knowledge *Blockchain*	
Digital goods	Copyleft (Open License **Open Source**) Open Access	Cooperation/ Coopetition Neutrality of infrastructure provider	Software Quality Open Formats Modularity Open Standards **Open Data** Distributed knowledge *Blockchain*	Affordability Business models on additional value, not on intellectual property rights

*Table 3: Favorable conditions for digital sustainability, **core conditions in bolt letters** and future possibilities in italics*

Table 3 differentiates between two domains (as already explained in chapter 2.2). On the one hand personal artifacts and on the other hand digital goods. Personal artifacts are personal data, which should be protected for personal integrity. Personal artifacts are exemplarily individual data about health conditions of a specific person. Such private personal data has to be protected, therefore the legal layer includes the term privacy. The main focus of digital sustainability lies on non-personal artifacts which are digital goods and is exemplarily government data or product description data.

The four layers build the guideline for developers and maintainer to create, maintain and develop digital goods. Before discussing the limitations, the definition of digital sustainability is recalled:

Digital Sustainability wants to generate, develop, sustain and ensure access to digital artifacts in a way that digital artifacts provide the highest possible benefit for society.

5.2 Limitations and Suggestions for Further Research

The thesis is based on a literature review and a conceptual model. Empirical evidence on the findings is therefore not provided. As sustainability is a concept in a long-term perspective, it will be hard to measure whether the findings are complete. A second limitation builds the fact that data, information, knowledge and source code are treated the same within the thesis. It is questionable if all the favorable basic conditions are relevant for all the four kind of digital artifacts. A third limitation lies in the fact that all the favorable basic conditions are weighted equal. The role of open source as a core element was discussed but it is unlikely that in every context, all the other favorable conditions are equally important. A fourth limitation is the fact that individual production, commons-based peer production and firm production face different requirements for the production of knowledge. Within the thesis, a differentiation between the different production models is not done. The last limitation considers the literature review. As this master thesis includes a systematic literature review over 120 sources, it is always questionable if all the relevant literature were found. Especially due to the fact that digital sustainability merges research from sustainability, open source, the knowledge commons and information ethics.

Further research should differentiate the level of analysis by an individual-, a peer- and an organizational-viewpoint. The differentiation of the level of analysis could be used to further investigate in the financial models as this is the vaguest layer within the favorable basic conditions in table 3. Secondly Case studies on sustainable communities should be conducted and examined, whether the assumed favorable basic conditions are complete or not. This could be done by qualitative interviews among several cases.

List of Figures

List of Tables

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