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Making the planet healthy again

An investigation of technology as a tool for creating value for nature
Master's Thesis in the Master's Programme
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Cover: A picture showing a man looking at the sun (Karün, 2019a).

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Abstract

The environmental problems of today are visualised by climate change and biodiversity losses among other. Current strategies to halt the rampaging effects of these environmental problems involves strategies to minimise negative impacts on nature. As the problems continue to be amplified, we cannot longer ignore the consequences that future generations will face, hence, we need to take action. What is missing is a conversation about how positive impacts on nature can be created, especially related to how this value can be created using technology.

Technology is usually described in terms of value-creation directed towards society, but could also be described as value-creation directed towards nature. The aim of this thesis is thus to investigate this value-creation in the natural domain, and how technologies that create value for nature can be separated from other types of technologies. The method consisted of extensive literature studies and thorough discussions about this novel way of describing and classifying technology.

The literature review confirmed our initial hypothesis; there is currently no literature that describes value-creation for nature by technology. Hence, there exists a need to develop a theoretical framework that classified technologies based on the direction of value-creation. This resulted in the development of the Triple R framework, including Regular, Restorative, and Regenerative technologies. Regular technologies create value that is directed towards society, restorative technologies create value that is directed towards nature, and regenerative technologies create value that is directed towards both society *and* nature. These categories can be qualitatively illustrated by existing technologies.

In conclusion, technology is not the ultimate answer to environmental problems, but an important part of it. However, the most important contribution of this thesis is a new way of discussing the possible positive impacts on nature created by society. It is not enough to minimise the environmental impacts, but we must move one step further and go "from less bad to really good" and develop more technologies that can have positive impacts on nature in the long run.

Keywords: Biodiversity loss, Climate change, Restorative, Technology, Triple R framework, Value for nature.

Contents

1 Introduction

Earth and its natural systems as we know them, are under threat (Steffen et al., 2015). Climate change and biodiversity loss are some of the most alarming issues, with human activities as the underlying cause for them both. The Intergovernmental Panel on Climate Change (IPCC) states that climate change caused by an elevated level of greenhouse gases, partly generated by the excessive use of fossil fuels, has lead to an increased global surface temperature (Bernstein et al., 2007). The temperature will likely continue to increase in the next decades according to current predictions. Other effects of climate change include extreme weather conditions, immense changes of ecosystems, and rising sea levels, threatening both humans and other species. The severity of threats related to climate change are also connected to food and water security, and human health. The Paris agreement was adopted in 2015 as a global response to these problems, aiming to limit the global warming to 2°C but preferably to 1.5°C (UNFCCC, 2015). In 2018, IPCC issued a special report on behalf of UNFCCC, stating that the climate risks will be lower if the global community succeeds in limiting the global warming to the lower temperature target of the Paris agreement (Masson-Delmotte et al., 2018)

Another environmental problem is the biodiversity loss caused partly by climate change but also by land use change and various external inputs of non-degradable substances (Reid et al., 2005). The increased rate of biodiversity loss is truly alarming. Reid et al. (2005, p.1) state that "Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history [...] This has resulted in a substantial and largely irreversible loss in the diversity of life on Earth". A staggering 60 % of all animals have been eradicated since the 1970s, putting ourselves in a position where we as humans are sleepwalking towards the edge of a cliff as described by Carrington (2018). Recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) claimed that 1 million species are today threatened by extinction (IPBES, 2019). Loss of species in an ecosystem will threaten the functioning of its ecosystem services, and thus, humans will suffer from these consequences as well; declines in food supply and lack of access to clean water and air for example. This can already be seen in parts of Asia where toxic smog prevents people from attending school (France-Presse, 2019), and we have already lost a third of all our arable land caused by pollution and erosion of soils due to conventional agriculture (Milman, 2015; Watts, 2017). The report by IPBES is thus not only a subject to saving species because of environmental ethics, but to human survival as well.

Regardless of how humanity feels about saving the polar bears in the Arctic or the orangutans in the rain forest, humans should care to have a habitable home. In order to sustain modern human societies, the natural systems that in total make up the features of the Earth should preferably not be pushed from the beneficial conditions in the pre-industrial state according to Steffen et al. (2015). Pushing these natural systems away from a pre-industrial state may cause disruptive and uncontrollable events, such as the ones we experience today like hurricanes and other extreme weather events (Center for Climate and Energy Solutions, 2019). Considering this, environmental issues such as climate change and biodiversity loss are alarming and ought to be addressed.

What humanity needs, is to obtain a balance between human development and maintaining natural systems in a certain state to achieve a sustainable society. Moreover, environmental issues are not a problem that is new to us. These issues have been of concern for thousands of years (Ponting, 2007), which humanity has attempted to cope with by different mitigation measures. One of the more contemporary approaches in today's technology-driven society has been to minimise the environmental harm by developing so called "green technologies" that are less polluting and demands less resources than conventional technologies (Investopedia, 2018; UN Environment, n.d.). Although such technologies are important, it seems as if they are not enough to combat the environmental issues we face today. Many scientists, among them Steffen et al. (2015) and Reed (2007), argue that natural systems need to be restored in order to truly safeguard humanity and the natural environment it depends on. The recent IPCC report (Masson-Delmotte et al., 2018) states that we will need to restore the climate system in the coming years by removing carbon dioxide from the atmosphere (i.e. achieving negative emissions), if we want to limit the global warming to 1.5°C and avoid an irreversible loss of ecosystems.

Another reason for why restoration of nature is required might be that humanity has a moral obligation towards other sentient beings but also towards future generations to restore natural systems. As humans are responsible for the harm done to nature, it can be argued that they should be bound to restore these damages (Torpman, 2017). Some even suggest that it might be eminent to assign legal rights to nature, and calls for a new perspective on nature and its interplay with society, meaning that humans have certain responsibilities towards nature itself (Thiel, 2019). While this position may sound irrational to some, something needs to be done if we want to achieve a sustainable society. Furthermore, it appears as if the prevailing approach to environmental problems, which focuses on technologies that "do less harm" to nature, is not enough. Instead, we may need to direct focus towards creating value for nature by restoring natural systems to a pre-industrial state. One approach to create this value might be through the use of technologies with certain characteristics.

Creating value for nature with technologies has received little attention, both within scientific fields of environmental studies and technology, as well as within society. In order to be able to discuss if and how technologies can create value for nature, descriptions of such technologies should exist. Furthermore, what separates technologies that create value for nature from technologies that do not, should be established. These distinctions seem to be missing today, and will hence be explored in this thesis.

The aim of this thesis is to investigate technology as a tool for creating value for nature by distinguishing such technologies from other technologies. This will be done by producing a conceptual framework that illustrates this distinction. The framework will be used to assess several existing technologies, partly to assess the applicability of the framework but also for attempting to classify existing technologies in a novel way.

The following research questions will be addressed in the thesis:

- Are there concepts in the literature that describe technologies that create value for nature? If so, how are these technologies described?
- How can technologies that create value for nature be distinguished from other types of technologies in a conceptual framework?
- Are there any existing technologies that can illustrate this type of conceptual framework?

The thesis will be structured as follows; First, we will introduce a theoretical foundation in Chapter 2, where we explain how technology is defined today, how systems thinking is used to understand and explain technology and its consequences, and how ecological and social value can be conceptualised. Second, we will describe our research design and data collection in Chapter 3. Following in Chapter 4, the results of our literature review will be presented and interpreted. After these results have been explained, we describe the features of our proposed framework in Chapter 5. We then continue to illustrate the application of our framework in Chapter 6, by presenting case studies of how a number of existing technologies can be classified within our framework. Finally, Chapter 7 provides a thorough discussion of our results, and future research opportunities, while we conclude the thesis in Chapter 8.

2 Theoretical foundation

In order to describe technologies that may or may not create value for nature, it is necessary to describe and explain how technology can be defined, how it functions and how it interacts with nature. It is also necessary do describe what is meant with creating "value for nature", and how nature can be defined for the purpose of this thesis. The definitions provided in Chapter 2.1 can be combined to complement each other, giving a more extensive description of the technology concept. It is important to know how technology is understood, in order to assess whether the current definitions can be applied in the framework or if they may need to be redefined for our purpose. To understand the multi-faceted impacts a technology may have, it is important to be familiar with systems thinking. The impacts can be both of positive or negative character, which affects different natural and societal systems. To describe these systems, the illustrative concepts Planetary boundaries by Steffen et al. (2015) and the Sustainability doughnut by Raworth (2012) are explained.

2.1 What is technology?

Coming up with several examples of different technologies is something most people would be able to do, as stated in the book *The nature of technology* by Arthur (2009). However, when asked about the definition of technology it becomes difficult, and is not something most people would be able to do. According to Schraube (2009, p.296), technology is commonly described as "a means to an end". The end is often defined as the value produced by the technology, which is created in the sociotechnical structures that the technology is a part of. This is related to the first definition presented by Arthur (2009), which describes technology as "a means to fulfill a human purpose" (Arthur, 2009, p.28). Thus, a technology is a method that is utilised to create some value for humanity. An air-plane is one example, where the value of being able to transport yourself large distances in a short amount of time is fulfilled. *The nature of technology* presents three definitions of technology, which can be combined as they describe different aspects. According to the second definition, technology is also an "assemblage of practices and components" (Arthur, 2009, p.28). By this definition it is understood that technology consists of several components, which in turn are individual technologies. The components may consist of sub-components, which also are technologies on their own, and so on. The third and last definition explains that technology is "the entire collection of devices and engineering practices available to a culture" (Arthur, 2009, p.28). By this definition, all "things" available to society are included. With these three definitions in mind, it becomes clear that technologies are not just machines or "technical things". Almost anything can be a technology. However, it seems like all definitions have one thing in common - the technology should primarily assist and create value for humans in some way.

To further enhance the understanding of technology, Arthur's ways of describing it can be enriched by the technology definition presented by Sandén and Hillman (2011). Technologies are a part of the sociotechnical system, and consist of heterogeneous elements, which in turn include physical objects, organisations, knowledge and regulation. These elements can be seen as an organisation of value chains in large bundles. Thus, Sandén and Hillman (2011, p.405) arrives at a definition of technology as a "bundle of value chains", which can be seen in Figure 1 below. In the figure, "Other upstream processes" and "Other downstream processes" can be understood as a combination of multiple different value chains. Furthermore, the "core process" should be understood as the process for which the output consists of the main product or the main service, for example a car. If applying Arthur's first definition, the ability to transport oneself in the car is the human purpose.

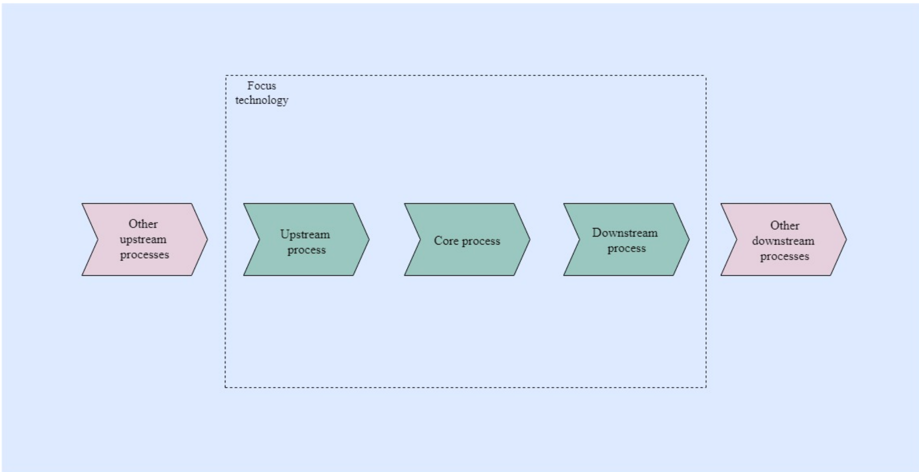

Figure 1: A representation of technology as a bundle of value chains.

A technology within the sociotechnical system is defined by its upstream supply chains, and downstream applications. However, as can be seen in Figure 1, the bundle of value chains has been limited to some processes. Sandén and Hillman (2011) states that a technology can be described as a limited bundle of value chains depending on the purpose of the study. Thus, it is reasonable to delimit an analysis of impacts created by the technology to certain processes of the value chain.

The technology's function or purpose might be provided by one of the core processes. Based on the definitions of technology that has been presented, our interpretation and overall understanding of technology is that it is something that primarily creates value in society.

2.2 Nature and society

Nature can be described as a collection of natural systems, including the biosphere, the atmosphere, the geosphere, the hydro-sphere and the energy system (Wu, 2006), that in turn are maintained through biophysical processes. Since it is difficult to consider how a technology affects nature in the sense that impacts occur in all parts of a natural system, the functioning of biophysical processes can act as an indication of the "health" of nature, or parts of nature. Thus, deterioration of these biophysical processes means that natural systems are impaired in some way, thereby harming nature. However, which of these biophysical processes could be used as indicators to describe a majority of the important natural systems? One model that has gained a lot of interest is the concept of Planetary Boundaries described by Steffen et al. (2015). This model may not be able to describe nature as a whole, but it is one of the best models available today, and makes use of nine important biophysical processes that describes parts of the natural systems. The planetary boundary model is described below in Chapter 2.4. Value for nature is thus described as something that has a positive impact on the biophysical processes in the planetary boundaries.

When it comes to society it is not an isolated entity in this world, but the physical construction is embedded within nature. Nevertheless, society and nature are separated in this thesis to simplify the reasoning about technology's impacts. Society can be described as a large group of people with individual beliefs and cultures, who live together in an organised way (Cambridge English Dictionary, n.d.*b*). It is almost impossible to define value for society, as what is valuable is a subjective opinion (it can be argued that this is true for natural values as well), hence we attempted to find a model that could describe societal value in general. One model that can be considered appropriate for this cause is the sustainability doughnut by Raworth (2012), as it describe certain basic human needs that should be fulfilled. This model will be explained further in Chapter 2.4.

2.3 Systems thinking and impacts

Considering a technology, each and every step of the value chain creates impacts of different character, which are related to one another. It is crucial to have a systems perspective when trying to understand connections between distant components of technological systems and also the interaction between the technology and other systems such as the natural systems. Systems thinking allows us to understand complex problems and describe patterns by integrating disciplines, to understand feed-backs, rebound effects, and other causal relationships (Haraldsson, 2004). It involves the concepts of systems analysis and systems dynamics as the practical application of systems thinking. System dynamics describe the feed-backs of a system, for example the rebound effects, and is used to understand dynamic responses in relation to changes that arise from either the outside or inside of the system. Systems analysis instead describes the organisational structures of systems and aims to explore the systemic causalities. Systems analysis is used to understand a problem by analysing the components and feedback relationships. Depending on the scale of these feed-backs, the technology can be seen either as deleterious or as beneficial, for example. One special case of systems thinking that evaluates impacts of technologies and products is the life cycle thinking.

A life cycle approach acknowledges the importance of evaluating products and services from a life cycle perspective. Life cycle thinking is a way to assess a product's or service's environmental performance by generating holistic information about it (Thabrew and Ries, 2009). With this approach, a decision can be made on whether or not an alternative product, technology or service is better or worse off than another alternative in terms of the environmental impacts produced. The environmental impacts from society is mainly caused by the consumption of resources, but also from emissions during the use and end-of-life phase, and from land use changes (Rebitzer et al., 2004). The life cycle is composed of all steps from cradle to grave, including raw material extractions, energy acquisition, materials production, manufacturing, use, recycling, ultimate disposal, etc., all of which needs to be evaluated. Having the understanding of what a technology is, based on previous sections, it can be understood that life cycle thinking is a way to evaluate impacts of a technology. A technology produces a wide range of impacts during its life cycle, which can influence both society and nature to different degrees.

Applying a systems thinking, it can be understood that a technology will always impact its surrounding to a certain degree. Arthur (2009) explains that it is impossible for a technology to create value without exploiting something. Figure 2 can be seen as one way of illustrating general characteristics of a technology in terms of the positive and negative impacts. In the thesis we will also use the term value-creation (or creating value) to describe positive impacts, and impact as a way to describe negative impacts, and they will be used interchangeably. Note that the division between society and nature in the figure is solely for analytic purposes, rather than an ontological distinction. This distinction is made as we want to analyse the impacts created in separate dimensions of society and nature later in our thesis (see Chapter 5 and 6). In the figure, it can be seen that every step of the value chain creates a positive impact (value) for society, illustrated by the yellow arrows. The value is created by capturing usually some natural phenomenon, thus implicating some negative impact on nature, illustrated by the red arrows. In addition, a technology can impact society negatively since it could exploit societal resources.

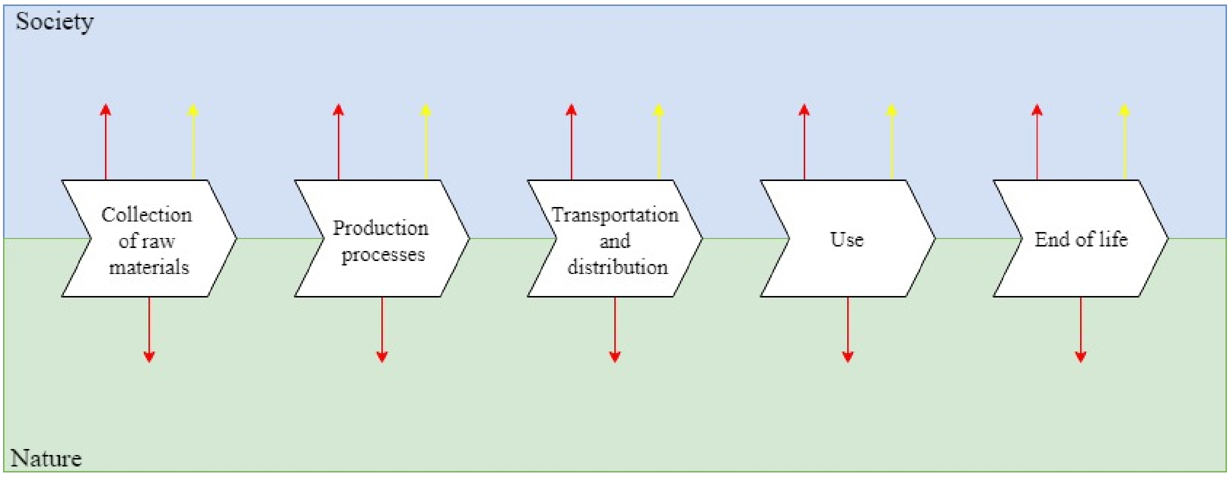

Figure 2: A representation of the interaction between society and nature by the means of a technology as defined by Arthur (2009). Red arrows depict negative impacts and yellow arrows positive impacts.

Furthermore, the figure represents technology as the interactive phase between society and nature, which partly can be described by Ahlborg et al. (2019). In the article, Ahlborg et al. (2019) highlights the interaction of technologies with their surroundings, as mediators of interplay between society and nature. These interactions can be described by socio-technical-ecological systems, connecting the research fields social-ecological systems and sociotechnical systems to better understand the complexity of technology impacts on both society and nature.

Moreover, to be able to understand and interpret the impacts and values created by a technology in Figure 2, is it necessary to apply systems thinking. Systems thinking enables us to theoretically separate technology from the surrounding domains including society and nature, and analyse the impacts in an isolated way.

2.4 Understanding impacts on nature and society

In order to understand how a technology affects its surroundings, the explanations of nature and society provided in Chapter 2.2 forms the basis for this thesis. Although there is a myriad of ways to describe both nature and society, these explanations was seen as suitable. Furthermore, to address where the effects of the positive and negative impacts occur, the definitions will be supplemented with two theoretical models as a way to categorise these systems. These two theoretical models are the planetary boundaries and the sustainability doughnut, and are described below. Even though we acknowledge that it is difficult to divide these complex natural and social systems into more fixed categories, the distinction is necessary for the continuation of this thesis.

The planetary boundaries framework is a model that identifies a number of biophysical processes that are vital for a stable functioning of the Earth (Steffen et al., 2015). The biophysical processes, referred to as "biophysical dimensions" hereafter, should be managed within a certain *safe zone* for maintaining the current geological epoch. According to the authors, maintaining the Holocene, which is usually referred to as the current geological epoch, is crucial for sustaining the modern human society and the natural systems as we know them with certainty. Steffen et al. (2015) states that human influence can increase the risk of pushing dimensions into a non-Holocene state, by transgression of "boundaries". The biophysical dimensions and their corresponding "risk-status" are shown in Figure 3. As explained earlier, instead of considering nature as a whole, we need to think of indicators for nature in order to address technologies that may or may not create value for nature. Thus, we argue that actions that seek to restore the biophysical dimensions included in the planetary boundaries concept can be interpreted as creating value for nature. Each dimension will be briefly described in the coming paragraphs.

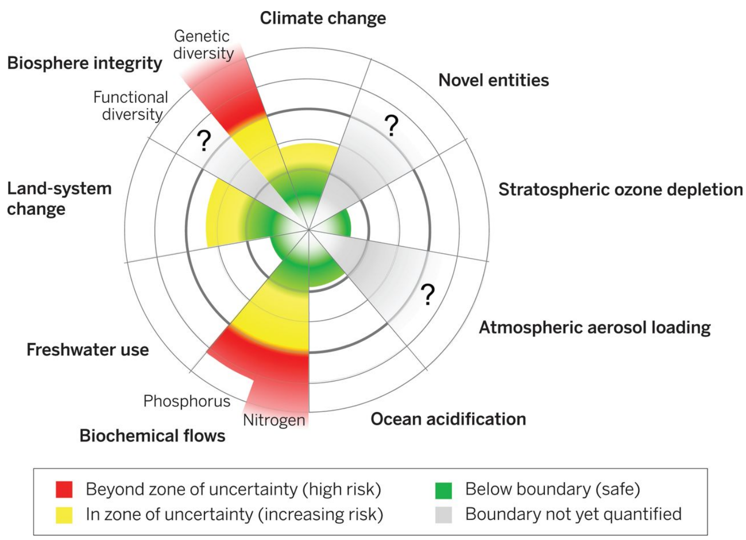

Figure 3: Biophysical dimensions in the planetary boundaries framework with their corresponding risk zones, on global level Steffen et al. (2015).

Climate change is caused by an increased concentration of greenhouse gases in the atmosphere, where the majority of the emissions are anthropogenic (NASA, 2019). The effects of climate change include an elevated global temperature, sea level rise and shrinking ice sheets to name a few.

Biosphere integrity or more commonly biodiversity, is defined as all varieties of life (Britannica, 2019*a*). Biosphere integrity consists of functional and genetic diversity, where the first form is the variety of roles performed by species in one particular community or ecosystem (D'agata et al., 2014). Genetic diversity is the amount of genetic material within a specie, thus the diverseness of DNA and chromosomes that differentiate one individual from another (United Nations, n.d.).

The introduction of novel entities to the environment is described by Steffen et al. (2015) as for example new substances and novel forms of already existing substances. Novel entities can furthermore be modified life forms that can give rise to unwanted effects, for example biological effects. Examples of novel entities include heavy metals mobilised by anthropogenic activities, chemicals, and other engineered organisms or materials.

Stratospheric ozone filters and thus protects the Earth from ultraviolet radiation of the sun (Rockström et al., 2009). The ozone hole, caused by anthropogenic emissions of specific substances, is an area in the stratosphere where the ozone has been heavily depleted (NASA, 2018). It is an example where the planetary boundary has been transgressed and also where humans have managed to reverse the negative trend (Rockström et al., 2009).

Atmospheric aerosol loading considers the increasing concentration of aerosols, caused by antrophogenic emissions (Rockström et al., 2009). Aerosols influence Earth's energy balance and thus the climate and also affect cloud reflectively (Rockström et al., 2009). This is due to the nature of the different types of aerosols, that either absorb or scatter sunlight in the atmosphere (Allen, 2017).

Ocean acidification addresses the increasing concentration of free protons (hydrogen ions) in the surface ocean (Steffen et al., 2015), resulting in a lowering of the pH. This is related to the increasing atmospheric concentration of carbon dioxide, and since the ocean is an important carbon sink which helps to regulate this concentration, it is severely affected. A reduced pH effects the marine life severely since many species are sensitive to pH changes (NOAA, 2019).

Biochemical flows consider both flows of phosphorous and nitrogen. Fertiliser use in agricultural practises around the world accounts for one of the largest phosphorus and nitrogen flows, which eventually accumulates in local watersheds and soils (Steffen et al., 2015). This causes problems with for example eutrophication (Lindahl et al., 2005).

Freshwater use in this context is the withdrawal of blue water, which includes water from for example rivers and lakes (Steffen et al., 2015). The major effects of society's manipulated freshwater use are seen in food and health security, biodiversity, and other ecological functioning (Rockström et al., 2009).

Land-system change is focused on the biophysical processes of the different telluric biomes, including grasslands, forests, savannas, tundras and others (Steffen et al., 2015). Land-system change is related to the processes that are directly linked to climate regulation, by monitoring the amount of remaining forest cover. When forests are removed, the climate will be affected directly by the release of carbon dioxide, but also in terms of changed evapotranspiration rates and altered albedo.

The sustainability doughnut is a sustainability concept that builds on the planetary boundaries by placing the social sustainability as the inner foundation, and the ecological limits of the planetary boundaries as a ceiling (Raworth, 2012). The social foundation is included to avoid deprivation of human needs, while the ecological ceiling is included to prevent degradation of the environment. Hence, protecting the environment while letting human development take place is possible, at least on a conceptual level. This symbiotic nature of humanity's and nature's development is the ultimate goal to be fulfilled. The social dimension are divided into Energy, Water, Food, Health, Education, Income and work, Peace and justice, Political voice, Social equity, Gender equality, Housing and Networks. Even though the sustainability doughnut includes a lot of important societal needs or goals, there are many that are not included. Hence, we argue that creating value for society should be understood as actions that seek to fulfil a human or societal need.

2.5 Summary of chapter

Based on the technology definitions presented in this chapter, it can be concluded that a technology can be described in different ways. In terms of value creation, we recognise the present technology definitions as something that create value for the society. Hence, we acknowledge that a new way of thinking is needed, in terms of to whom or what technologies should produce value for. We believe that a definition of technology as something that creates value for nature should be included as well.

We selected the planetary boundaries framework and the sustainability doughnut as models to clarify what we mean by "value for nature" and "value for society". Note that henceforth, value for nature implies a restoration of the biophysical processes included in the planetary boundaries concept. In terms of social values, the dimensions of the sustainability doughnut will not be used strictly as we acknowledge that there is a myriad of important social values that are not included in the doughnut. In addition, we came across a dilemma associated to the social dimensions in the sustainability doughnut. One of the dimensions includes work and income, which we believe is something that is created by all technologies. To be able to distinguish technologies that create value for nature from other technologies, we have to disregard social dimensions such as work and income. Hence, we argue that actions that seek to fulfil a human or societal need is seen as creating value for society.

It is important to understand that these models are not without flaws. In terms of the planetary boundary concept, it has been criticised, mainly in terms of the boundary values (de Vries et al., 2013; Montoya et al., 2018). However, since we will not perform a quantitative analysis later in the thesis, the boundary values are of less importance. Instead, we want the reader to bring an understanding of the dimensions used in the planetary boundary model, and the divisions of nature they describe.

3 Research design

In this chapter, we present the research design of this thesis. The chapter is divided into two sections, *Method* and *Data collection*. The first section describes and justifies the methods that have been used, and the other one explains how relevant literature, i.e. data, has been gathered.

3.1 Method

This thesis builds on a qualitative research design. The method selection is motivated by that qualitative research is explorative and is used when research aims to find answers to questions such as ”why”, ”how” and ”what” (Berk et al., 2015). Observing the thesis aim and research questions it can be seen that these are the types of questions we want to answer, hence it is an appropriate method to use. Another argument to justify a qualitative approach is that we had no other option, since it would be difficult to gather such quantitative data that can support our thesis aim.

To approach the initial purpose of the thesis we began by formulating an aim, framing the thesis. The aim was then rephrased a few times after the initial aim was developed (see Figure 4). Based on the aim, a literature review was conducted to examine whether or not our research questions could be answered using concepts that exist in the current literature. This was followed by a search for literature of fundamental concepts that could be used as a theoretical foundation. Based on the collected literature and discussions, we uncovered new principles and ideas of how the framework should be built up, and developed the framework based on the ideas. The second and empirical part of this thesis began with an analysis of several case studies that we believe could illustrate parts of the framework. However, as can be seen in Figure 4, we did not develop every individual part of the thesis in a linear way. Instead, an iterative working process was adopted, since we got new insights during the working process.

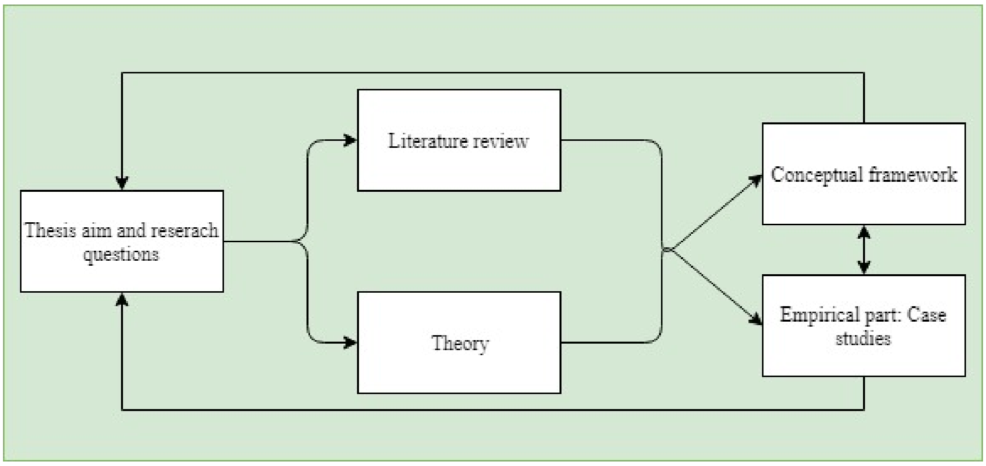

Figure 4: The thesis working process.

3.2 Data collection

We mainly used literature studies to support our answers regarding the aim and research questions. Literature was collected in the form of books and research articles using reliable data bases including Web of Science[1] and Scopus[2], accessed from the University library. Furthermore, grey literature such as newspaper articles, company websites and, organisation websites were also searched. Nearly all literature was collected using English keywords. The keywords can be found in the Appendix. However, when we came across something of relevance in Swedish, this information was included.

Relevant literature regarding technologies that create value for nature did not exist, according to out initial hypothesis. Thus, a literature review was conducted by using a structured approach of searching in the literature. Keywords were brainstormed, and those that were considered relevant were listed, which can be found in Table 2 in the Appendix. Some keywords were used as themes, in order to generate more keywords. As an example, ”Restoration” was one of the themes used. By using ”Restoration” as a theme, we could come up with ”Restoration technology”, ”Restoration economy” and ”Restoration ecology” for example. Furthermore, refining the results with additional keywords within a search was done in some cases, where it was considered appropriate. Articles were sorted by relevance and high citations to yield different results on the first page. Depending on the quantity of articles, one to six pages of the search results were screened. When finding interesting articles that contained one or more keywords, the abstract was screened in search of interesting concepts. Additional keywords were obtained from articles and books found when using the brainstormed keywords, which in turn were used to find new articles that

[1] http://apps.webofknowledge.com.proxy.lib.chalmers.se/WOS_GeneralSearch_input.do?product=WOS&search_mode=GeneralSearch&SID=E3i4z7lH4jtKXxe73yl&preferencesSaved=

[2] https://www-scopus-com.proxy.lib.chalmers.se/search/form.uri?display=basic

could be of interest. This strategy was used to screen as much literature as possible. A representation of the screening approach is illustrated in Figure 5.

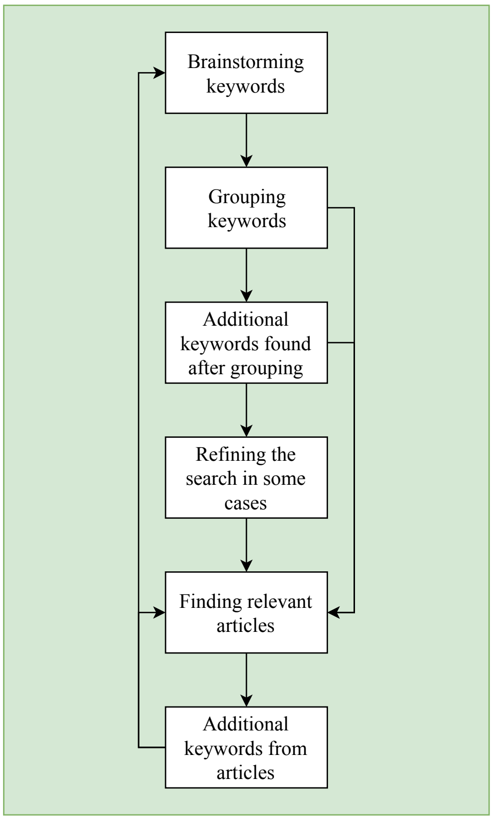

Figure 5: Screening approach for the literature review.

Workshops were held with our two supervisors where we discussed relevant ways to move forward with the conceptual framework and its implications. This approach was used in order to brainstorm what concepts could be related to the framework and also how the actual framework should be constructed. Insights that arose from the workshops lead to a lot of individual discussions that, in combination with supporting literature, were used as the basis for developing the framework. As explained earlier, developing the framework was an iterative process and hence different parts of it came together at different points in time.

We initiated the empirical part by conducting a broad search on potential technologies that could be used as case studies. In this case, Google[3] was extensively utilised since information regarding relevant technologies could be found on company websites and in newspapers. A search of the Swedish media archive on the database Retriever Business[4] was also performed, in order to find interesting technologies. All possible technologies that

[3]https://www.google.com/
[4]https://web-retriever-info-com.proxy.lib.chalmers.se/services/archive/

were considered relevant were listed, and the relevance was based on the technology's value-creation. A first selection between technologies was made based on the amount of available information. Then, a second selection was conducted based on within what environmental problem (should be understood as within what biophysical dimension) a particular technology created value. This selection was made to obtain technologies within a broad spectra of environmental problems. For every selected technology, general information regarding how it functions and if it exists on some scale today was collected. After that, more detailed information was gathered in order to assess in what way the technology could illustrate the conceptual framework. The screening approach regarding existing technologies is presented in Figure 6.

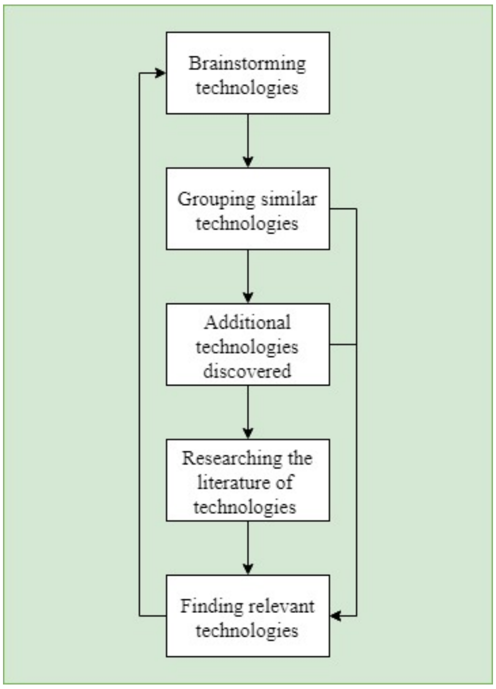

Figure 6: Screening approach for finding existing technologies.

4 Literature review results

The keywords used in the literature search were quite different from one another, however, most of them related to technology or environment in some way. We began with some distinct keywords in our searches, for example restorative technology, and then broadened it more as the process went along. We found four major themes of the articles, and collected similar results in clusters. We added a fifth cluster for the keywords that were not useful and did not generate interesting articles. See Table 1 below for examples of keywords and articles in each of the four clusters. To view all the keywords and their combinations, see Table 2 in the Appendix.

Table 1: The findings from the literature review performed by searching Scopus and Web of Science.

Cluster	Description/Theme	Examples of Keywords	Examples of Articles
1	Articles that describe technologies that are more efficient or includes biobased materials	Green technology Green economy Green growth Eco-innovation Bioeconomy Adaptation technology Sustainable/Sustainability Zero emissions	Faruk et al. (2012) Cao and Wang (2017) Klemmer et al. (1999) Cvjetko Bubalo et al. (2015) Scarlat et al. (2015) Medellín-Azuara et al. (2008) Matthews and Caldeira (2008) Alonso et al. (2012) Trærup and Stephan (2015)
2	Articles that describe value creation for nature, but do not create value for nature	Environmental benefit Environmental(ly) positive Carbon handprint Eco-profit Eco-benefit Value for nature Life cycle assessment Positive climate impact Value for nature	Ma and Hanna (1999) Hill et al. (2006) Demirbas (2009) Grönman et al. (2019) Čuček et al. (2012) Bockstael et al. (2000) Hawkins et al. (2013) Bakshi et al. (2015)
3	Articles that describes value creation for nature but not closely related to technology, and other useful concepts	Nature-based solutions Regenerative design Restorative Negative emissions	Keesstra et al. (2018) Reed (2007) Kabisch et al. (2016) Cohen-Shacham et al. (2016) Du Plessis and Brandon (2014) Cole (2012) van Vuuren et al. (2011) Lal (2004) Yang et al. (2019)
4	Articles related to keywords that were not useful	Decoupling De-growth Living system(s) Climate positive Reconciliation Resilience Post-carbon Regenerative	Schneider et al. (2010) Nicholson et al. (1999) Gardner et al. (2005) Dudgeon et al. (2006)

The clusters above describe recurrent themes that were discovered during our literature review. We grouped examples of articles related to the keywords (in Table 2 in the Appendix) that were searched on Scopus, sorting the results by "relevance" and "cited by (highest)". In the following paragraphs, we will describe and explain our results based on the literature review. However, not all keywords that were searched will be explicitly illustrated, but what we consider to be the more interesting findings will be discussed.

The first cluster describes articles that were mostly about typical technology "improvements", for example increased energy efficiency or replacing (old) materials with new bio-based materials. This is what many people today associate to as "environmentally friendly" technologies, "green" technologies, or "environmentally sound" technologies. Although having a lower environmental impact compared to the initial technology, they are in fact not friendly towards the environment, they are only less bad than their precursors.

One interesting result that we came across was when we were searching for "adaptation technology" and its different combinations. Several of these articles discussed how agricultural and water sectors could be adjusted to the consequences of climate change, in order to secure food and water supplies. However, all of these articles focused on how to ensure that humans did not suffer from environmental consequences such as drought, rather than focusing on how to sustain and improve the environment, see for example Trærup and Stephan (2015), Palanisami et al. (2015), and He (2017). Similar results were also discovered when searching for adaptation technology and environment and climate positive. However, some articles also discussed policy interventions in reference to climate adaptation, but not related to technology, and so these articles were not classified as relevant. Another interesting result related to adaptation technologies was provided in Smith et al. (2009). This article discusses nine strategies for how governments should act in response to climate change, involving political leadership for example, but also the "technology development and diffusion" (Smith et al., 2009). The suggestion is however to create more efficient technologies and management practises, implying a development of "less bad" technologies, instead of developing technologies that benefit the environment.

Articles that examined eco-innovations were as expected focused on green technologies and improving existing technologies to consume less resources and energy, or use alternative raw materials for example, but also how to change behaviours to be more environmentally conscious. Klemmer et al. (1999) explains eco-innovations as measures that relevant actors take by developing new ideas, behaviours, products and processes and apply or introduce them, to contribute to a reduction of environmental burdens or to specified sustainability targets. This is an interesting approach towards sustainable development, and of course necessary, but it is not what we are searching for to develop our framework as it is mainly focused on minimising the environmental harm.

Searching for sustainable futures and sustainability, we found many diverse examples of strategies on how to achieve a state of sustainability within different sectors or for larger societies. However, no articles described sustainability as something that could create value for nature. Instead, when searching for the combination ”sustainability” and ”value for nature”, articles mainly described the economic valuation of ecosystem services, for example Bateman et al. (2011).

Cluster 2 describes articles that often had an intriguing title or describing an idea of value creation for nature in the abstract, but that do not in fact describe concepts or technologies that create value for nature. This created another cluster of articles that for example wanted to market products for their environmental benefits by their ”carbon handprint”. Searching for ”positive climate impact” yielded only four results, where one article described this ”carbon handprint”, as ”An approach to assess the positive climate impacts of products” (Grönman et al., 2019, p.1059). However, when reading the article, it was about the comparison of a new and improved ”green technology” with the conventional baseline technology, using the example of renewable diesel compared to fossil diesel. According to Grönman et al. (2019, p.1059), this can be achieved by ”comparing the carbon footprint of an improved product with the carbon footprint of the baseline product, and subsequently calculating the reduction in greenhouse gas emission that can be achieved by utilising the improved product”. This is of course a nice approach for marketing purposes, claiming that something has positive climate impacts when it really only has a reduced impact compared to something else. We believe that this is yet another new and innovative way of ”green washing” products.

Čuček et al. (2012, p.87) describes the concept of eco-profit as ”the difference between burdening (eco-cost) and unburdening (eco-benefit) the environment, where eco-cost and eco-benefit calculations are based on LCA”. This concept describes the fact that a product or service can produce both impacts and values for the environment. We argue that this concept is similar to our thinking regarding ”doing good for nature”. However, it is an LCA-approach and not a technology approach. The eco-benefit phrase only generated 21 results, indicating similar results as the climate positive search. Technologies and practises that create value for nature are not well addressed in the scientific literature.

The search results for environmental benefits were a bit surprising actually. Many of the articles were about bioenergy in various forms, for example Ma and Hanna (1999), Demirbas (2009), Kim and Dale (2005), Heller et al. (2003) and Zah et al. (2007). There were also examples of alternative fuel cells and polymers. However, the common trait these articles shared was the fact that they discussed the environmental benefits of bio-alternatives compared to conventional alternatives, rather than actually discussing how to create beneficial conditions for the environment.

The keyword ”environmentally positive” was yet another disappointing search result. Only 34 articles were found on Scopus, and they were mostly about alternative agricultural practises. This was quite similar to the articles generated when searching for environmental benefits, describing the advantages with alternative agricultural practises compared to conventional ones. Searching for "environmental positive" gave 21 results, that mainly discussed biotechnology applications of various forms.

We also performed a search for "life cycle assessment" and "life cycle analysis" combined with "climate positive", "environmental positive", "positive environmental" and "environmental benefit" to whether there were any existence of earlier life cycle analyses that assessed a positive environmental impact of products or technologies. There was one interesting article written by Bjørn and Hauschild (2013) that suggests assessing the "positive footprint" by products. Continuing reading the article reveals that they suggest that a positive environmental impact can be created by designing "eco-effective" products, and also state that "Instead of exclusively focusing on how negative environmental impacts may be reduced, the positive attributes of a product should also be included (whether they are environmental, economic, or social)" (Bjørn and Hauschild, 2013, p.330). It is not entirely clear what the authors want to communicate with this statement however, more than the fact that this information can be used for marketing purposes. The other articles generated in the search assessed alternatives to current practises to examine whether or not the environmental impacts from the alternative were more or less severe. Thus, there was no indication of articles that assessed a positive contribution to nature by a product or technology.

The term "value for nature" generated only 47 results in total. Many of them describing monetary valuation of ecosystem functions or services. Some were also describing issues related to biodiversity. Furthermore, an article discussing the development of indicators for biodiversity threshold values in nature protection areas was also found. These are rather methods relating to LCA weighting and issues that are discussed on a political level, rather than describing how technologies can create value for ecological systems.

Cluster 3 describes some kind of concepts that are related to value creation in the biosphere and also other interesting concepts that could be used. We found our main inspiration to our framework when we searched for the term "regenerative design". Within the built environment field, Reed (2007) describes the concept of Regenerative design. In the article "Shifting from 'sustainability' to regeneration", he describes how buildings and other societal structures can be designed in order to restore natural values. Today, the focus of the construction business is doing "less harm" to nature, instead of creating a mutually beneficial relationships, which could be done if a regenerative design approach is applied. Furthermore, Reed (2007) argues that more of incremental technological improvements are not needed in society, what is needed is a transformation of the whole mental model of our mechanistic view of the world, to shift to an ecological view of the world. This calls for an understanding of the whole or living systems thinking, with the ultimate goal of maintaining life-enhancing conditions. A living systems approach includes three levels of increasingly more wholes in the construction business; the restorative design, the reconciliation design, and the regenerative design. Reed (2007, p.677) describes restorative design as ..."design in terms of using the activities of design and building to restore the capability of local natural systems to a healthy state of self-organization".

Reed (2007) further uses the notion of regenerative design as a way to focus the design process on the development of the whole system that it interrupts with. Thus, Reed (2007, p.677) describes regenerative design as "the design process [that] builds the capability of people and the 'more than human' participants to engage in continuous and healthy relationship through co-evolution". This means that the ambition of the design process is not doing things *to* nature, but to participate as partners *with* and *as* nature.

Articles on nature-based solutions address for example the promotion of green and blue areas in cities as a climate change mitigation measure (Faivre et al., 2017; Kabisch et al., 2016). Other articles described how management of nature-based solutions can be used to improve ecosystem services (Keesstra et al., 2018). This concept seemed to be potentially relevant to our search for technologies that could create value for nature. Essentially, nature-based solutions are about green solutions in urban areas, and are defined as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016, p.xii).

The search for negative emissions and negative emission technology yielded what we expected. The articles were about the need to achieve negative emissions in order to halt climate change, and also describing technologies that theoretically could produce negative emissions, such as bioenergy with carbon capture and storage (BECCS) and direct air capture and carbon storage (DACCS). This was not relevant for the development of the framework, as the articles did not talk about technologies in terms of providing value for nature. However, some of the articles could be used for the empirical part of the thesis.

The restoration keyword and its combinations provided us with many examples of why it is necessary to restore natural ecosystems and its functions. There were also interesting suggestions to restore nature to combat climate change (related to nature-based solutions), for example grassland biodiversity restoration as a soil carbon sequestration method (Lal, 2004; Yang et al., 2019). However, the articles were more focused on the biological functioning of systems and how they could be restored after a period of degradation, and not mentioning how technologies could create different values for nature. One quite alarming (in our own, personal view) article regarding how graphite-based photocatalysts could be used for artificial photosynthesis (Ong et al., 2016). Applications of the material are many, including the imitation of natural photosynthesis. They do state that this can be an alternative to harvest solar energy and use as clean energy, but the article is mainly focusing on the technology itself and does not mention potential ethical drawbacks. The development of artificial photosynthesis might create incitements of not restoring ecosystems and instead relying on technological fixes for the biological degradation we have caused. This is the opposite of what we want to use technology for. Instead of using technology to restore ecological values, they consider using technology to replace natural processes instead.

It was also very surprising to find it when searching for restoration of ecosystems, where all other articles focused on the values of restoring coastal and terrestrial ecosystems for example.

Besides from one hit on carbon sequestration in drylands, the term ”restorative technology” generated only 15 results, where the other 14 was about bio-medicine and dental technologies. Expanding the search to filter on restorative combined with technology and ecology yielded many articles that were about soil carbon sequestration as well. However, we could still not find any examples of discussing these climate mitigation technologies as creating value for nature.

The fourth cluster consists of the keywords that did not generate articles that were relevant and were of no use to develop the framework. This included searches for ”climate positive” and ”post-carbon” for example. When searching for the phrase ”climate positive”, only 36 results were found in Scopus. Most of them referred to creating a positive climate in social situations rather than achieving a positive climate impact.

Many of the articles found for ”regenerative” and regenerative technology were about medical research such as tissue engineering, 3D bioprinting, wound repair. This is probably due to the meaning of regenerative is twofold (see Section 5.1.3), and can also mean to heal or grow again after being exposed to damage. There were no descriptions of regenerative technologies as something that could create value for nature, not even when adding the term ecosystem or ecology to the search.

Searching for ”technology” alone resulted in more than 3 million articles on Scopus. Combining it with ”value for nature”, gave 17 results. Out of these 17 articles, there was still none that described how value could be created *for* nature, but rather discussing the value *of* nature (in monetary value).

There are of course a lot more keywords and combinations that could be included in the search and hence possible more results to consider in this chapter. Nevertheless, we did not find any concepts that described technologies that create value for nature. The only theme describing value for nature in its essence was ecological restoration. Still, there was one interesting concept in the literature that we found intriguing - regenerative design, describing how society could create a mutually beneficial relationship between itself and nature. Due to the gap in scientific literature we chose to include a concept from the grey literature that focuses on an interesting aspects of creating ”planet benefit”. This concepts will be further outlined in coming paragraphs.

The company U&We, is a Swedish consultancy bureau, that focuses their work around sustainability and the environment. U&We coined the expression of *”Planet benefit”* (in Swedish phrased as ”Planetnytta”), which means that they have a vision of doing good instead of less bad (U&We, 2017). The company focuses on creating positive impacts through the analysis of the whole value chain of their customers, using tools and concepts such as circular economics, biomimicry, fossil-free production and cradle to cradle. U&We makes use of the sustainability doughnut as their guiding principle to create benefits for the whole planet, and to keep their operations within the limits of the doughnut. This can be achieved through a various of means and approaches, for example by planting trees, or to produce more renewable energy than it consumes. This way, U&We hope to have a positive impact on the planet.

The gap in scientific literature related to technologies that create value for nature is troubling, even though there are some concepts that are related to the scope of this thesis. Examples include ”eco-profit”, ecological restoration and of course regenerative design and planet benefit. However, based on this review it appears as if using technology as a tool for creating value for nature is not described. Thus, this description is needed and will be presented in the next chapter.

5 The Triple R framework

As we have seen, if we want to sustain modern societies with certainty, natural systems such as the climate system should preferably be restored. Regardless of ethical belief, the health of nature cannot be disregarded since human societies depend on those systems. What technology can accomplish as a tool in regards to this subject is the starting point for this framework. In order to discuss if and how technologies can aid in the restoration process, descriptions of such technologies should exist. As presented in Chapter 4, conceptual distinctions that differentiate technologies that create value for nature from other technologies could not be found in the scientific literature nor the grey literature and hence, we develop a framework that involves such distinctions.

The framework draws upon several theories. The planetary boundaries framework, described in Chapter 2 presents biophysical dimensions (processes) that in this context illustrate nature. The sustainability doughnut provides additional social dimensions, which are of significance in order to safeguard societal interests. However, the social dimensions within the sustainability doughnut may be too general and we will not rely on the strictly to describe society, but it will serve as a staring point for describing value for society. These models are the most appropriate to use since we could not find any other models that can describe nature and society on this general level.

As this thesis focuses on technology as a tool for creating value for nature, it is of significance how the technology concept is defined. We acknowledge that there are several definitions, however in relation to this framework we will mainly utilise the value chain approach by Sandén and Hillman (2011). We base this on the fact that a value chain approach should be used, in order to obtain a more complete picture of the value and the negative impacts created by a technology. The definitions by Arthur (2009) provides an easy understanding of that technology can be almost anything. This aspect of technology will also be considered in the framework.

The basic idea with our framework is that there is a point with differentiating technologies depending on where they create value. This aspect implies that an understanding of which values (positive impacts) and negative impacts are included must be in place. The staring point is that direct values and direct impacts that the technology actually creates should be addressed. However, we realise that a technology also creates indirect values (and impacts) as a result of direct values. The line between direct and indirect might be subtle. Furthermore, by stating that technologies can create value in different domains, we implicitly say that these domains are separated from one-another. We want to once again emphasise that dividing society and nature into two domains is necessary from an analytic point of view but this does not mean that the world is constituted in this way. Based on the aspects brought up in this section, several technology categories can be motivated and will be presented below.

5.1 Three overarching technology categories

This section will focus on the value-creation of a technology. Given that the direct value created by a technology can be oriented towards society, nature or both, three overarching categories can be identified. Regular technologies are oriented towards creating value for society, restorative technologies towards creating value for nature and regenerative are oriented towards creating value for both domains. Note that regular technologies fit all definitions brought up in Chapter 2. However stating that a technology can create value for nature conflicts with some of the definitions by (Arthur, 2009). Thus, we acknowledge that existing definitions can be further developed. Thus, we refine one of the definitions by Arthur (2009) by stating that a technology can be defined as *A means to fulfil a value that may arise in both social and natural domains*. The three categories are conceptually illustrated in Figure 7.

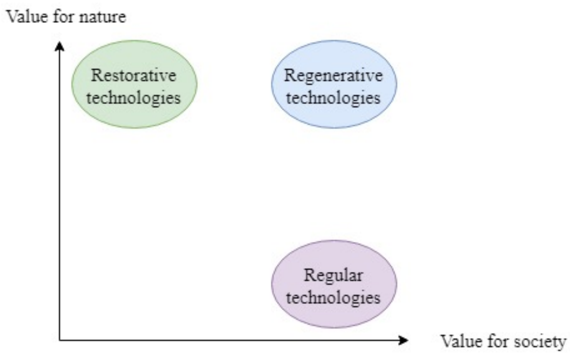

Figure 7: The technology categories within the Triple R framework create value within different domains.

5.1.1 Regular technologies

As mentioned above, regular technologies are oriented towards creating value for the society. According to Cambridge English Dictionary (n.d.*a*), the word *regular* can refer to *often*, *even* or *usual*. In this context, usual is appropriate to use since technologies are *usually* understood as tools that fulfil a human purpose.

According to the thesis authors, three categories within regular technologies can be identified; *Conventional technologies*, *Green technologies* and *Circular technologies*, even though there are other ways of categorising regular technologies. This technology category is included since we acknowledge that it or parts of it is and will be needed in society. Furthermore, it serves as a basis for comparison in relation to the other categories since the framework should illustrate the distinction between technologies that create value for nature from those that do not do this. On a general level, regular technologies do not direct its value-creation towards nature.

Conventional technologies can be seen as a part of the "business as usual" thinking, where economic sustainability is superior to ecological sustainability (D'Amato et al., 2017). Thereby, there is no explicit ambition to consider aspects that would minimise the damage on nature. Hence, conventional technologies orient its value-creation to society at the expense of nature. Think of this category as a starting point or baseline in terms of regular technologies. Throughout the value chain the technology creates societal values and the burden is directed towards nature.

Green technologies can essentially be described as technologies that do "less harm" to nature, compared to conventional technologies (Green technology, n.d.). The term green technology (or greentech) is often related to clean technology and sustainability technology and can be defined in multiple ways (Hoff, 2012). On a general level they can be linked to more efficient practices in terms of resources and energy and thus reduce the environmental burden. However, there is still no consensus on what green technology actually is, according to (Behl and Pal, 2019). Moreover, it is often implied that the output from these green technologies are not doing any harm to nature. They are also related to the "Environmentally Sound Technologies" in some contexts. These technologies are described by the UN Environment as "technologies that have the potential for significantly improved environmental performance relative to other technologies" (UN Environment, n.d.). Furthermore, the UN Environment also states that "[Environmentally Sound Technologies] protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes" (UN Environment, n.d.).

Circular technologies can be seen as a part of the circular economy concept, meaning that materials are circulated in a closed loop within an industrial system (Geissdoerfer et al., 2017). Circular technologies should not be dependent on the extraction of natural resources, but utilise the resources that already exist within society. The concept of creating a circular economy aims to achieve a decoupling effect between the economic growth and the environmental impacts that it causes, thus achieving a balance between society and nature, by means of technological and societal approaches such as reuse and recycling programs (Ghisellini et al., 2016). The main principle of circular economy is that society and its resources are located in a closed system without exchange of matter with the surrounding environment, and hence has no or minimal effect on it.

A circular economy is possible to some extent according to certain scientists (Lacy and Rutqvist, 2015). We do however acknowledge that circular technologies might only be a theoretical description of a sociotechnical system that reuses material and energy in other processes of the system and thus has only a marginal impact on nature. Furthermore, the processes themselves cannot be without environmental impacts, as they all require energy to function, and this energy has an impact on nature that cannot be removed. Hence, it might be difficult to achieve a decoupling effect utilising this concept.

5.1.2 Restorative technologies

According to the Cambridge Advanced Learner's Dictionary and Thesaurus, the word *restoration* means "the act or process of returning something to its earlier good condition or position" (McIntosh, 2013). The word "restoration" is appropriate to use for an action that restores something to a state, that is considered healthy or of good quality.

Restorative technologies direct their value-creation towards nature, within one or more of the biophysical dimensions of the planetary boundaries framework. They may also produce value for society, but these values are of indirect character. For example, ecosystems services provided to society by ecosystems that are restored as a result of deploying a restorative technology should be seen as indirect values. Furthermore, a restorative technology should preferably create a positive impact that is larger than the negative impact within the particular biophysical dimension, otherwise the intention with the technology is lost. If the value is larger than the impact, the technology should have the theoretical possibility to restore degraded biophysical dimensions described by the planetary boundaries framework (see Fig 3). Physical resources and energy needed for restorative technologies could preferably be extracted from society to some extent, but may also come from nature (during the construction or running of the technology for example). Regardless of the origin of resources, the negative impacts that arise as a result of utilising resources should preferably not overshadow the value that the technology intends to create. For example, a restorative technology that creates value in the climate change dimension should create more value in that particular dimension in comparison to how it negatively impacts it.

5.1.3 Regenerative technologies

Regeneration or regenerative, both originates from the word *regenerate* that can refer to either the verb *improve* or the verb *grow. Regenerate* is in this case related to the definition referring to *improve* by the Cambridge English Dictionary, and means "to improve a place or system so that it is active or producing good results again" (Cambridge English Dictionary, 2019). In this context, the meaning of regenerated as *improve* is how the word should be understood.

A regenerative technology should, as inspired by Reed (2007), partner with nature in order to orient its value-creation towards both nature and society. Thus, regenerative technologies have restorative properties, but in addition create a positive contribution to society as well. In terms of values created for nature, they can be produced in one or more biophysical dimensions. Societal values could be created within the dimensions of the sustainability doughnut, but the values can also be of different character compared to the doughnut. Furthermore, social values that are considered for regenerative technologies are related to the use phase of the technology since values such as job opportunities are disregarded.

5.2 Applying the framework

With the explanations of the three overarching technology categories in place, the question is how the framework can be applied. Thus, how should a certain technology be assessed in order to state if it is regenerative, restorative or regenerative?

As mentioned in the beginning of this chapter, a value chain approach to technology should be used in order to be able to argue about a technology's overall impact. A technology can create values throughout the value chain. These values can be created within different domains, either nature or society or both. More specifically, the values may be created within one or multiple of the biophysical dimensions, or one of more of the social dimensions. However, negative impacts are also produced by a technology. They can, as values, be directed towards both domains.

Based on the reasoning about positive and negative impacts, a technology can create positive impacts in some biophysical dimensions, and impact other biophysical dimensions negatively. But the key aspect is that creating value for nature implies that more positive than negative values should preferably be created within the biophysical dimension or dimensions in focus. By assessing positive and negative impacts throughout the value chain, it is possible to distinguish one technology category from another one. On a conceptual level, all categories presented in this chapter can be differentiated from each other related to their value chain characteristics. However, this depends on how much of the value chain that is included in the study.

The value chain characteristics of every technology category is illustrated in Figure 8. Note that the negative impacts have dotted lines. The intention with using different arrow designs is to minimise the focus on the magnitude of the arrows. The main focus should be on which domain the technology creates values. However, regarding restorative technologies and regenerative technologies, red arrows are smaller than the yellow arrows in order to indicate that these technologies should create a positive value within the biophysical dimension it intends to create value. Furthermore, potential negative impacts on society have been disregarded in the figure to make it more clean plus this type of impact is not the main focus.

Furthermore, it might be tempting to state that a technology that creates value for nature should create a net value, meaning that it should overall create a positive impact considering all biophysical dimensions. However, stating that a technology should have a net positive impact entails that some kind of weighting must be conducted. If and how this weighting can be conducted in an objective way is difficult to know. Therefore, we summarise these arguments by stating regardless of where (nature or society) the values are created, a net positive impacts is of course the aspiration, however it might be impossible.

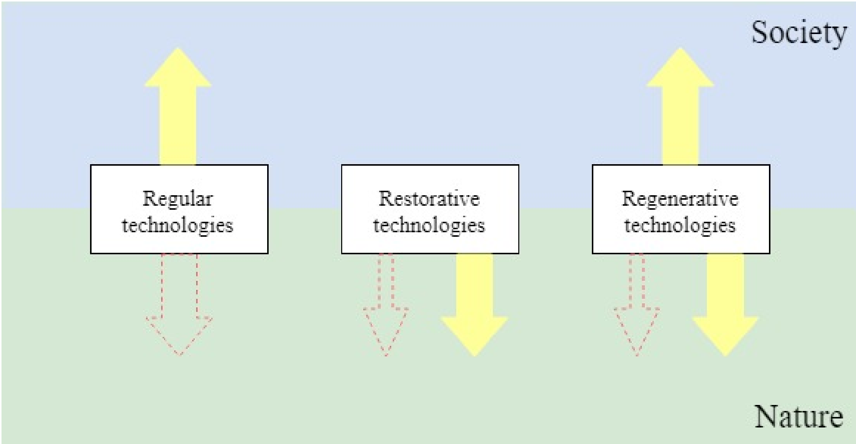

Figure 8: The figure illustrates the value chain features regarding the three technology categories. Boxes should be understood as a value chain (the technology), red arrows as negative impacts and yellow arrows as positive impacts. Negative impacts on society are disregarded in this figure.

5.3 Inherent complexities and trade-offs

The potential positive net value will be further argued about to illustrate the complexity. If applying a net positive value, it can seem as if apples and oranges must be compared. However, can apples and oranges be compared? How large should the value which the technology creates along the value chain be in order for it to be net positive? We argue that this comes down to the subjective area of ethics. Thus, it is impossible to quantify both the positive and negative impacts created by a technology and compare them. Because, how could marine biodiversity be compared to resource depletion? One approach could be that a fundamental respect for the systems that support all living species, it may become clear which values are of such importance that the technologies that create these values must have a net positive value, at least on a conceptual level. However, this depends on which perspective is applied. Hence, we acknowledge this as a complexity that does not have an obvious solution and a net positive value should therefore be seen as a theoretical aspiration.

Continuing, there is a need to consider scale aspects of a technology. A technology that is utilised in a small scale may have certain properties that makes it regular, restorative or regenerative. When the technology is scaled up, the created value will increase. However, the negative impacts will also be scaled up accordingly. Thus, the classification of a technology depends on the scale. It might be the case that a fully deployed technology can never be regarded as restorative or regenerative.

Furthermore, since a technology always exploits something to create value, trade-offs are impossible to disregard. Trade-offs can be discovered at different tempo-spatial levels, between different biophysical dimensions and between biophysical and social dimensions.

Even though it is self-evident, it should be impossible for any of the technologies to produce value in all biophysical or social dimensions. We acknowledge that inherent complexities and trade-offs exist and are difficult to deal with. They will be further discussed in Chapter 7. Due to mentioned complexities, the Triple R framework should primarily be regarded as a new way to describe technologies which includes the new definition of technology. Furthermore, it can be used to illustrate the differences between technologies by dividing them in three different "levels".

6 Illustrative Case studies

In this chapter, we will illustrate our framework by reviewing existing technologies that may be placed within the three categories. It should be emphasised that it is beyond the scope of the thesis to perform quantitative life cycle assessments and that we do not claim to prove the characteristics of our case studies. Our intention is rather to reason about positive and negative impacts on society and nature, and make a high-level assessment of the overarching characteristics in relation to the Triple R framework. Furthermore, our ambition with the case studies is to present a wide spectra of technologies that show similar properties in relation to the technology categories. Thus, this evaluation contains some technologies that may seem simple, and others that appear more complex.

Furthermore, figures illustrating the technology as a value chain will be used in this chapter. Note that the magnitude of the arrows indicating positive (yellow) or negative (red), should be disregarded, since we simply do not know the magnitude of different impacts regarding the case studies. They are solely used to depict in which dimension the impact is created. To soften the impression of the figures, regarding this aspect, the red arrows have dotted lines. Moreover, the descriptions under the arrows are examples of impacts.

6.1 Regular technologies

In this section we will present two technologies that can be considered to be regular. The technologies refer to the value chains that includes the extraction/production and use of the products crude oil and solar cells respectively, and represent two different categories within regular technologies.

6.1.1 Crude oil

One type of fossil resource is crude oil (liquid petroleum) which can be refined and used in multiple application areas (Britannica, 1998a). Fossil resources consist of residual biological material that has been subject to geological processes for millions of years and can be found in porous rock formations in Earth's crust (Britannica, 1998a; Kopp, 1998). There are more types of fossil resources, such as coal and natural gas that create significant values for society, however crude oil and its refined products will be considered in the paragraphs below.

The technology refers to the practice of extracting the crude oil from the ground by fracking (Britannica, 2011), refinement by cracking and use of the refinement products, for example gasoline (Britannica, 1998b). This technology gives rise to multiple social benefits. Firstly, products such as gasoline and diesel can be used as transportation fuels. Secondly, other products of crude oil cracking can be used for heating houses or be utilised within the chemical industry to produce for example plastics.

A simplified value chain of the technology is presented in Figure 9. It includes extraction, refining and use of the refining products. As can be seen, the technology produces direct values for society. However, it does this on the expense of, to a large extent, nature. One major environmental impact originating mainly from combustion of the products such as gasoline but also via energy use throughout the whole value chain is climate change via emissions of greenhouse gases. More negative impacts include deforestation, ecosystem destruction and chemical contamination to name a few (O'Rourke and Connolly, 2003) which can in turn be divided into the biophysical dimensions such as land-system change and biosphere integrity. In addition, indigenous people may be displaced due to discovering of new oil deposits.

In summary we argue that extraction and use of crude oil is a regular technology since it primarily directs its value-creation towards society, in multiple aspects. More specifically, crude oil technology can be seen as a conventional technology, which can be used as a basis for comparison in relation to the next technology.

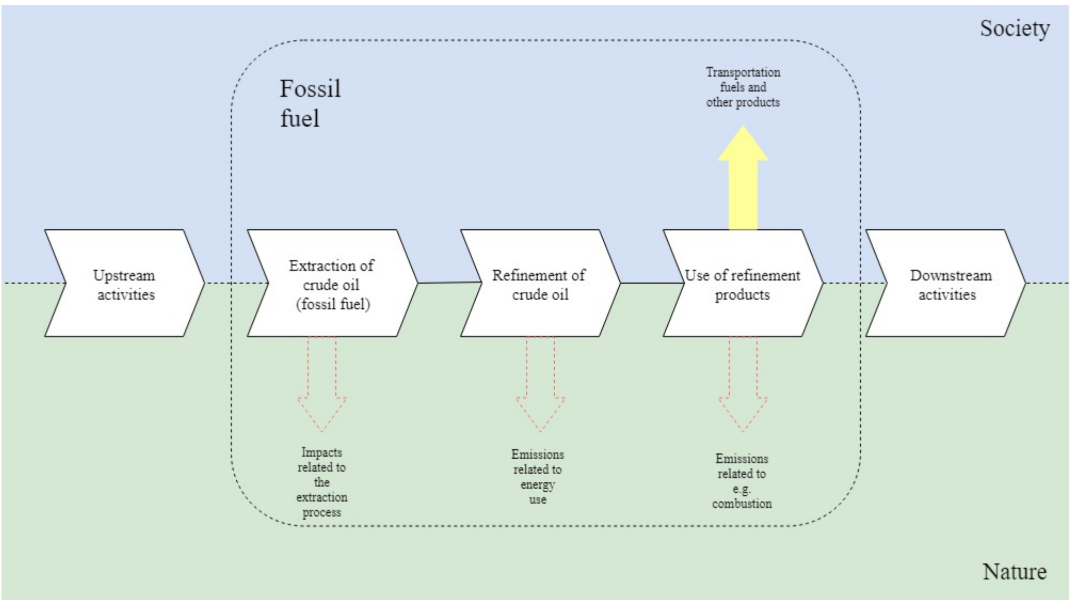

Figure 9: Fossil fuel illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.1.2 Solar cells

A solar cell is a device that converts light energy into electric energy using photovoltaic energy conversion (Soga, 2006*a*). The energy converted from sun light to electricity can be used to supply power to industries. Furthermore, solar cells can supply power to electric devices such as electrical vehicles, radiators in houses and light bulbs. Solar cells can be produced using many different materials and can be built with different structures, for example thin films, dye-sensitises and organic- and carbon-based solar cells (Soga, 2006*b*).

The technology refers to the construction, installation and use of solar cells. This technology creates one major benefit. It provides a source of clean and renewable energy, as there is no need for fossil fuels. The solar radiation constantly strikes Earth and therefore, no "fuel" is needed for the energy conversion into electricity (Soga, 2006*b*). However, resources to construct the solar cells are needed.

The value chain of solar cells can be seen in Figure 10. Note that in this figure, there is a deliberate choice of making the red arrows smaller, since we know that negative impacts in terms of climate impacts are less for every kWh electricity generated with solar cells compared to electricity generated from fossil resources (for example oil or coal) (Hosenuzzaman et al., 2015). Nevertheless, it does produce environmental impacts for every kWh produced, even though they are minor. Furthermore, depending on the solar cell type, different resources such as metals need to be sourced from nature (Tao et al., 2011). Resource extraction should imply negative impacts in multiple biophysical dimensions.

Solar cells are thus an example of a less polluting technology compared to for example electricity generation from fossil fuels (mainly coal) (OECD, 2017). Hence, this can be seen as a more responsible development of the conventional technologies, but it is still focused on creating value for society, and is not creating value for nature. Therefore, we consider this technology to be a green technology within the regular technology category in relation to the Triple R framework.

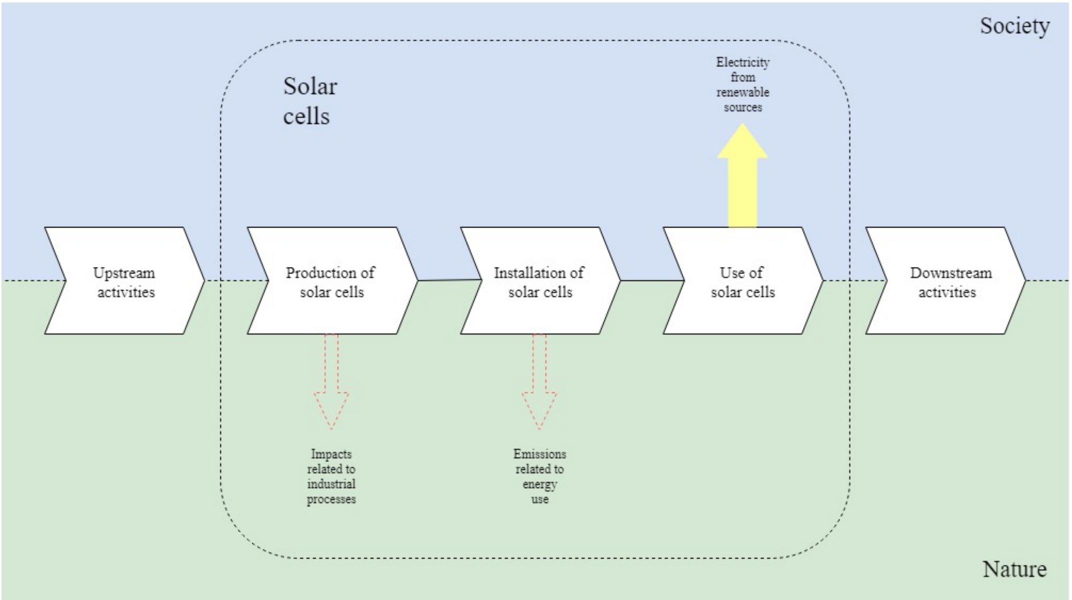

Figure 10: Solar cells illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.2 Restorative technologies

Here we will illustrate the category restorative technologies with multiple examples. They include production and use of fish ladders, direct air capture and storage, coral reef restoration and ocean cleanup.

6.2.1 Fish ladders

Fish ladders can be described as structures that enable migrating fish to pass over or around an obstacle on a river, according to NOAA (2018). Several fish species such as salmon, eel and sturgeon migrate upstream and downstream as part of their natural spawning behaviour. Man-made manipulations of rivers such as dams disturb this behaviour. Fish ladders are an important technology as they may assist fishes in their spawning and thus sustaining fish populations at normal levels (Brown et al., 2013). One specific type of fish ladder is the Salmon Cannon^{TM}, developed by Whooshh innovations. The Salmon Cannon can transfer fish over or around obstacles, such as hydro power constructions (Whooshh innovations, n.d.). Using a system with a soft and flexible tube, the fishes are transported forward as a result of a pressure difference. The fishes can enter the Salmon Cannon by human assistance or voluntary. In Figures 11, 12 and 13, the entire transportation process is illustrated.

Focusing on the Salmon Cannon, the actual technology refers to constructing, using and

Figure 11: A fish voluntarily enters the Salmon Cannon (Whooshh innovations (2018*b*)).

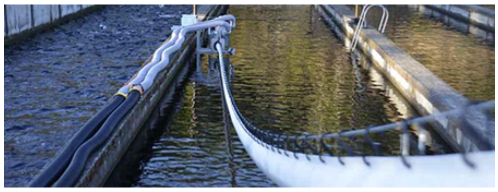

Figure 12: A picture showing the pneumatic tube (Whooshh innovations (2018*b*)).

Figure 13: A fish exits the Salmon Cannon^{TM} (Whooshh innovations (2018*b*)).

maintaining the fish ladder to transport fish. The technology produces a number of benefits. First and foremost, it provides a passage over obstacles for fishes that does not require much effort from the them (WSU Insider, 2018). It should also be stated that, according to Geist et al. (2016), the technology does not imply any stress or injuries to the fish, compared to other fish ladder technologies.

In Figure 14, the technology is represented as a value chain. The Salmon Cannon produces values, but it also creates negative impacts. It can be seen that it impacts nature in all steps, however the impact is probably greater in the production and construction phase since these steps involve some kind of industrial process which should require more power, than the use phase. Depending on the origin of the electricity generation, it will affect biophysical dimensions to different extents. However, the climate change dimension will certainly be affected, at least as long as we depend on a non-renewable energy system. In terms of the use phase, the power requirements will differ depending on the layout of the Salmon Cannon (Whooshh innovations, 2018*a*). Furthermore, resources will certainly be needed to construct the Salmon Cannon, which should imply some environmental impacts in several biophysical dimensions. Even though resources may have to be sourced from nature, the energy can be sourced from renewable sources. Since a lot of fish species are endangered (WWF, 2019), and we still need for example hydro power constructions, the value might outweigh some or all of the negative impacts.

The Salmon Cannon technology orients its value-creation towards nature in terms of safeguarding migrating fish species. Thus, it is creating value in the biosphere integrity dimension. However, it can be argued that the Salmon Cannon creates indirect values for society by restoring parts of a biophysical dimension that in turn provides ecosystem services. Therefore, it can be argued that the Salmon Cannon is a restorative technology in relation to the Triple R framework.

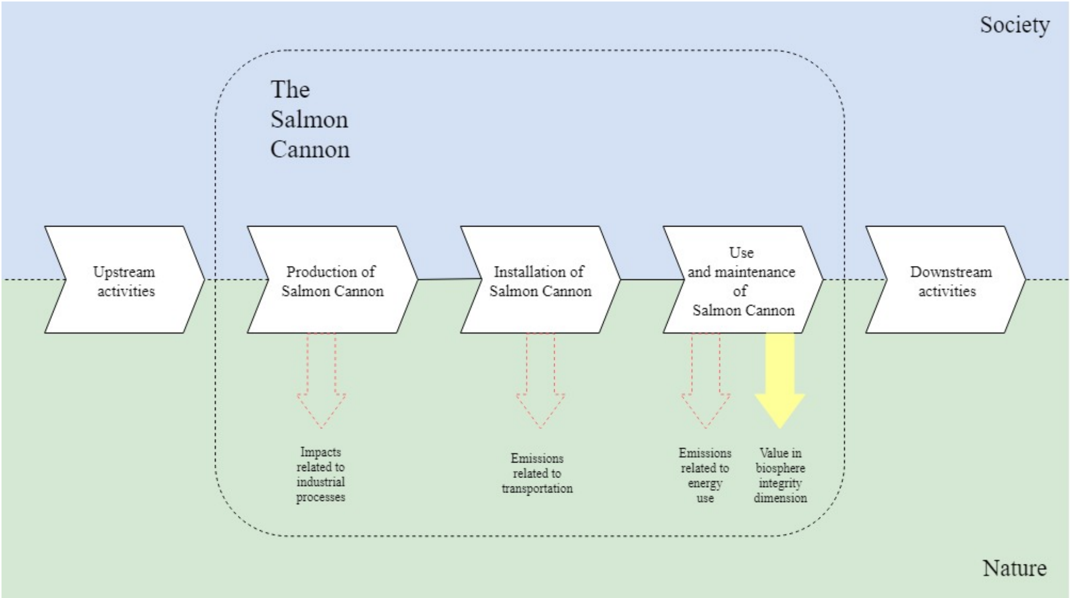

Figure 14: The Salmon Cannon is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.2.2 Direct air capture and storage

Direct air capture (DAC) utilises a chemical procedure to remove carbon dioxide from the atmosphere (Azapagic et al., 2018). It can be operated with a combination of different technologies to make use of the captured carbon dioxide, either to store it in geological deposits or use the carbon dioxide for other purposes. Chemicals are placed in a filtering medium (the separating agent) to which the carbon dioxide binds by adsorption. Once the filter is saturated, it is treated with heat or water (or both) - releasing the carbon dioxide from the filter and capturing the high purity gas, followed by for example geological storage by mineralisation or utilisation. In the following paragraphs, storage will be in focus.

One way to store the captured carbon is to turn it into solid minerals in the underground bedrock, a process developed by the company Carbfix (CarbFix, 2019). This is done by letting the carbon dioxide gas that is captured dissolve in water, after which the water is injected into basalt bedrocks, where the water solution can react with the basalt to form stable carbonate minerals. This technology combination (which can be seen as one technology) gives rise to one main benefit, carbon dioxide is removed from the air. In Figures 15 and 16, a direct air capture plant and carbonate minerals can be seen.

Figure 15: Direct Air Capture plant in Hellisheidi, Iceland, at the site for the CarbFix2 project. Photo by Zev Starr-Tambor (Climeworks, 2017).

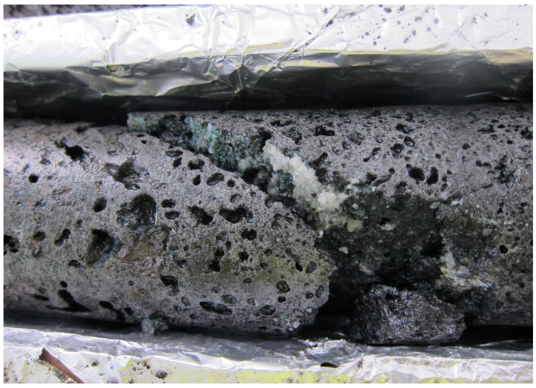

Figure 16: Stable basalt core formed after pumping carbonated water into the basaltic bedrock. Photo by Sandra O. Snaebjornsdottir (Climeworks, 2017).

The value chain for the technology can be seen in Figure 17. It can be seen that it produces negative impacts on nature. The DAC systems have high energy requirements, and one way to potentially reduce these energy requirements is to integrate the DAC with other systems that generates waste heat for example, or applying the captured carbon dioxide to nearby industries that uses carbon dioxide in their production process (Azapagic et al., 2018). Furthermore, resources will be needed to build these installations. However, the material for the DAC could potentially be scrapped from metallic waste for example to reduce the environmental burden, and the chemicals in the filter are reused within the system. Even though, some material might be recycled, a lot of virgin materials will of course be needed. Constructing the storage sites should also require a lot of resources and energy, and it is impossible to say to which magnitude the negative impacts reach. They will however for sure override the positive impacts in the beginning of the technology's lifetime. It also depends on the capacity and efficiency of the DAC to absorb carbon dioxide from the air, and how often it operates at maximum capacity.

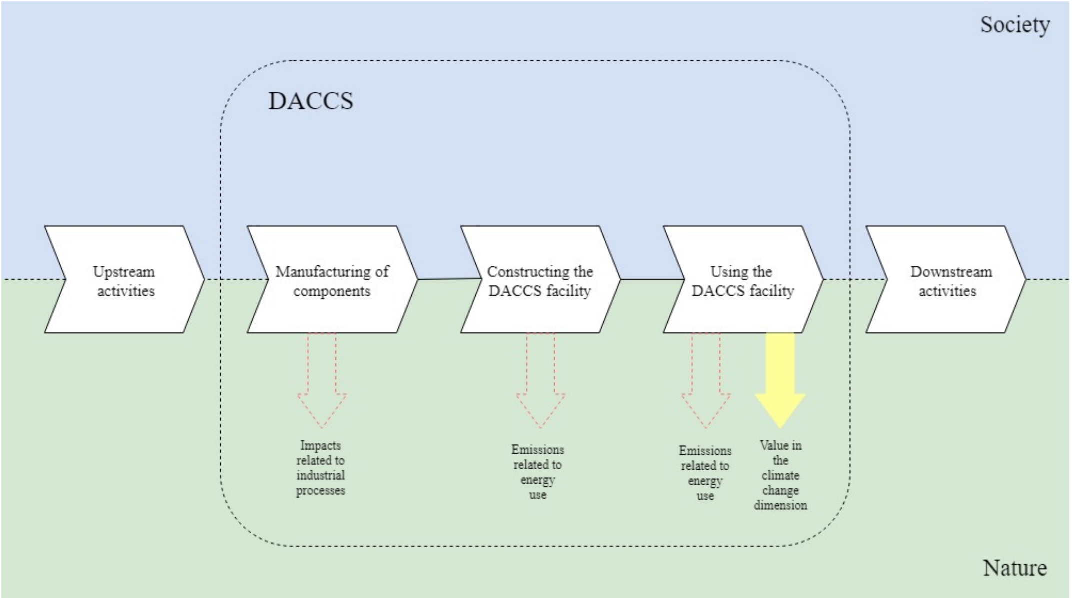

Figure 17: DACCS is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

Even though we cannot know the magnitude of the negative impacts in the construction phase in relation to the positive impacts in the use phase, it could be argued that the technology should create a net positive value within the climate change dimension, since it is the intention with the technology. Since it orients its value-creation towards parts of nature, it is thus a restorative technology in relation to the Triple R framework.

6.2.3 Coral reef restoration

The degradation of coral reefs is an ongoing worldwide process, affecting a major part of the oceanic ecosystems (Cox, 2019). According to Bellwood et al. (2004), the coral reefs need to be restored, which could be achieved with new management practices and an improved understanding of coral reef resilience (Coral Restoration Foundation, 2018a). Coral reef restoration is a practice where coral reefs are extended by planting out new corals.

The technology refers to utilising a coral nursury program to grow corals which then can be planted out on existing restoration cites (Coral Restoration Foundation, 2018a). The technology makes use of the corals' asexual reproduction mechanism called *fragmentation*, where they fragment small pieces of corals that are then hung onto a Coral Tree ^{TM} (see Figure 18). This tree is made of PVC pipes, allowing the corals to grow larger in the coral tree "nurseries". After six to nine months in nutrient-rich waters with affluent sunlight, the corals have reached a substantial size and are ready to be planted out in the different reef restoration sites. Once the corals are planted out on the reef by divers, they reproduce sexually through spawning. The technology utilises several species of corals under the

Endangered Species Act, and are now working with more than 300 genotypes across 11 different species of corals (Coral Restoration Foundation, 2018b).

Figure 18: Coral tree nursery in Bonaire. Photo by Beth Watson (Reef Renewal Foundation Bonaire, n.d.).

Utilising this technology provides benefits for nature. Most importantly, this technology provides a measure to restore degraded coral ecosystems. More specifically, it might reduce the risk of coral extinction and other species that are dependent on the corals. This technology gave rise to the first naturally occurring spawning of nursery-raised corals ever documented (Coral Restoration Foundation, 2018a).

Figure 19 shows the value chain of Coral restoration. Besides the benefits, the technology does not require a lot of different resources apart from the PVC pipes that the coral trees are made of. PVC is produced from ethylene (Britannica, 2019*b*). Ethylene is made from either oil or renewable resources such as sugar crops (British Plastics Federation, n.d.). Regardless of which raw material is used, some negative environmental impacts occur. Furthermore, transportation by boat, which probably use fossil fuels, is used to monitor the corals. In total, this technology should at least impact the climate dimension to some degree.

Coral reef restoration is thus a technology with restorative properties within the biosphere integrity dimension, since it provides possibilities for endangered corals to recover. We therefore regard it as a restorative technology within the Triple R framework.

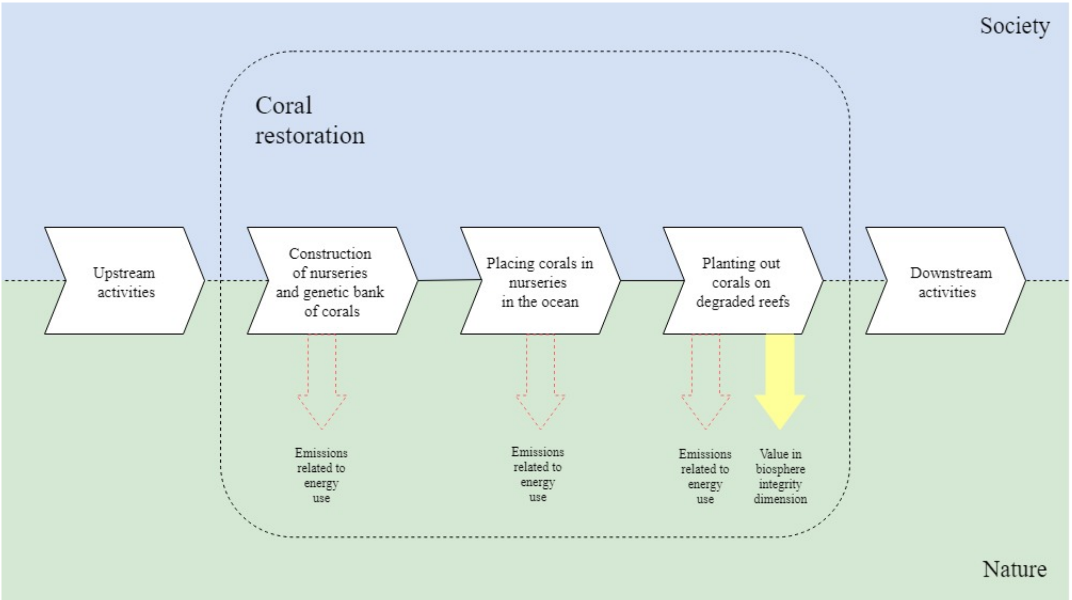

Figure 19: Coral reef restoration is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.2.4 Ocean cleanup

One of the initiatives that has gained a lot of public attention, in terms of removing novel entities (plastics) in marine ecosystems is the Ocean Cleanup project (The Ocean Cleanup, 2019). The Ocean cleanup product is a device that collects waste such as plastics from the ocean. The collecting device is a giant buoy, 600 meters long with a floater above surface and a three meter long ”screen” beneath the surface. This allows the buoy to move faster than the floating plastic debris. Natural forces such as wind and current makes the buoy form a U-shape which enables the debris to accumulate in the middle of the U-shaped system.

The ocean cleanup technology involves production and construction of the collecting device, using it to collect plastics, and then remove the plastics from the ocean with boats in order to be further processed (The Ocean Cleanup, 2019). Note that if the technology would also refer to using the plastic waste to produce a product, it would have regenerative characteristics. Utilising the Ocean Cleanup technology results in one major benefit. It provides a cleaner ocean and thus a healthier environment for marine organisms (Havs- och Vattenmyndigheten, 2018). Figure 20 portrays the first deployed version of the technology, located in the Great Pacific garbage patch.

Figure 20: The Ocean Cleanup's first deployed system together with a collecting vessel, located at the Great Pacific garbage patch (The Ocean Cleanup, 2018).

The value chain for this technology involves constructing the buoy, using it to collect debris and then remove the debris using boats, which is shown conceptually in Figure 21. Even though this technology provides an important benefit, it also creates negative impacts. These arise during the construction, maintenance and operation of the buoy. Transportation of the plastics to the mainland must also be considered. As for all other technologies, this one requires resources and energy that will give rise to environmental impacts in several biophysical dimensions. Using renewable energy is one obvious way, which has been brought up earlier, to decrease the environmental burden. However, this technology contributes to a healthier ocean and the importance of a healthy ocean cannot be disregarded. Summarising, we regard this technology as a restorative technology in the novel entities dimension since it created values oriented towards nature.

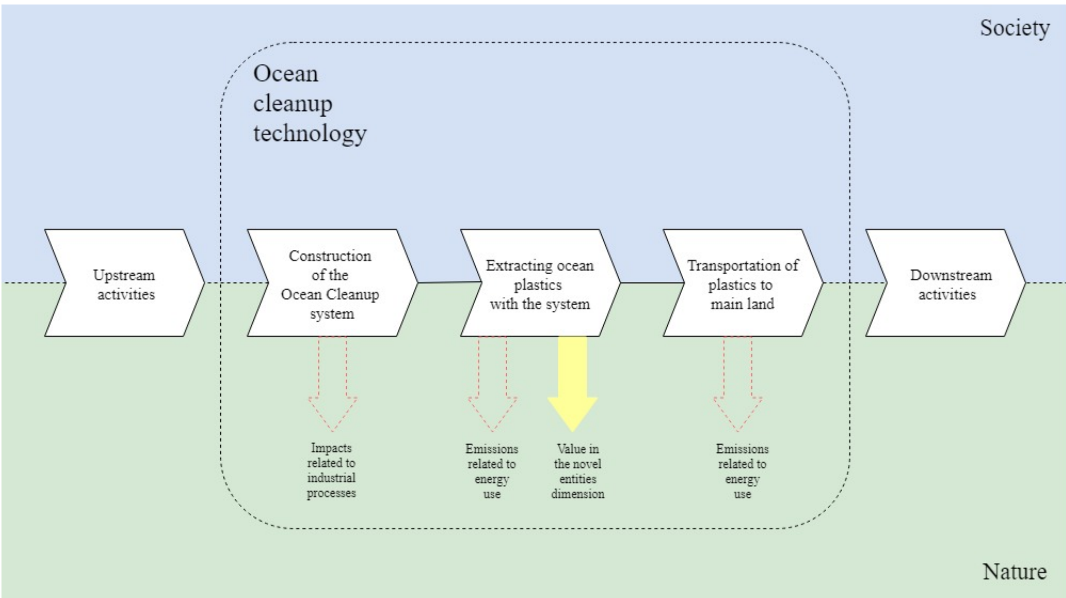

Figure 21: The Ocean cleanup technology is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.3 Regenerative technologies

In this section we will present a number of technologies that have the potential to be classified as regenerative technologies. These include eye-wear of recycled materials, bioenergy with carbon capture and storage, biochar, green roofs and mussel farming. The technologies produce values within multiple biophysical and social dimensions.

6.3.1 Eye-wear of recycled materials

In this section we will consider eye-wear made from recycled plastics and wood, developed by the company Karün. The recycled plastics, such as old fishing webs and ropes seen in Figure 22, is collected from the sea and the wood from old constructions (Karün, 2019b). However, the following sections will focus on recycled plastics as the raw material. The particular technology refers to producing and using eye-wear from raw materials that pollute the environment. This technology gives rise to a number of benefits. Firstly, plastic debris is removed from the oceans, which results in a cleaner ocean. Secondly, it produces value in the social domain by providing a fashion item that may also offer sun protection and improved vision.

Figure 22: An example of what a local entrepreneur collects and sells as raw material to Karün (Karün, 2017).

The value chain of this technology involves three major steps, as seen in Figure 23. First, ocean debris is collected from the Chilean coast with boats. After the waste has been collected from the environment, it is sent to Europe for recycling and remoulding of the "raw material", and for the production of eye-wear. The plastic waste is converted into plastic pellets that can be used in the manufacturing of the eye-wear. The process is called ECONYL®(Karün, 2019c). This process makes regenerated nylon from scrapped waste that can be "recycled, recreated and remoulded again and again" according to ECONYL® (n.d.). The result of the ECONYL process is a pure virgin material which can then be used to produce textile yarn for example, or be moulded into new products like sunglasses.

Besides the values that the technology creates, it also produce environmental impacts. The transportation of the raw materials might be dependent on fossil fuels and thus have a negative impact in the climate change dimension. Furthermore, the ECONYL process and the process to convert waste to eye-wear also demands a lot of energy, that probably is partly based on burning fossil fuels, resulting in negative impacts in several biophysical dimensions (Epstein et al., 2011). Using renewable energy sources would decrease the environmental burden.

In total, this technology produce direct values for nature, in the form of removing novel entities from the ocean. It also creates values for society in the form of sun protection or assistance with human eye vision. We therefore consider it to be a regenerative technology in relation to our framework.

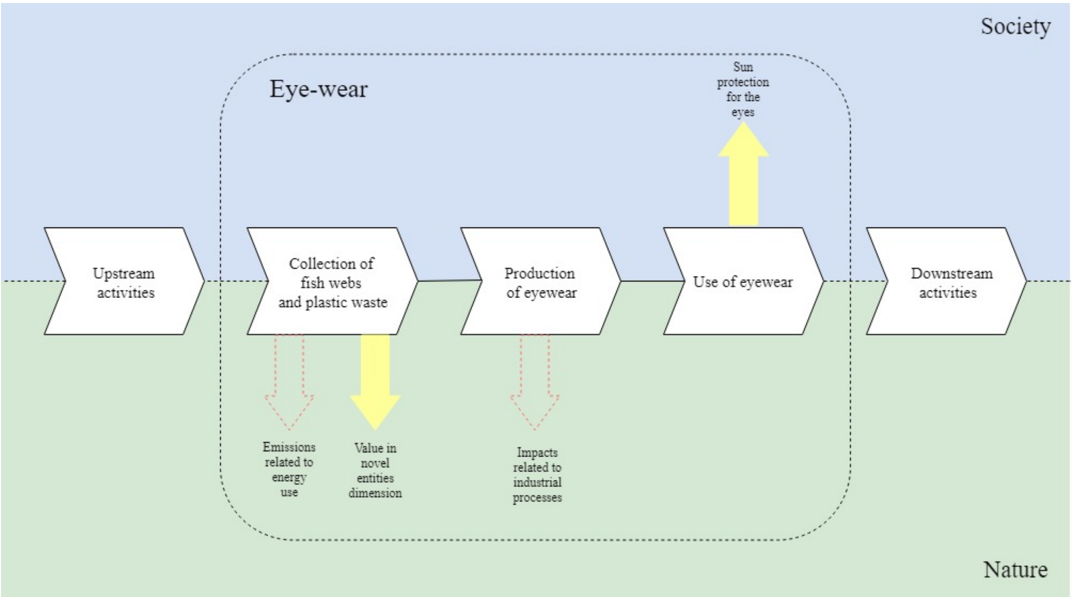

Figure 23: Eye-wear from recycled materials as a technology is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.3.2 Bioenergy with carbon capture and storage

Bioenergy with carbon capture and storage (BECCS) is a technology that can be utilised to achieve greenhouse gas removal from the atmosphere, and has gained a lot of attention in political climate debates and conferences around the world (Azapagic et al., 2018). It is seen as a possible solution to how we can slow down the global warming, and eventually even reverse the negative trends of climate change. BECCS is a technology that utilises two technologies and combines them into one, namely provision of electricity and heat from renewable biomass production as the first process, and carbon capture and storage (CCS) as the second process (Azapagic et al., 2018). The theoretical net effect of this is that more carbon dioxide is absorbed from the air and captured, than what is being released in remaining parts of the value chain, thereby "creating" negative emissions.

The technology refers to the practice of (1) constructing BECCS facilities including storage sites and power plants if needed, (2) growing, harvesting and processing biomass, (3) biomass combustion to generate power and heat (4) CCS. This technology contributes to several benefits. Firstly, it absorbs carbon dioxide from the atmosphere and thus might help to reverse climate change. The benefits created in the climate change region depend on the type of biomass, since different biomass sources differ in yield and moisture content according to (Fajardy and Mac Dowell, 2017). Secondly, it provides a source of renewable energy to society.

In Figure 24, the technology is depicted as a simplified value chain. Even though this technology might produce benefits in the climate change dimension, it creates a number of negative impacts. First and foremost, it is claimed that BECCS may in fact release more carbon dioxide than it removes from the atmosphere (Fern, 2018). This is partly due to carbon stocks in the soil may be reduced. Furthermore, emissions related to energy requirements and transportation of biomass are other sources to negative impacts in the climate change dimension. Secondly, BECCS requires a lot of land, depending on the scale deployed, which can lead to negative impacts within for example biosphere integrity dimension. Thirdly, it may require a lot of fertilisers which should impact at least the climate change dimension (Daghash, 2012). Lastly, constructing the BECCS facilities, including the geological storage, will imply that a lot of resources are needed and in addition require a lot of energy.

To summarise, BECCS might create value for nature within the climate change dimension, in the same time as it provides renewable energy to society. Thus, BECCS creates values in both domains and therefore, we regard this technology as a possible regenerative technology in relation to the Triple R framework.

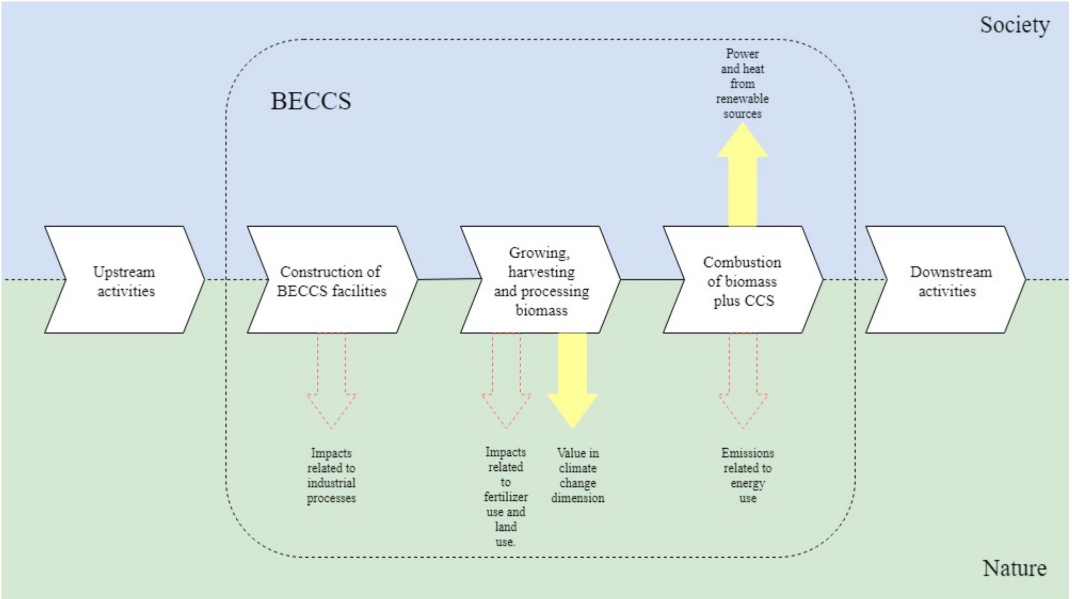

Figure 24: BECCS is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.3.3 Biochar

Biochar is a stable and long-lived material similar to charcoal. It is not a new invention, but rather a naturally occurring substance. For example, biochar is created as residue from vegetation fires and has been used in old agricultural practices for thousands of years (International Biochar Initiative, 2018*a*).

Biochar technology refers to the practice of producing biochar by pyrolysis of biomass and then storing it in the soil. This gives rise to a number of benefits. Firstly, since the biochar is resistant to decomposition, the technology reduces the concentration of carbon dioxide in the atmosphere. Secondly, biochar improves soil fertility, by improving nutrient and water retention as well as microbial activity (Harter et al., 2014). Adding biochar to agricultural soils thus reduces the demand for nitrogen fertilisers in crop growth and reduces nitrogen emissions (Zheng et al., 2013). The increased bioavailability of nitrogen also reduces the need for fertiliser application, which in turn reduces costs and energy use in food production. In addition, the use of biochar decrease the need for frequent irrigation and enabled lowered irrigation volumes, which may reduce the use of increasingly scarce freshwater resources. Thirdly, the pyrolysis of biomass creates by-products in the form of oil and gas, which can be used as renewable fuels. The feedstock used to produce biochar is often waste from other industries such as forestry, agriculture and food production, which reduces the need for land to grow new biomass for pyrolysis at the same time as removing waste from the pollution cycle (International Biochar Initiative, 2018*b*).

The value chain for biochar technology involves the growing, collection and transportation of biomass, the pyrolysis of biomass, and the application of biochar to soils (International Biochar Initiative, 2018*c*), which can be seen in Figure 25. These activities not only give rise to the benefits described above, but also implies negative impacts on the environment. In particular, transportation of biomass and biochar, as well as the pyrolysis process itself, requires a great deal of energy. To the extent that this energy comes from fossil resources, it may reduce and even outweigh the positive effect biochar storage has on climate change since fossil fuels give rise to negative impacts in a number of biophysical dimensions (Epstein et al., 2011). However, energy may be sourced from renewable sources and there are many benefits beyond reduced carbon dioxide levels in the atmosphere, which may compensate for the energy requirements (International Biochar Initiative, 2018*b*; Woolf et al., 2010).

Biochar technology accordingly creates direct values for nature in several dimensions, including climate change, freshwater and biogeochemical flows, while providing societal value by improving soil quality and providing renewable fuels. We therefore argue that biochar can be considered as a regenerative technology in relation to the Triple R framework.

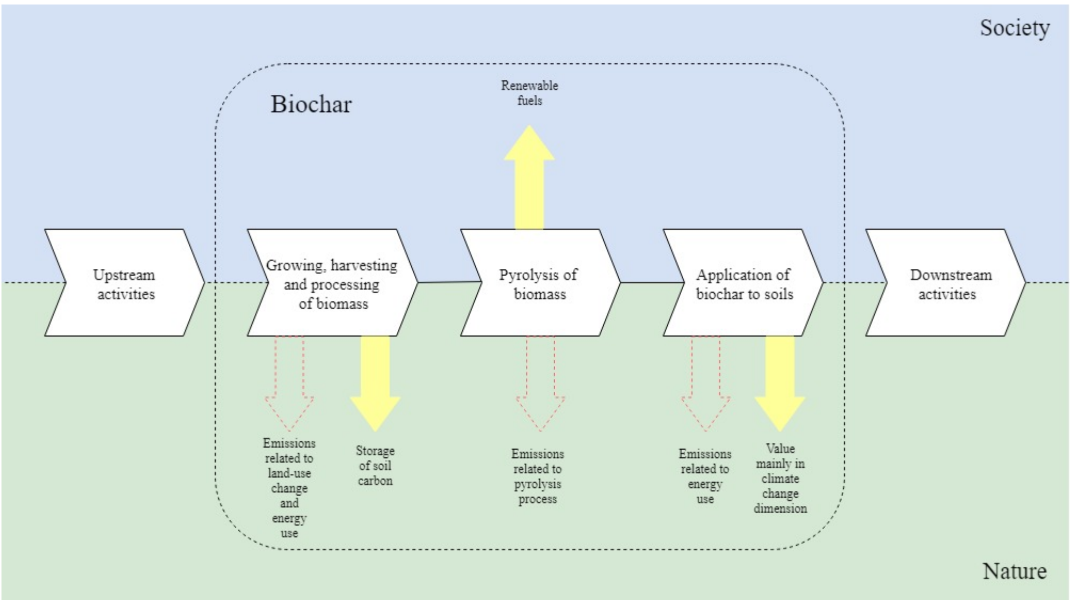

Figure 25: Biochar is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

6.3.4 Green roofs

Green roofs are horizontal building constructions which are covered with plants and trees to varying extents used for human shelter (Green Roofs for Healthy Cities, n.d.). The green roof does not necessarily have be put on the top of a building, however it should not have contact with the ground. One example of a real green roof that is used as an urban garden is the High line in New York. This green roof is situated on an old elevated rail track which was rebuild to an urban garden in 2006 (Friends of the High line, 2019*a*). It has over 500 different native species that attracts native pollinators (Friends of the High line, 2019*b*). Figure 26 shows a picture of the High line.

Figure 26: The High line stretches through New York city. Photo: Iwan Baan.

The green roof technology involves the construction of the actual roof, using and maintaining the roof and its plants. These installations may provide multiple positive impacts for both nature and society. Firstly, green roofs can sustain or enhance biodiversity in a specific area where they are deployed (Scandinavian Green Roof Institute, n.d.). This is achieved partly via the actual plants and invertebrates that exist on the particular roof but also through ecological connectivity. The connectivity provides opportunities for fragmented ecosystems to be reconnected (Sicirec, 2009), and thus, populations of different species have better possibilities to flourish (Green Roofs for Healthy Cities, n.d.). Secondly, the roof aspect of green roofs evidently provide shelter for humans. Thirdly, the aesthetics of green areas can provide multiple social benefits. Furthermore, green roofs may provide a local food source and improved health thanks to reduced air pollution may also be achieved (Scandinavian Green Roof Institute, n.d.). Additionally, the social spaces that the green roofs provide (if constructed as an urban garden) might increase some of the social dimensions even more.

In Figure 27, a simplified illustration of the value chain of Green roofs is represented. Besides the benefits described above, it can be observed that the technology produces impacts in all steps, however it can be argued that the magnitude of the impacts should be smaller in the using and maintenance phase compared to the other phases. It can also be concluded that resources of varying sorts are needed. For example, steel might be needed entailing that negative impacts on the environment in multiple biophysical dimensions will likely occur (Greenspec®, n.d.). Depending on the plants that are used, the water consumption that is needed to maintain the plants will differ which results in that the freshwater use dimension will be affected to varying degrees. Using recycled materials and drought tolerant plants are two examples that can minimise the described impacts.

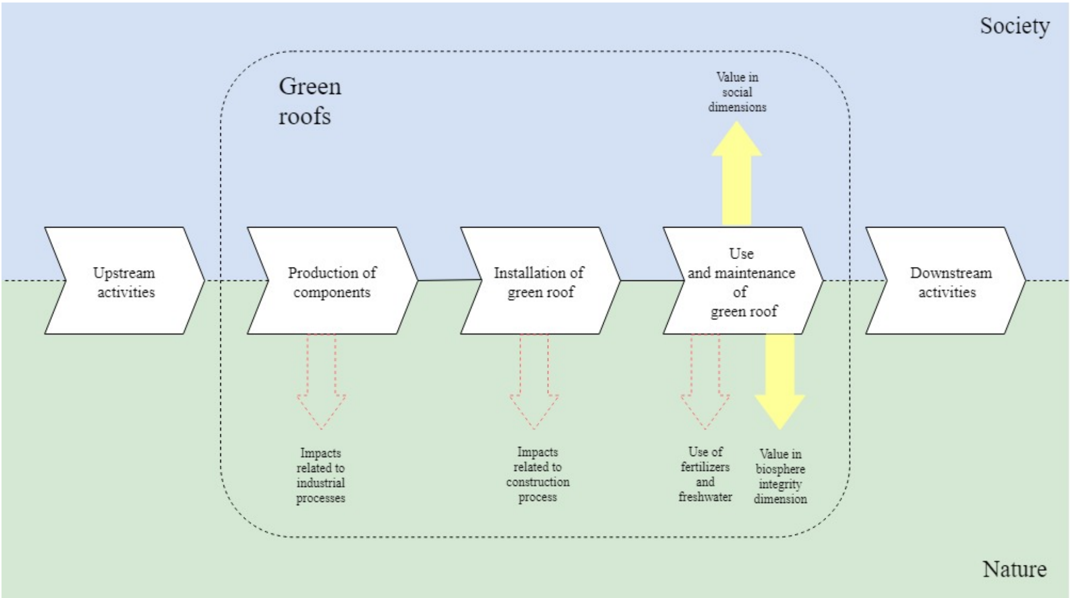

Figure 27: Green roof technology is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts..

In total, the green roof technology provides direct values for nature in primarily the biosphere integrity dimension but also in the climate change dimension since plants absorb carbon dioxide from the atmosphere. In addition, it provides multiple social values in for example shelter and increased well-being. Thus, we consider it to be a regenerative technology within the Triple R framework.

6.3.5 Mussel farming

Mussels, for example blue mussels, are experts on filtering water and live of phytoplanktons in the ocean (Lindahl et al., 2005). The mussels can clean the ocean regarding excess nutrients and can be consumed by humans. The places where the mussels grow are in streaming water that is rich in nutrients (Scanfjord, n.d.).

The mussel farming technology refers to the practice of growing mussels in a planned and concentrated way, and then utilising the mussel meat in several applications. The mussels play in May, which is when the cultivation system is placed in the sea (Scanfjord, n.d.). The mussel larvae attache themselves to ropes and begin to grow. They are ready for harvesting after 18-36 months. The cultivation system is made of ten long parallel suspension lines attached to a girder that is fastened to the bottom with an anchor. The suspension lines are carried up with buoys so that they are floating, and the ropes that the mussels grows on are attached to the suspension lines. This technology creates multiple benefits. Firstly, harvesting mussels can remove substances such as nitrogen, phosphorous and carbon from the ocean, thus mitigating, among others eutrophication. In addition, since phytoplanktons are a consequence of increased concentrations of nitrogen and phosphor, mussels help to combat algal blooms (Lindahl et al., 2005). Secondly, mussel farming provides a human food source. Thirdly, the technology can also be used as organic feed or as an organic fertiliser.

In Figure 28, a mussel farming technology is presented conceptually. It does not only create positive impacts but also negative ones. Vessels (Scanfjord, n.d.*b*) and trucks (Scanfjord, n.d.*a*) with diesel engines are used for harvesting, maintenance and transportation, which mainly impacts the climate change dimension negatively by releasing greenhouse gases and particles to the atmosphere. Furthermore, the trucks require cooling aggregates which further increases the pressure on the climate change dimension.

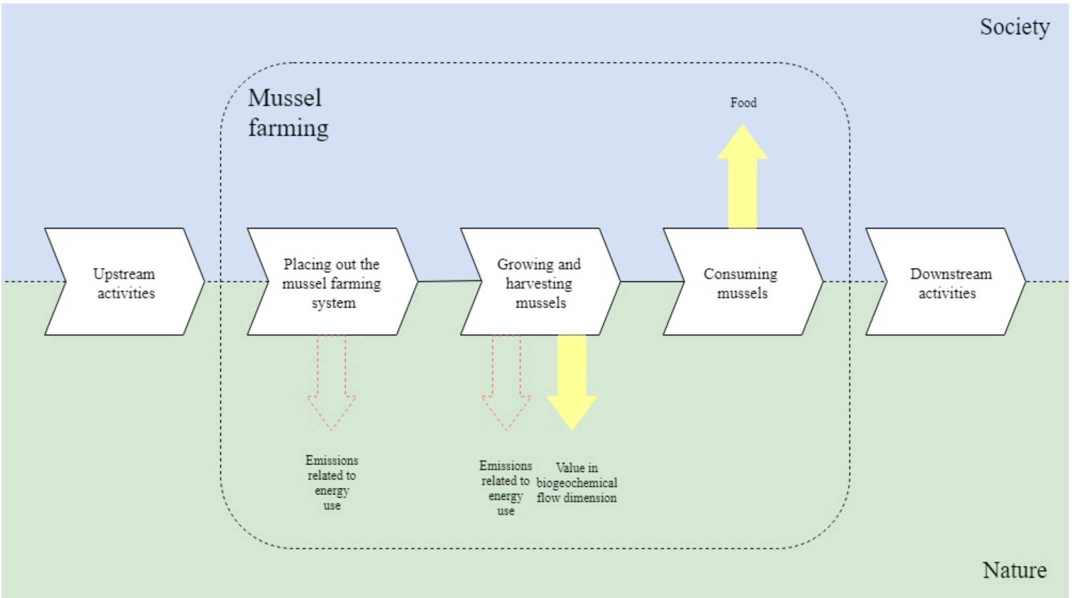

Figure 28: The mussel farming technology is illustrated as a simplified value chain. The red arrows indicate negative impacts and the yellow arrows indicate positive impacts.

The technology can be used to restore values in the biogeochemical flow dimension, in the same time as it provides social values such as food and fertilisers. As mussel farming orients its value-creation towards both nature, as ocean cleaners that reduces the effects of eutrophication, and society, we see this as an example of a regenerative technology in relation to the Triple R framework.

7 Discussion

In previous chapters, we explained the theoretical background of the framework, the construction and characteristics of the framework, and the use of the framework. During these phases, we encountered several ambiguous issues including ethical considerations of nature for example, as well as issues with trade-offs and other complexities being made when applying the framework. The discussion will hence address such issues that relates to previous chapters, and also suggestions of how the findings in this thesis can be used and improved in future research for example.

7.1 Why bother about nature?

There are many reasons to why ethical considerations are important to discuss in regards to the Triple R framework. The foundation of the framework is based on the fact that the society and the humans living within it should be responsible for nature's well-being and the values it provides. This care for nature could potentially be based on the fact that some believe that nature should be given an intrinsic value and moral status. While it is both difficult and problematic to assign value to non-sensing beings like ecosystems, it might be important to at least feel some kind of moral duty towards nature in order to act. Furthermore, even if we disagree on the notion to give nature a moral status, we can recognise the services that the natural systems provide us. Damages done to for example the ecosystems cannot be reversed if they are destroyed completely. Without these ecosystem services, we would be left without food, and clean air and water. A more specific example, if all the bees die, we would not have pollination of plants and trees, which could in turn lead to trophic cascades. In addition, the availability of food would decrease as a consequence of non-existent pollination (Potts et al., 2016). In order to not get to this irreversible state of natural catastrophe, we must restore natural systems by creating value for them. Hence, whatever the intention is with caring for nature, we do believe that regardless of your individual ethical view we can all agree that we need to develop technologies and change our behaviour to eradicate damages to nature as much as possible. That is, if we want our children and the rest of future generations to live a good and decent life.

The ethical consideration might also be important when analysing the companies in their intentions with technology development. Is it to make a lot of money on a new technology or is it to really change the purpose behind what they are doing? Of all the technologies that were assessed, only one could be related to a company that clearly stated that they want to change the worldview, and that their company's motive is "...about a completely different way to see the world" (Karün, 2016). Karün had a completely different goal of doing good instead of less bad, and suggest a holistic approach to an environmental problem. Interestingly enough, they describe their value chain as circular and regenerative, and defines regenerative by declaring it as "a process with a positive impact on the environment and our society" (Karün, 2017), which is relatively similar to our definition of a regenerative technology (see Section 5.1.3). Furthermore, they express their care for nature by stating "We are sharing this planet with million other species, we need to be conscious. We need to respect it." (Karün, 2019a). It is essentially the last part of this; conscious and respect, that we feel is the key to creating a better world where nature is prosperous and can continue to perform all its activities that are necessary for all survival.

This leads us to the problem with designers, developers and companies own ethical views. When constructing a house for example, how well do you utilise the materials and all the space? Do you consider the integration of nature and the ability of the buildings to co-develop in a regenerative design like Reed (2007) suggests, or do you only build the cheapest house there is to maximise profits? This also applies to all other human beings, which can be placed along some kind of spectra, from "nature lovers" to "concrete enthusiasts". How well one is connected to nature and how much of it that one has experienced, is probably influencing how highly you value nature. Compare that to a person that lives in a large western city and has never been "connected" to nature in any way, that person would probably value nature much lower. Even though we have not analysed the intention of a company deploying a certain technology, we believe that the connection to nature could play an important role when developing technologies that create value for nature.

7.2 Framework

With this framework we have tried to present a different way of thinking regarding what technologies are and how they can be used to do "good" for nature. We argue that more attention need to be put on how to provide value for nature instead of only focusing on how to minimise the environmental damage. Thus, this justifies the need of developing a framework that highlights the difference between technologies that create value for nature, such as restorative and regenerative technologies and technologies that do not.

Furthermore, it can be argued that highlighting technologies which create value for nature implies that the degradation of natural systems is made (more) visible. This aspect might in turn lead to an enhanced awareness and understanding for nature which in turn could enhance the sustainability debate. Even though there are difficulties in applying the framework, the underlying ideas of it should not be disregarded. Having stated some overall contribution of the framework, a few features of the framework will be further discussed.

Starting with regular technologies, they are included in the framework as we realised that it would be difficult to create a technology fleet that is solely relying on restorative and regenerative technologies. Otherwise, it might be difficult to achieve a safe and just space for humanity, or fulfil the sustainable development goals (UN, 2015). Hence, we still need to use technologies that create value for society and impacts nature. However, we argue that these technologies should be "high level" green technologies and aiming at achieving a circular material system, to avoid the depletion of natural resources. Ideally, in the future, we would be able to live in symbiosis with nature, but since we are far away from that future right now, we need to complement the two Rs (restorative and regenerative) with a third one (regular). This is further necessary to avoid the deprivation of human needs, as many people still are suffering from hunger and lack of access to clean water and air. There is a risk that developing a lot of potentially expensive restorative and regenerative technologies only would benefit the wealthy people in the western world. This in turn would create even more inequalities than what is present today regarding the fulfilment of basic human needs. Thus, even if regular technologies are bad or less kind to nature, we still need to include them, at least for a while.

Furthermore, it is interesting to highlight how acknowledged organisations such as UN explain green technologies. They refer to Environmentally sound technologies which we consider as green technologies. UN states that this type of technology "protects the environment" (UN Environment, n.d.). This is a great example of how minimising the environmental damage is misunderstood as doing good for nature. We argue that a technology that has a smaller burden on nature in relation to another one will never protect the environment. It will only decrease its negative impact on nature. It is this misunderstanding that is the foundation for developing concepts that consider the actual "protection aspect". In terms of technologies, these concepts can be related to restorative and regenerative technologies.

Restorative technologies are characterised by a value-creation that is oriented towards nature in order to restore nature, in this context divided into biophysical dimensions. If this technology category can contribute to the enhancement of one or several biophysical dimensions to some extent is difficult to know. Deploying such technologies might give an indication of this over time. What is important though, as mentioned before, is the way of thinking. What can be accomplished in terms of restoring nature with technology as a tool? Furthermore, even though it can be argued that nature and society are embedded in each other, restorative technologies highlight that our own short-term interests might have to be put aside in some aspects. Or at least, it would be beneficial for the status of some parts of nature if we could do this.

In terms of regenerative technologies, they should have restorative properties, but also create value for society. As for restorative, it is the way of thinking that is of importance. This category was included in the framework since we acknowledged that some "Restorative technologies" also produced a positive impact for society. We think it is important to separate technologies that create direct values for nature from technologies that create direct values for both nature and society. This is vital due to services that nature provide should be highlighted.

Furthermore, as for restorative technologies, it is difficult to know if and to what extent a regenerative can provide positive impacts in the dimension/dimensions it intends to create value. It can only be known by deploying it and having the point of departure that some trade-offs must be made. Note that it might be problematic to only rely on this type of technology for restoring biophysical dimensions and perhaps also in terms of enhancing social dimensions, due to for example scale issues.

Continuing, since we describe creating value for nature as restoring biophysical dimensions included in the planetary boundaries concept, does this imply that restorative and regenerative are not needed when we have restored all parts of nature? If we found a way to live in symbiosis with nature, meaning that we did not have to deal with severe environmental issues, that would be great. However, since we currently have not found this way of living, we argue that restorative and regenerative technologies will be necessary, at least in the near future.

Another aspect, that is related to all technology categories is the notion of value. Which values should be taken into account? Favourably, final values such as happiness or healthy populations of a specie rather than instrumental values such as green areas within a city or clean oceans should be used. As can be understood, the characteristics of the value-creation depend on the technology. For example, it can be argued that the value that coral restoration provides is more final than the value that the ocean cleanup technology creates. The motivation is that coral restoration directly creates a more healthy coral population whereas an ocean cleanup technology provides the fundamental preconditions for healthy populations of marine organisms. We believe that both technologies restore vital values of nature. Thus, it is hard to argue about what type of value a technology should create. Taking social values in to consideration as well, it becomes more complex since values in the social dimensions are even more difficult to classify as instrumental or final. For example, is health a final value or is it an instrumental value in order to feel happy?

As mentioned earlier, there are difficulties in applying the framework in the way that it is presented in Chapter 5. These are inherent complexities that do not have an evident solution. However, trade-offs need to be discussed since they will always have to be considered. The most important trade-offs will be discussed in next subsection.

7.2.1 Trade-offs

There are many trade-offs made when classifying the technologies into different categories. Starting with trade-offs between dimensions, a restorative technology that restores value in one dimension of the planetary boundaries framework might inflict harm within another dimension. For example, the Ocean Cleanup technology restores value in the "novel entities" dimension, but since it collects the waste with boats running on diesel, it affects the climate change dimension negatively. Another example, BECCS should create value within the climate change dimension but does surely impact dimensions such as biosphere integrity, land-system change and freshwater use. This type of conflicting impacts and value-creation between biophysical dimensions is one of the main problematic issue with classifying technologies as having a net positive impact. One approach to deal with trade-offs is to value the dimension that is more degraded than the other/others. This might however be difficult to apply in reality. What is evident is that we have not been able to come up with an appropriate way to deal with trade-offs. When it comes to regenerative technologies, also trade-offs between social dimensions and trade-offs between social and biophysical dimensions must be considered. This makes the issue of trade-offs even more complex.

Trade-offs related to a technology also occurs between the three dimensions of sustainability. They can for example occur between economic sustainability and ecological sustainability, where the economic sustainability has largely been prioritised over ecological sustainability. One aspect with describing the regenerative technologies however, is that these should not have a large trade-off between the social and ecological sustainability. However, there can definitely be positive secondary impacts from restorative technologies, for example an increased number of job opportunities that in turn can improve the economic sustainability, and improving nature might enhance spiritual and cultural values for humans (improving social sustainability). Regular technologies can on short term notice improve the economy, but in the long run it may impoverish the society rather than enrich it, as the severe consequences arising from a continued environmental pressure might face society with droughts, extreme weathers and ecosystem collapse to name a few examples.

Other trade-offs that can be discussed is the scale of the technology. A technology might have for example restorative properties in a small scale implementation, but will cause disastrous impacts in large scale implementation. BECCS for example might work well locally where the conditions are advantageous, but large scale implementation such as the scale that would be needed to meet the 2 ℃-target would certainly produce dominantly negative impacts. To meet the 2 ℃-target with BECCS (assuming that only BECCS is utilised), a total land area up to two times greater than India would be needed (Fern, 2018). Furthermore, this implementation would result in biodiversity losses and the irrigation volume that is needed compared to the volume that is now used per year for food production would have to be doubled. In addition, large scale implementations of technologies could result in a huge need for resource extraction which in turn might aggravate working conditions for people working in developing countries, like the rush for cobalt to build batteries for electrical vehicles, resulting in almost slave like working conditions for the mine workers and also child labour as an example (Kara, n.d.). However, it large scale implementations must not necessarily result in such consequences but are important to have in mind.

Furthermore, including trade-offs between the different geographical levels should be addressed. These levels include local, regional and global values and impacts on society and nature. The effects (positive and negative impacts) of a technology can exist on one or multiple geographical levels and depend on several factors, for example, the scale of the technology that is used, which has been addressed in the paragraph above. However, also the inherent properties of the particular dimension that is influenced affects the geographical trade-off. For example, climate change is in itself a global environmental problem and thus technologies that create value within this dimension produce a global value. Coral restoration on the other hand create primarily a local value. Since all technologies produce some kind of climate impact, they will all affect on a global level. Thus, trade-offs between different geographical levels need to be addressed.

Lastly, there are also temporal trade-offs. Temporal effects of a technology are challenging to estimate, especially for longer time scales of several hundred years, but should not be overlooked. As an example, in the case of Carbon Capture and Storage (CCS) the long term storage is an eminent problem, as the places for storage are not infinite, nor is there a guarantee that the storage will not leak the captured carbon dioxide back into the atmosphere (Klusman, 2003).

7.2.2 Strengths and possible criticism

The Triple R framework has multiple strengths. First and foremost, it highlights an important knowledge gap in the literature regarding how technologies that create value for nature can be distinguished from other technologies. Furthermore, using the planetary boundaries framework as an underlying theory is appropriate since it provides general descriptions of how a complex domain can be divided into several dimensions. It was the most appropriate option to describe values of nature that we could find. The planetary boundaries framework justifies the importance of our thesis aim, that we should restore nature by creating value for it, if we want to sustain modern human societies and in addition respect other sentient beings.

Criticism can possible be justified regarding several aspects of the framework. For example, it could be argued that all technologies are regenerative since humans have a hard time caring for things they do not value. Taking the Salmon Cannon or the Ocean cleanup technology as examples, it can be argued that the technologies help restore parts or whole ecosystems with the intention of doing good for nature. However, it can also be argued that humans will benefit from the restoration of nature and that is why the technologies exist. Regardless of the intention, technologies that create value for nature in some way are needed, even though a company that truly care for nature might have a more holistic solution, as described earlier.

Furthermore, the choice of underlying theories can be questioned. In terms of the planetary boundaries framework, we chose to work with this acknowledged model since it describes significant processes that affect the Earth's functioning. A way of describing natural values on a very general level was desired and the planetary boundaries framework provided this. In addition, we asked ourselves about why humanity should care for nature, and especially why the "current nature" or the way the ecosystems are constructed right now should be cared for. We found interesting answers in the planetary boundary framework since it illustrates the importance of respecting biophysical dimensions that support human societies as we know them. Furthermore, we address consumption of resources when illustrating the framework with existing technologies even though it is not a biophysical dimension described in the planetary boundaries framework. We argue that this aspect is important to address and we furthermore found it a bit odd that resource depletion is not included in the planetary framework, since it is the main driver for many of the environmental pressures we see today. Clearly, resource depletion in itself is not a vital biophysical dimension for the stability of Earth (maintaining the current geological epoch). It is rather the consequences of resource extraction that can aggravate the status of biophysical dimensions that are considered as vital.

In addition, we acknowledge that the planetary boundaries framework has been criticised, as mentioned in Chapter 2. The criticism against the framework is partly regarding the misunderstanding that there are "tipping points" for the biophysical dimensions (Montoya et al., 2018). Steffen et al. (2018) responds to this criticism and state that they have never argued that such tipping points exist. According to Steffen et al. (2018), the use of "boundaries" should be understood as there is an increased risk that a certain biophysical dimension is pushed to a non-Holocene state when the boundary is transgressed. Since the Holocene is the only geological epoch that has sustained human societies as we know them, it is imprudent to drive the Earth system to a non-Holocene state. Observing the criticism and the response, we felt comfortable to use the framework as a theoretical foundation.

Regarding the sustainability doughnut, the Triple R framework can be critiqued since it is difficult to evaluate an enhancement of a particular social dimension created by a technology. We acknowledge this, and chose to argue about the social dimensions on a general level in Chapter 6. Furthermore, the sustainability doughnut is not a good representation considering all social dimensions that are regarded as significant. But we acknowledge that it was the most appropriate model that we could find. Thus, it is rather critique towards the sustainability doughnut than of the framework.

Continuing, criticism against technologies including BECCS and DACCS is justified according to some scientists, as they claim that such technologies only create incentives for a prolonged use of fossil fuels. It can be argued that these technologies do not contribute to the change that is needed in the fossil fuel infrastructure since we can capture the emissions and bury them. Fern (2018) states that BECCS is a barrier to the necessary energy transition needed as it encourages companies and industries to continue using oil and coal. Their solution is instead to protect and restore natural forests, to improve conditions for biodiversity and decreasing the levels of carbon dioxide to improve the climate. They also claim that this would bring social benefits (Fern, 2018), however they do not mention in what way.

The extraction and use of fossil fuels should indeed be diminished and eventually also removed completely. However, it is not done instantly and we probably need a transition period before we get to clean and renewable fuels. As some technologies (BECCS and DACCS) might create incentives to continue with business-as-usual, we argue that ethical considerations have their place in order to not overlook the damages that the continuation of the fossil community can have on humans or other species.

Thus to answer this criticism, it can be argued that technologies such as BECCS and DACCS might increase people's environmental awareness. Highlighting that such technologies are needed in order to avoid severe environmental consequences may increase the understanding and gratitude for the natural systems that support human societies. These technologies do not therefore necessarily give incentives to continue a fossil based society. They can act as bridging technologies and increase the environmental awareness. Therefore, we argue that this critique is not totally justified.

7.3 Research design and literature review

To construct the framework and find existing technologies that match the categories within the framework, a research design that was based on literature reviews and qualitative analyses was needed. There are some aspects related to the choice of research design that can be discussed. Furthermore, the actual literature review will also be discussed to some extent.

First of all it can be questioned if the research design was optimal in relation to the thesis objectives. We argue first and foremost that there was no other option than a qualitative approach since a quantitative research design is difficult to match with our purpose and time frame. This is due to the type of data that would be needed does probably not exist. Remember that the primary focus of this thesis is to illustrate a way of thinking regarding of what technology as a tool can achieve in order to create value for nature, not to prove that these technologies exist. Thereby, a qualitative research design is justified.

In terms of the literature review, scientific literature was mainly screened (see keywords in Table 2 in Appendix), during the first phase of the thesis to search for concepts describing technologies that creates value for nature. Due to the limited amount of time, it was impossible to spend more than three weeks on the initial literature review when searching for related areas of interest. As a result, relevant articles might have been missed. Furthermore, there were probably some combinations of keywords that could have generated even better search results; keywords that seemed not relevant but could have an unexpected benefit when combining them for example. Continuing, our own previous experiences within the field of environmental research did certainly influence the words and articles that we found relevant, that biased our results from the literature review. To increase the credibility of our results, we could have asked for more external input of interesting and relevant keywords during our search, but due to the limited amount of time and the working process of developing the framework and searching for interesting case studies, we did not have more time to check our search with anyone else.

If the time frame would have allowed, some aspects of the research design could have been refined. For example, we adopted an iterative process when developing the framework and structure of the thesis, and this could have been done even more times to increase the comprehensiveness of the thesis. The construction of the framework (and what theoretical foundation the framework should have) has consumed the majority of the time. If more time had been spent on the case studies, they would probably have been more refined. However, that would entail that the framework had to be finished earlier. As a result, the framework would have been less refined. Nevertheless, if the time constraint would have allowed, the case studies could have been refined in terms of obtaining a more complete description of the technologies' impacts. Moreover, the collection of technologies could be enhanced with additional technologies that create value in more biophysical dimensions than the ones addressed.

The search for any scientific literature that described technologies or activities that may create value for nature was however disappointing. We did not find any literature describing this concept, and the reasons for that can of course be numerous, but we believe that one cause may be related to the overly enthusiastic trust that is put in green technologies by many industrial sectors for example. Furthermore, the political discussions in society are also focused on minimising the damage on the environment rather than offsetting positive impacts. The popular sustainable development goals (SDGs) that was proposed by the UN in 2015 have a distinct anthropogenic focus, which of course is necessary in a world of inequalities, but the lack of awareness that no one will manage without a healthy planet to live on can be seen in the few ecological goals, only three have a clear focus on the environment. Stockholm Resilience Center (2016) suggested ”the wedding cake” model of the SDGs, with the ecological sustainability as the important foundation, or the bottom layer of the cake. On top of this is the social SDGs, then follows the economic SDGs and the partnership goal permeates all layers. The arrangement of the other goals can be questioned, however, what we do agree on is that the ecological goals should be viewed as the foundation for a thriving society on a healthy planet, and partnering to solve environmental issues is vital.

Furthermore, the political situation today probably contributes to the low commitment in environmental issues. Not many politicians are willingly to admit that there is actually an ecological crisis going on, as they rather want to please the crowd instead. Nevertheless, the tides are turning in society today, as more and more individuals become aware of the issues we face. One major contribution to this ”awakening” has been sparked by the Swedish school girl Greta Thunberg. She has had a large influence on youths all around the world, and in a speech to the EU-Parliament she urges politicians ”to act like the house is on fire” (Guardian News, 2019). She also explains in the same speech, that it is no longer enough to do your best, meaning that people and politicians have to try even harder to decrease emissions and halt the biodiversity losses.

The literature review confirmed our hypothesis regarding that there are no concepts describing technologies that create value for nature. Thereby a potentially important gap in the literature exists which the Triple R framework developed in this thesis attempts to fill to some extent.

7.4 Future research

We argue that there are a lot of subjects for future research related to this thesis. One of the more important changes is how to create a greater understanding of the value that nature creates for human societies, which in turn may help to prioritise the restoration of nature. Another one is that a structured way of dealing with trade-offs should be established. There will always be trade-offs, however more research might give insights of how to deal with them in a way which enhance the status of as many biophysical dimensions as possible. In addition, there is a need to understand how technologies that create value for nature can be developed and diffused in society. Thus, there is a need to study innovation processes related to restorative and regenerative technologies.

Furthermore, reasoning about impacts, both positive and negative, in the way that has been done in this thesis can serve as a starting point for developing the LCA methodology. This is partly already discussed by for example Čuček et al. (2012) and their concept "eco-profit". However, we came to the same conclusion that LCA could be used to evaluate the positive impacts and we want to emphasise that. Instead of using LCAs to evaluate the environmental burden of a product or technology, it might be possible to develop it to determine positive impacts instead. That way, companies would probably aim at high scores on positive impacts rather than low scores on negative impacts. This in turn can make product developers and designers to think in a completely new way when designing products or technology. Today, product development and creating positive environmental impacts depend a lot on the individual designer and his or her own values. As an example, some newly built apartments have roofs that protects the residents from the weather in tin or metal. Others choose to use the roofs for energy generation through solar cells, while others put sedum roofs on top of buildings. If we developed a new way to measure environmental effects that focused on doing good rather than less bad, we believe that a lot more buildings would be built with sedum roofs for example. This would automatically nudge companies in the right direction.

Even if this approach would be used, it is probably difficult to make all technologies and products restorative or regenerative. We do however believe that aiming for a development of a restorative or regenerative product could result in high level green technologies, meaning green technologies that are substantially better than the green technologies that exists today. This would also influence all technology development in general, in striving for technologies and products that can create real value for nature, and potentially completely change our view on what technology is. It could also influence companies that cannot use positive technologies to still create value for nature by compensating nature for the harm that has been done.

Technology cannot on its own restore nature or parts of it, but we need a combination of strategies to keep nature, what we as humans consider, healthy. We need to develop and use policies that hinders severe degradation of nature, and an obligation to compensate for damages that has been inflicted on nature. The solution to the environmental problems we face is not universal - we need more than technology, and we need to combine technological solutions with policy measures and a changed mindset about nature. We need to value nature for its life supporting systems. Furthermore, different geographical places calls for different technological solutions, as well as different scales of the use of certain technologies. Even with a combination of mitigation measures, we still acknowledge the need for technologies that can restore values related to critical biophysical processes, for example by creating negative emissions to compensate for all the emissions that are being released today, and will last hundreds of years in the atmosphere if we do not act fast. Because we owe it not only to the future generations to come, but to planet Earth itself that has provided us with the opportunity to live a better life than ever before.

8 Conclusion

Based on the information that has been presented in this thesis, a number of conclusions can be drawn and our research questions in Section 1 now have answers. Related to the first research question, we conclude that there is a huge gap in the scientific literature regarding technologies that create value for nature. There is however an extensive amount of literature describing *why* we should restore nature, but what is lacking is the strategies of *how* natural values could be restored with technologies. Furthermore, to be able to answer the second research question, we extended the definition of technology, and redefined it as "a means to fulfil a value, that may arise in both social *and* natural domains". By developing our Triple R framework including regular, restorative, and regenerative technologies, we have found a conceptual way to distinguish between technologies that create value for nature from other technologies, based on the orientation of the direct value-creation by the technology. The final research question is to some extent answered. There are technologies that can illustrate the three categories of our framework, however, only at a highly conceptual level. Thus, in order to justify this classification of technologies, further quantitative evaluations must be performed.

Nevertheless, to be able to make the planet healthy again, we cannot put all our trust in technology. We need to change the way we think about nature, and develop a combination of policies and technologies to protect nature from human destruction. Because what we have failed to realise, is that *we are all nature*.

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9 Appendix

Table 2: The Keywords used in the literature search. They were used on their own or in combination according to the setup in the table.

Keyword	Combination 1	Combination 2	Combination 3	Combination 4
Adaptation technology	+ climate	+ environment	+ climate positive	+ ecology
Bioeconomy	+ technology			
Climate positive	+ technology	+ environment		
Decoupling	+ climate	+ technology		
Degrowth	+ technology			
Eco-benefit	+ technology			
Eco-innovation	+ technology			
Ecological engineering	+ technology			
Eco-profit	+ technology			
Environmental benefit	+ technology	+ LCA		
Environmental positive	+ technology			
Green	+ technology	+ economy	+ growth	
Life cycle assessment	+ environmental benefit	+ climate positive	+ environmental positive	+ positive environmental
Living system	+ technology	+ approaches	+ thinking	
Nature-based solutions	+ technology			
Negative emissions	+ technology			
Reconciliation	+ technology	+ environment	+ ecology	
Regenerative	+ technology	+ ecosystem	+ design	
Resilience	+ environment	+ technology	+ ecosystem	
Restoration	+ ecology	+ economy	+ technology	+ ecosystem
Restorative	+ technology	+ climate	+ environment	+ ecology
Positive climate impact	+ technology			
Post-carbon	+ society	+ technology		
Sustainable (future)	+ technology	+ ecology	+ environment	+ restorative
Sustainability	+ value for nature	+ technology		
Technology	+ value for nature	+ ecosystem		
Value for nature	+ technology			
Zero emissions	+ technology			