Metrics of making knowledge in a wilder Anthropocene

The roles and implications of produced knowledge in the governance of synthetic biology for biodiversity conservation

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LUCSUS
Lund University Centre for Sustainability Studies

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Supervisor: Sara Brogaard, LUCSUS, Lund University

Abstract

Under the growing influence of dominant discourses such as ecological modernisation and neo-liberalisation, proposed alternative conservation approaches focus more and more on efficiency. In the realm of biodiversity conservation, synthetic biology - the application of engineering to facilitate and accelerate the design or modification of genetic materials in living organisms – has emerged as an efficient approach. However, the international governance of synthetic biology with the aim of biodiversity conservation is fraught with uncertainty, risk, uncertainty, and contrasting values.

I discuss the role of knowledge production in the governance of making use of synthetic biology for biodiversity conservation. In this thesis, through an examination of documents involved in these international governmental processes, I apply a perspective of discourse interested in the social production, circulation, and transformation of knowledge (SKAD). I furthermore analyse the data with theories on knowledge production systems and the politics of environmental knowledge.

My analysis shows a prioritisation of creating knowledge with the purpose of policy-relevance, resulting in synthetic biology being rationalised and preferred due to its potential of efficiently creating measurable ecosystem services of biodiversity. Relevance within interactions of policy, knowledge, and society has become embedded in procedures not often questioned. This analysis carries an undertone of warning. If we do not create a knowledge system with a diverse inclusion, solutions implemented to deal with synthetic biology for biodiversity conservation can, and probably will, backfire because the complexities of the issue are not properly addressed. However, the findings discussed in this analysis can also be viewed in a positive light. Acknowledging the diversity of knowledge by including other perspectives and knowledges can be an opportunity for more meaningful interactions between policy, knowledge, and society. A distribution of power more equal can be achieved by questioning the procedures of produced knowledge and opening them up for more diversity and accountability.

Keywords: international biodiversity governance, Sociology of Knowledge Approach to Discourse (SKAD), measurementality, novel entities, sustainability science

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Table of contents

List of Figures

List of Tables

Glossary

Term	Definition
Novel entities	New substances, new forms of existing substances, and modified forms (Steffen et al., 2015, p. 7).
Biodiversity	The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (CBD, 1992, p. 3).
Biodiversity conservation	The protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence (IUCN, 2020, p. 13).
Synthetic biology	The application of science, technology, and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms (Scientific Committees SCCS, SCHER, and SCENIHR of the European Commission, 2014, p. 5).
Gene drives	Genetic elements capable of spreading into a population even if they confer a fitness cost to their host (Marshall & Hay, 2012a, p. 2150).
Synthetic gene drives	The process of stimulating the biased inheritance of specific genes (Champer, Buchman & Akbari, 2016, p. 146)
CRISPR-Cas9	Approach to genome editing, adapted from a naturally occurring genome editing system in bacteria (NHGRI, 2020, para. 3)
Strategic research	Producing knowledge which combines relevance with scientific excellence (Hessels and van Lente, 2008, p. 743).
Post-academic science	A radical, irreversible, worldwide transformation in the way science is organised, managed, and performed. (Zinman, 2003, p. 67)

1 Introduction

1.1 The interplay between biodiversity conservation and synthetic biology

Humanity is at risk of pushing the Earth system into a new state. The planetary boundary concept identifies a safe operating space for humanity based on biophysical processes regulating the stability of the Earth system (Rockström et al., 2009). Anthropogenic perturbations cause the levels of climate change, biosphere integrity, biogeochemical flows, and land-system change to exceed the safe operating space, as can be seen in Figure 1 by Steffen et al. (2015). We are thus at substantial risk of destabilising the current state of the Earth system.

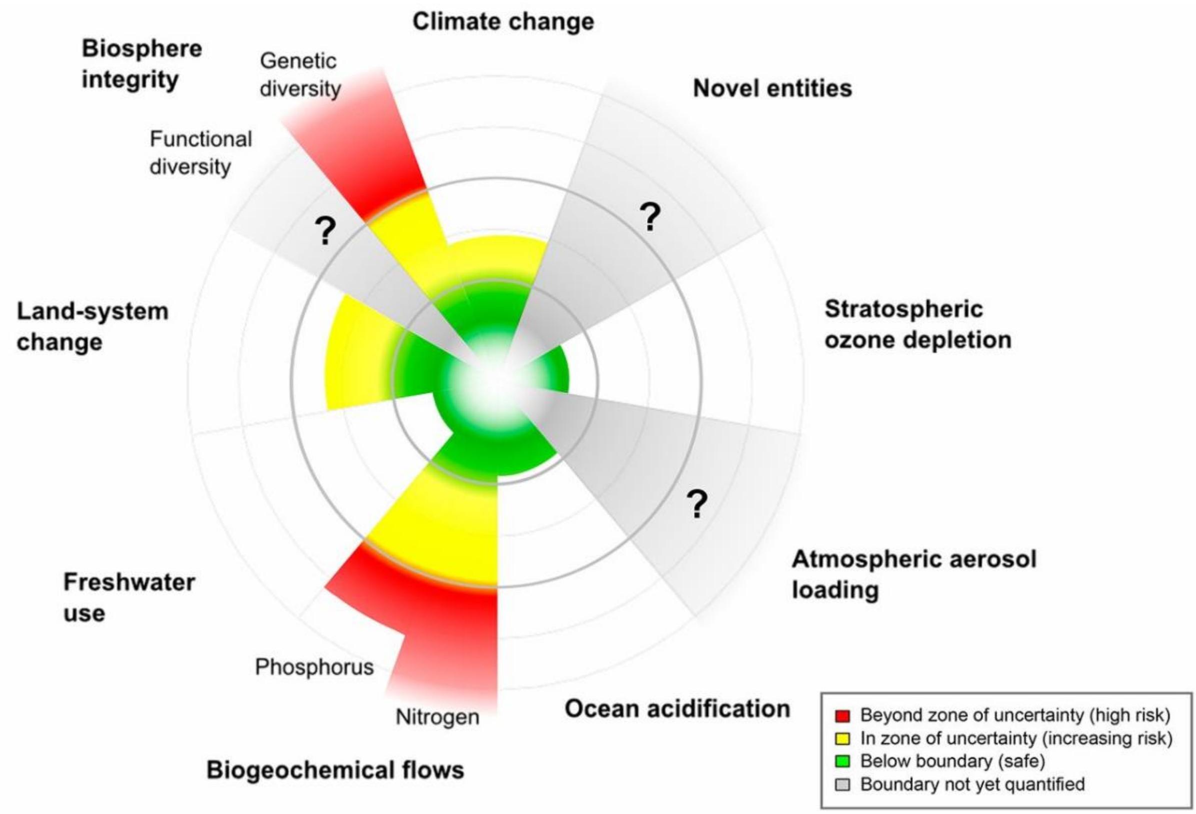

Figure 1. Status of control variables for seven of the nine planetary boundaries. Levels of climate change, biosphere integrity, biogeochemical flows, and land system change exceed the safe operating space. The boundary of novel entities, relating to synthetic biology, is not yet quantified. Reprinted from "Planetary boundaries: Guiding human development on a changing planet" by W. Steffen et al. 2015. Science, 347(6223), p. 6.

Diversity in the biosphere provides resilience to ecosystems and increases the Earth system's capacity to endure the pressures of other planetary boundaries (Steffen et al., 2015). Due to the recognition of biodiversity being of great importance, and the realisation that the loss of biodiversity is unprecedented and accelerating (IPCC, 2014), global conservation efforts have been developed in the form of targets such as the Aichi biodiversity strategy and the United Nations (UN) Sustainable Development Goals (SDGs). However, even decades of commitments, initiatives, and efforts from governments on a global scale have not been able to slow the overall trend of biodiversity loss (Gavin et al., 2018; Butchart et al., 2010; Brooks et al., 2015). Views of current biodiversity practices not being sufficient has led to the proposal of new visions for conservation (e.g.: Büscher et al., 2017; Miller, Soulé & Terborgh, 2014; Wilson, 2016). One of these new visions for conservation gaining attention in recent years is the use of synthetic biology, meaning the application of engineering principles to fundamental biological components (Johnson et al., 2016; Redford, Adams & Mace, 2013).

Novel entities, defined as "new substances, new forms of existing substances, and modified life-forms", are included as a planetary boundary due to their ability to change the state of the Earth system (Steffen et al., 2015, p. 7). Examples of novel entities are chemicals and engineered materials or organisms not previously known to the Earth system, created through, for example, synthetic biology techniques (Rejeski, Leonard & Libre, 2018). Anthropogenic introduction of these novel entities to the environment can have positive and negative consequences for the other planetary boundaries and is thus of global concern and debate. This debate within international biodiversity governance is primarily focussing to maximize the environmental benefits from synthetic biology techniques, and to minimize their potential adverse effects (Bierbaum et al., 2020).

In biodiversity governance, knowledge production is a fundamental source of power (Mol, 2016). Which and whose knowledge claims, definitions, and environmental information are considered of importance develops government aims and agendas, making the production of knowledge a key issue in biodiversity governance (van der Molen, 2018). This thesis aims to increase understanding of how knowledge influences the development, assessment, and decision-making of synthetic biology in biodiversity conservation governance.

1.2 Research aim and question

Viewing knowledge as performative can unleash the potential for enabling well-informed biodiversity governance by recognising the relationships between political processes, ethical decision-making, and environmental knowledge. I aim to demonstrate a need for deeper understandings of the role of knowledge in the governance of synthetic biology for biodiversity conservation, by showing it to be central to power structures. More precisely, this study aims at understanding how knowledge is being reported, as well as its practices and consequences. I draw on the Sociology of Knowledge Approach to Discourse (SKAD) to demonstrate the centrality of knowledge in governmental processes. By applying theories on knowledge production systems and the politics of environmental knowledge, I examine the wider implications of the role of knowledge for biodiversity governance related to synthetic biology. In doing so, this study contributes to a wider understanding of this role, by following the research questions:

1) What are the roles and responsibilities given to actors, by themselves or by other actors, in governmental discussions of synthetic biology for biodiversity conservation?
2) How are synthetic biology and biodiversity conservation represented in governmental processes?
3) Which reasons, arguments, and kinds of knowledge are considered valid for governmental discussions?

To address these research questions and explore the role of knowledge in the governance of synthetic biology for biodiversity conservation, I apply a discursive approach. The context of this discourse analysis is the governmental processes and governance debate on an international level. The focus is on international organisations, policy, and planning. It is important to specify that the implications of all three research questions are key to this study as well. The implications shown in this study can potentially be extrapolated beyond this context.

1.3 Outline

After this chapter introducing the thesis, the background follows in which I contextualise synthetic biology in relation to biodiversity conservation. The background chapter aims to show that there are implicit values and principles in the way concepts are discussed. Chapter 3 presents the theory, providing the foundation for the role of discourse analysis in this thesis, followed by a section in which the theory "environmental knowledge in politics" is linked to biodiversity conservation governance. Chapter 4 follows, in which I present the research design, the methods of this study, and the materials to be analysed. Included is an analytical framework, providing the basis of my analysis. Chapter 5 consists of the analysis following the research questions. In all three sections of the analysis, implications are discussed in close relation to the theory. At the end of the analysis, I summarise the main findings of the thesis and discuss potential further research. Lastly, in the concluding chapter, I reflect on the thesis and discuss the wider implications and potential of the findings.

1.4 Link to sustainability science

Before going further, it is important to clarify the relevance of this thesis to sustainability science. First of all, sustainability problems often include an aspect of ethics combined with urgency, with a deeply normative nature (Miller, 2013; Swart, Raskin, & Robinson, 2004). Furthermore, ethical norms are a key part of conservation biology due to its crisis-oriented nature (Soulé, 1985), resulting in the need of competing norms in society to be understood and be part of research in sustainability science (Isgren, Jernick & O'Byrne, 2017). This study fits in with the normative foundation of sustainability science by researching how synthetic biology becomes rationalised by its potential of increasing measurable ecosystem services of biodiversity and nature in general. The recognition of the relationships between the environment, ethical decision-making, and political processes is an increasingly important theme in the field of sustainability science.

1.5 A wilder Anthropocene

Lastly, it is important to link this study to the concept of the Anthropocene. While defining the Anthropocene is difficult, this new epoch marks a fundamental change in the relationship between humans and the Earth system (Lewis & Maslin, 2015). Crutzen (2006) argues that human activities are outcompeting natural processes in exerting impacts on the environment, making humans the main influence on the Earth system. Synthetic biology raises the debate of a wilder Anthropocene by humans, or at least the group of humans with the power to do so, not just influencing the Earth system but also creating it. Lövbrand et al. (2015) asks how we can engage with the Anthropocene concept, arguing that there is a challenge in exposing and extending the ontological assumptions that inform how we govern our changing environment. This study aims to address this challenge by analysing the role of knowledge in the governance of synthetic biology for biodiversity conservation.

2 Background

To contextualise current discourses and governmental processes, it is important to understand what biodiversity conservation and synthetic biology entail, their origins, and which implicit values exist in these conceptualisations. Afterwards, I summarise how these two different disciplines interact, and how their entanglement led to biodiversity governance principles and actors on an international level. Lastly, I review literature about knowledge production in governance, forming the basis of the theoretical section.

2.1 Conceptualising biodiversity conservation and synthetic biology

2.1.1 Conceptualising biodiversity conservation

The UN Convention on Biological Diversity (CBD) defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems" (CBD, 1992, p. 3). Taking a look at the current situation and the projected trajectories of global biodiversity, it is clear that we are in a critical position (Costello, May & Stork, 2013; Sinclair, 2000; Steffen et al., 2015). There has been a growing understanding of how the loss of biodiversity negatively affects ecosystems and in turn society (Cardinale et al., 2012). Hens & Boon (2005) identify the main causes of biodiversity loss, in which the common theme is an anthropogenic drive.

To stem the loss of biodiversity, conservation efforts have been attempted. The International Union for Conservation of Nature (IUCN, 2020, p. 13) defines conservation as "the protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence". Michael Soulé (1985) distinguishes conservation biology from other biological sciences by pointing out its crisis-oriented and multi-disciplinary nature, as shown in Figure 2. He describes the goal of conservation biology as "to provide principles and tools for preserving biological diversity" (Soulé, 1985, p. 727). Without conservation efforts to stem the loss of biodiversity the global biodiversity situation would doubtlessly be worse.

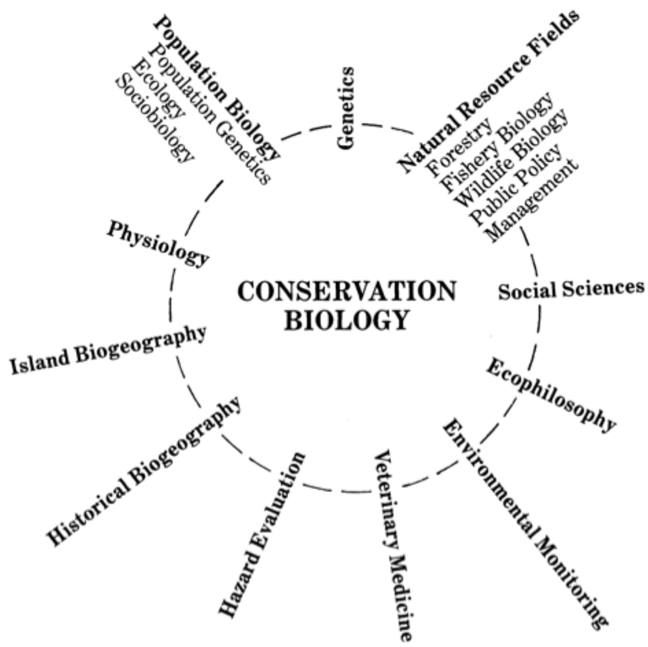

Figure 2. Conservation Biology. The aim of the figure is to: (1) explain that conservation biology shares many characteristics with other crisis-oriented fields and disciplines, (2) show that many questions, techniques, and methods come from a broad range of fields, (3) illustrate the dependence on social science disciplines within biological sciences, and (4) show the artificiality of the dichotomy between pure and applied disciplines. Adapted from "What is Conservation Biology" by M. Soulé, 1985, BioScience, Vol. 35, No. 11, p. 728.

However, even decades of commitments, initiatives, and efforts from governments on a global scale have not been able to slow the overall trend of biodiversity loss (Gavin et al., 2018; Butchart et al., 2010; Brooks et al., 2015). This led to new, often competing, visions of conservation. Examples of these approaches are "Half-Earth" (Wilson, 2016; Büscher et al., 2017; Noss et al., 2012) and "New Conservation Science" (Kareiva, Lalasz & Marvier, 2011; Miller, Soulé & Terborgh, 2014). In recent years, synthetic biology as an approach for conservation has been gaining attention as well (Piaggio et al., 2017; Redford, Adams & Mace, 2013; Johnson et al., 2016).

2.1.2 Conceptualising synthetic biology

The field of synthetic biology is dynamic in nature, which is reflected in the plethora of varying definitions that are used by organisations, institutes, and scholars. Definitions have developed from 1912 onwards (Campos, 2009), and differ depending on the organisation or company. To provide a good starting point for discussion, I will use the definition by the Scientific Committees SCCS, SCHER, and SCENIHR of the European Commission: "Synthetic biology is the application of science, technology, and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms" (2014, p. 5).

Even though there is no agreed-on definition of synthetic biology (Osbourn, O'Maille, Rosser & Lindsey, 2012), partly since more and more disciplines are being included (Shapira, Kwon & Youtie, 2017), the common theme is the application of engineering principles to fundamental biological components in DNA (deoxyribonucleic acid). LEGO, a rightfully popular toy, is often used as a way to explain synthetic biology (see for examples: Cserer & Seiringer, 2009; Collins, 2012; Sherman, 2005; Maddalena & Katherine, 2014). Figure 3 provides an example of this. Each LEGO piece has different characteristics and by putting them together you can create a plethora of structures that all have different functions. The LEGO building blocks here represent biological components that can be synthetically built. The (re-)design of life is a key theme that can be identified in differing definitions of the concept (Benner, 2005; Szostak, Bartel & Luisi, 2001; Benner, 1987).

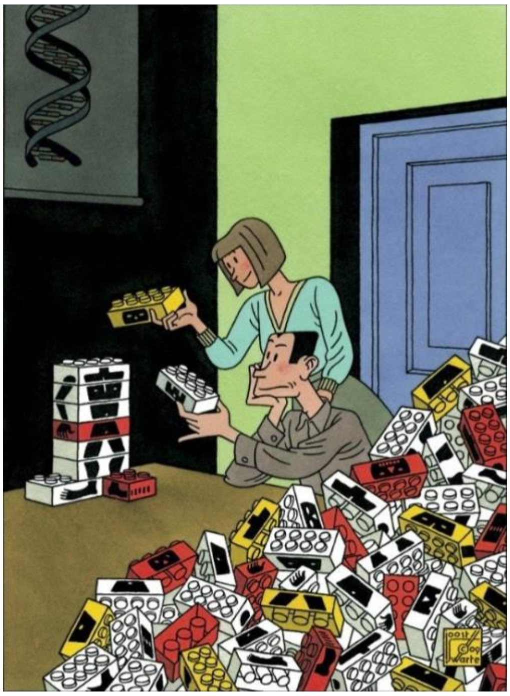

Figure 3. Example of the toy LEGO being used as metaphor to explain synthetic biology, in which biological components are the building blocks that are synthetically put together to create different structures. Illustration by J. Swarte. Reprinted from: "A life of its own – where will synthetic biology lead us?" by M. Specter, 2009, in *The New Yorker,* Issue of September 28.

Using LEGO as a metaphor usefully allows us to see synthetic biology in a certain way. However, it also creates a way of not seeing that might be dangerous. By using LEGO as a metaphor, synthetic biology can be seen as simple acts of designing and building – which it is not. In truth, many of the building blocks are not well characterized or defined and work differently based on the condition and context they are in (Kwok, 2010).

The continuous addition of disciplines and processes enables synthetic biology to design life more efficiently. Redford et al. (2019) mentions examples of synthetic biology techniques, including genome editing, whole-genome sequencing, and functional screening. The growth of innovation in the field of synthetic biology is considered to be exponential, playing a big part in the Fourth Industrial Revolution (Schwab, 2017). Scientists are currently working on gene drive systems using synthetic biology techniques (The Royal Society, 2018), of which the development can be accelerated by CRISPR-Cas9 (Simon, Otto & Engelhard, 2018).

Engineered gene drives

While there are several approaches to changing an organism's DNA by altering the genetic material at particular locations in the genome (called genome editing), the CRISPR-Cas9 approach[1] has generated the most excitement (NHGRI, 2020). This is because if the old approaches of genetic manipulation were like a map, CRISPR-Cas9 is like a GPS system – a technology that makes techniques of synthetic biology more (cost) efficient, precise, and easy (Williams, Henao-Mejia & Flavell, 2016). As seen in Figure 4, by changing the genetic information of an organism, the edits will only be inherited by half of the offspring according to Mendelian inheritance, which is why the synthetic biology method "gene drives" is more efficient (Delborne et al., 2018).

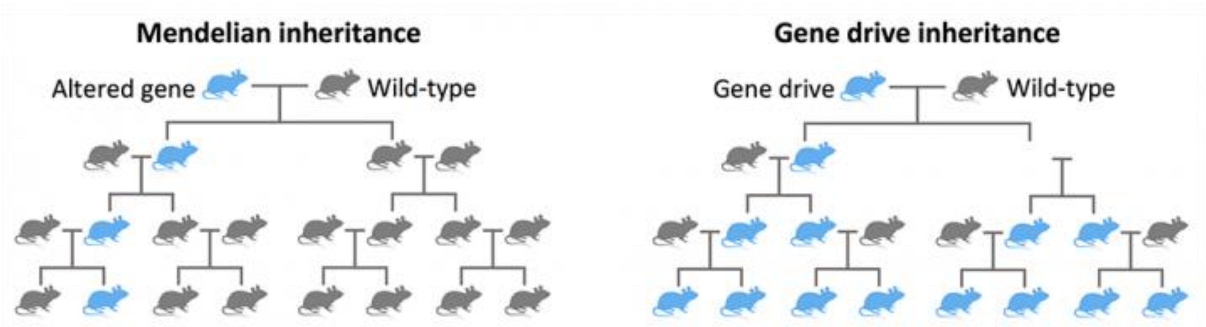

Figure 4. A CRISPR-based altered gene, in the picture depicted as the upper blue mouse, will at some point die out due to Mendelian inheritance. By adding a CRISPR-based gene drive, it is possible to drive the altered gene through a population. Reprinted from: "CRISPR-Based Gene Drives" by G.R. McFarlane, B.A. Whitelaw, and S.G. Lillico, 2018, in *Trends in Biotechnology*, Vol 36, Issue 2, p. 132.

Gene drives, also called gene drive systems, are a natural phenomenon (Austin, Burt & Trivers, 2009). There are numerous examples of different types of gene drives, and how they bias inheritance in nature (see for examples: Burt & Koufopanou, 2004; Lyttle, 1991; Charlesworth & Langley, 1989; Chen et al., 2007). The definition of gene drives is "genetic elements capable of spreading into a population

1 CRISPR-Cas9 is short for clustered regularly interspaced short palindromic repeats, with the associated nuclease 9 (Shalem et al., 2014). For more information about CRISPR-Cas9, see Appendix A.

even if they confer a fitness cost to their host" (Marshall & Hay, 2012a, p. 2150). Scientists are looking to use these gene drives to spread new traits through populations, by either repurposing natural gene drive systems or by developing engineered gene drives (Champer, Buchman & Akbari, 2016; Drury, Dapper, Siniard, Zentner & Wade, 2017). Correspondingly, the definition of engineered gene drives is "the process of stimulating the biased inheritance of specific genes" (Champer, Buchman & Akbari, 2016, p. 146). Some gene drive types are localised, meaning that they are not predicted to spread beyond the populations to which the gene drives are introduced (Marshall & Hay, 2012b). Other types are expected to keep spreading to most populations of the targeted species (Noble, Adlam, Church, Esvelt & Nowak, 2018).

2.2 Synthetic biology in relation to biodiversity conservation

The fields of synthetic biology and biodiversity conservation do no longer exist in isolation from each other. There is an expanding understanding of the applicability of synthetic biology to biodiversity conservation, as well as the relevance of interaction between scientists of the two fields (Piaggio et al., 2017). A vast number of articles are calling for a continuous and established dialogue between the two fields to maximise utility for nature, while minimising harms (Revive & Restore, 2015; Piaggio et al., 2017; Redford et al., 2014).

Based on the assessment of Redford, Brooks, Macfarlane & Adams (2019) and additional literature on synthetic biology applications, I created Table 1 to show the possible synthetic biology applications for conservation goals and the risks associated. Below table 1, I will give an example in the form of a current case for the solutions "limiting invasive species" (case 1) and "improving species resilience to threats" (case 2).

Table 1. How synthetic biology organisms, applications, or products can work towards the conservation goals "mitigation of threats" and "adaptation of species".

Mitigation of threats 1: **Limiting invasive species**	*The problems:* - Effects of invasive alien species on wildlife and ecosystems are immense, being the second biggest driver of species extinction[1], biggest on islands[2]. - Invasive species have large negative impacts on ecosystem function[3]. - Impacts can be exacerbated by habitat disturbance and climate change[4].
	Current conservation practices: - Managing threatened hosts/ reducing population of vector of disease. - Physical and chemical management practices (e.g. poison baiting), direct intervention (e.g. shooting), and biological control with natural enemies[5].
	Synthetic biology possibilities: - Gene drive systems with the possibility for self-dissemination /spread through populations[6,7].

	Adverse effects/limitations: - Adverse effects on non-target populations of the same species. Might spread beyond the target population to the same species[8]. - Adverse effects on non-target species due to interbreeding. - Low consensus on which location to try the techniques on, unfair distribution of attempts[9].
Mitigation of threats 2: **Reducing pressures from wildlife trade**	*The problems:* - Unsustainable international commercial trade (legal or illegal), is a big threat to wildlife[10,11], threatening biodiversity of species as well as their habitats[12].
	Current conservation practices: - Measures to increase the sustainability of trade, including quotas and zoning. - Enact legislative change to render trade illegal. - Reduce demand.
	Synthetic biology possibilities: - Developing and making a synthetic product as a substitute for wild product, taking pressures of the wildlife.
	Adverse effects/limitations: - Item may not be a perfect substitute. Users of wild-sourced products believe that synthesized products are less successful in producing the desired result[13] and are less willing to pay for non-wild sourced products[14]. - Opening a market for synthetic products while the market is currently illegal, it could make enforcement of illegal trade difficult or even impossible. of illegal trade difficult or even impossible.
Adaptation 1: **Improving species resilience to threats**	*The problems:* - Persistent biodiversity challenges such as invasive species, overharvesting, and habitat destruction are made worse with climate change and disease[15]. Together, this leads to isolation and fragmentation of natural populations[16]. - When populations fall below a threshold of numbers, inbreeding depression can happen, as well as a lack of variation that is necessary to overcome environmental challenges[17].
	Current conservation practices: - Habitat protection, vaccination/treatment approaches, genetic rescue/facilitate migration[18].
	Synthetic biology possibilities: - Genome editing - altering or introducing genes with the goal of enhancing the survival of a species against disease or climate change. - Improved species viability through reintroducing extinct genetic variation into extant populations. - Building resilience/ restoration of keystone species, preventing ecosystem collapse[19].
	Adverse effects/limitations: - Targeting just a few genomic regions may not be enough to produce a phenotypic change needed to provide a conservation goal[20]. - Impacts on non-target populations[21]. - When used to alter a fundamental aspect of a species, it could change the evolutionary trajectory of the species. For example, if a climate change adaptation is engineered, and climate change eventually reversed, this could have negative consequences on the species.
Adaptation 2: **Creating proxies of extinct species**	*The problems:* - Sixth mass extinction[22,23]. Rate of extinction is higher than the planet has ever seen in the previous extinction events[24].
	Current conservation practices: - De-extinction or species revival through selective breeding, back-breeding, or animal cloning.
	Synthetic biology possibilities: - De-extinction through synthetic biology has caught the public eye the most, due to significant attention from popular press[25]. However, applying synthetic biology for de-extinction is complex, and technical challenges are immense[26,27]

	Adverse effects/limitations: - Costs would be considerate and could divert funding from other conservation actions. - It might diminish extinction itself by changing the public perception and making society feel better about its attitude towards nature[28]. - The species might become invasive. - No legal framework in place is suited for such a species[29].

Note. [1]Bellard, Cassey & Blackburn, 2016. [2]Spatz et al., 2017. [3]Pejchar & Mooney, 2009. [4]Early et al., 2016. [5]Persons & Eason, 2017. [6]Campbell et al., 2015. [7]Piaggio et al., 2017. [8]Marshall & Hay, 2012. [9]Geralde et al., 2018. [10]Challender, Harrop & MacMilland, 2015. [11]Jackson & Bührs, 2015. [12]Ripple et al., 2016. [13]Gratwicke et al., 2008. [14]Davis, 2019. [15]Sala et al., 2000. [16]Stowell, Pinzone & Martin, 2017. [17]Marsden et al., 2016. [18]Whitely, Fitzpatrick, Funk & Tallmon., 2015. [19]Bland et al., 2015. [20]Johnson et al., 2016. [21] Vettori et al., 2016. [22]Ceballos, Ehrlich & Dirzo, 2017. [23]Ceballos & Ehrlich, 2018. [24]Kolbert, 2014. [25]Revive and Restore, 2018. [26]Shapiro, 2015. [27]Johnson et al., 2016. [28]DeSalle & Amato, 2017. [29]Wagner et al., 2017.

2.2.1 Example case 1: Preventing extinctions of native bird species in Hawai'i

Native Hawaiian bird species have been going extinct at an alarming rate, and populations still extant are dwindling (Ricklefs, 2017; Paxton et al., 2016). The introduction of the non-native southern house mosquito vectoring avian malaria was, and is, majorly responsible for this (Pyle & Pyle, 2017). Climate change is worsening the situation, since the mosquitoes are now able to expand into higher elevation forests (Atkinson et al., 2014; Paxon et al., 2016; Fortini et al., 2015). Even though significant effort has been made to conserve the forest birds (e.g. localised predator control and habitat restoration), most populations continue to decline (Genz, Brinck, Camp & Banko, 2018; Paxton et al., 2016). Currently, a possible synthetic biology application is proposed by the American Bird Conservancy, the Hawai'i Department of Land and Natural Resources, and the US Wildlife service (Redford et al., 2019). The technique that is explored works by injecting the southern house mosquitoes with the gene drive system Wolbachia, a genus of bacteria that usually occurs naturally (Weinert, Araujo, Ahmed & Welch, 2015), which can lead to population suppression and even eradication (Atyame et al., 2016; Mains, Brelsfoard, Rose & Dobson, 2016). The eradication of malaria-carrying mosquito species has been proven possible in a laboratory experiment using CRISPR (Kyrou et al., 2018). Another synthetic biology application proposed recently is to facilitate adaptation of the birds by using gene editing to create malaria-resistant populations or to increase disease tolerance (Samuel, Liao, Atkinson & LaPointe, 2020; Ramos et al., 2019).

2.2.2 Example case 2: Protecting coral reefs from climate change and acidification

Since 1980, 94% of coral reefs have experienced severe coral bleaching due to global temperature rise and increasing temperature extremes (Morrison, 2020). The IPCC Special Report on 1.5°C (2018) warns that with future global average temperatures of 2°C above pre-industrial levels, virtually all coral reefs around the globe will be lost. Models show only a 5% chance that global temperature increase will be less than 2°C by 2050 (Raftery, Zimmer, Frierson, Startz & Liu, 2017). Since warming will certainly occur in this century, mitigation might not be enough to ensure coral reef persistence into the future. Therefore, adaptation interventions are increasingly explored. Synthetic biology with gene-editing tools can be used to insert genes with an antioxidant enzyme or to introduce synthetic microbes able to produce antioxidants (Levin et al., 2017), enhancing thermal tolerance (van Oppen et al., 2017). Another synthetic biology application can be to reduce crown-of-thorns starfishes, the largest predators of corals in the Indo-Pacific, with a CRISPR-Cas9 gene drive system (Pratchett, Caballes, Rivera-Posada, Sweatman, 2014; Kayal et al., 2012; Hall et al., 2017).

2.3 Actors and principles in biodiversity governance of synthetic biology

2.3.1 Actors

On an international level, in response of the growing recognition that species and ecosystems are threatened and with the added knowledge that biodiversity is of great importance and value, the United Nations Environmental Program (UNEP) summoned the Ad Hoc Working Group of Experts in 1988 to explore a possible international convention on biological diversity (CBD, 2020). By 1992 the convention was opened for signature at the Rio Earth Summit and to date 193 Parties have signed (UN, n.d.). The governing body of the CBD is the Conference of the Parties (COP), meeting every two years for decision-making and the review of priority subjects. Synthetic biology has been a such a priority, as seen in the proposals for new and emerging issues, and in the supplementary agreements “Cartagena Protocol on Biosafety to the CBD” in 2000 and “Nagoya Protocol on Access to Genetic Resources” in 2010 (CBD, 2012).

Implying a transition from “government” to “governance”, Abbot (2012) describes that non-state actors can increasingly play an important role in the regulation of rapidly evolving technologies. The non-state actors often involved in environmental governance are business and industry organisations, environmental organisations, research organisations, and supranational organisations (Nasiritousi, Hjerpe & Linnér, 2016; Arts, 2006).

2.3.2 Principles

The previous section 2.2 shows that synthetic biology applications can provide a means to sustainable development, but that the risks could affect sustainable development as well. Sustainable development is one of the principles Redford et al. (2019) identifies as important in biodiversity governance of synthetic biology. Others are state sovereignty, the precautionary approach, access to information, and consent of local and indigenous peoples, all explained in Appendix B. Important to note is that the "role of knowledge related to risk and scientific uncertainty" is argued to be a key aspect of the precautionary approach (Wiener, 2018, p. 179), and directly related to synthetic biology governance (Zhang, Marris & Rose, 2011).

2.4 Theoretical background: knowledge production and governance

2.4.1 New knowledge production: Mode 2

Gibbons (1994) describes a new knowledge production system called "mode 2" that we have entered, and are now locked-in to (Rip, 2002). Five attributes of mode 2 are described by Gibbons: (1) context of application, explaining that knowledge results from a broad range of considerations, and is thus only produced when intended to be useful to someone, (2) transdisciplinarity, showing that suggestions for solutions come from a knowledge beyond that of a single discipline, (3) heterogeneity and organisational diversity, meaning that knowledge is not coordinated by a central body, but by a great variety of organisations and institutions, (4) reflexivity, showing that sensitivity to the impact of knowledge must be considered when it is produced, and (5) quality control, explaining that a mode 2 knowledge system makes it difficult to determine what "good" science is because its evaluation is not limited to one perspective. A key perspective of mode 2 is that societal spheres are increasingly overlapping, making that society now "speaks back to science" (Gibbons, 1994, p. 50). Gibbons argues that the development towards mode 2 affects scientific activity in its epistemological core.

2.4.2 Post-normal and post-academic science

Linked to the first attribute context of application, Hessels & van Lente (2008) argue that due to the increased importance of science for innovation and decision-making, more emphasis is placed on relevance when producing knowledge. Strategic research, meaning producing knowledge combining relevance with scientific excellence, is the main aspect of "post-normal science", described as science that focusses on research with relevance for policy (Gibbons, 1994; Hessels & van Lente, 2008).

Ziman (2003) explains the concept of post-academic science as characterised by five elements. These elements resemble the attributes of mode 2. For example, the third element "stress on utility" explains that knowledge being produced must have utility, putting pressure on scientists to deliver value for money. Zinman (2003) not only relates this to political utility from the expectation of governments to create science that is policy-relevant, but also to economic utility from industry and the public's expectation of the application of scientific knowledge to practical products or solutions. Taking another example, the fourth element aims to show that competition for money precedes competition for credibility in scientific knowledge production.

2.4.3 Power and knowledge

The third element of post-academic science shows that science is valued primarily as wealth creation or for policy. As a consequence, it is argued that other functions of knowledge production are overlooked, including the creation of critical scenarios and world pictures and the production of independent experts (Hessels & van Lente, 2008; Etzowitz et al., 2000).

According to Gorden & Grant (2013), power is inadequately addressed in theories of knowledge production systems. They argue that power is only indirectly included in the notion of "knowledge is power", and that while this is important, a power-as-strategy approach is needed as well. This approach draws on Foucault's theories, and is reflected by the work of Flyvbjerg (1998), showing that while knowledge is power, power is also knowledge. With the context of power shaping knowledge production, an inseparability of the two is established.

3 Theory

In this chapter, I present the theoretical backdrop underlying the discussion and analysis of the use of knowledge in the governance debate of synthetic biology for biodiversity conservation. These will be presented as related theories stemming from the philosophical foundations of constructivism and poststructuralism. I contend that knowledge has a key role in the governmental processes of synthetic biology for conservation, and as such a discourse approach is adopted in this thesis. This chapter aims to provide the theoretical foundations needed to address different angles of the research question and is thus closely linked with the methodology section. To unpack the use of knowledge in governance processes, I employ the Sociology of Knowledge Approach to Discourse (SKAD), an approach of discourse based on theories of Michel Foucault (Leipold, Feindt, Winkel & Keller, 2019). I supplement this with theories that help explain the constitutive and performative role of knowledge for biodiversity policy.

3.2 Discourse analysis

Hajer (1997, p. 60) defines discourse as "a specific ensemble of ideas, concepts, and categories that is produced, reproduced, and transformed in a particular set of practices and through which meaning is given to physical and social realities". I take a discursive approach to environmental politics, meaning a focus on political and policy processes as discourses dependent on specific social constructions of environmental problems (Clapp & Dauvergne, 2011; Hajer, 1995). As evident in this approach, the ontological and epistemological assumptions made in this thesis hail from a constructivist and post-structuralist perspective. The theoretical framework used in this thesis is the Sociology of Knowledge Approach to Discourse, providing a conceptual language that has gained importance in the study of knowledge in environmental politics (Leipold, Feindt, Winkel & Keller, 2019).

3.2.1 The Sociology of Knowledge Approach to Discourse (SKAD)

Keller (2011) defines SKAD as a theoretical framework, with a perspective of discourse interested in the social production, circulation, and transformation of knowledge. An important concept in the approach is "knowledge societies", representing the social relations and politics of knowledge, with a focus on what Foucault calls problematisations (Keller, 2011). SKAD links arguments of social constructionism with arguments from Michel Foucault.

The arguments of social constructionism mainly stem from Berger and Luckmann (1966), who differentiate between society as an "objective reality" and how this reality is influenced by socialisation processes of subjects. Above all, they emphasise how knowledge is "realised" and "legitimised" through social processes. In their book "The social construction of reality" they analyse structures of knowledge, and question how situated knowledge is internalised and subjectively adopted by actors in the process. In the context of social constructivism, knowledge refers to stocks of knowledge constituted by systems that mediate between humans and the world, including larger theorems of for example globalisation and sustainable development. As social constructionism does not aim to account for processes of knowledge in larger knowledge circulations (Keller, 2011), SKAD includes arguments of Foucault.

SKAD is heavily influenced by Foucault's interests in discourse as a practice of power and knowledge. Therefore, the approach is argued to be more than text analysis by considering (1) knowledge and the power effects of discourses, (2) the infrastructures of discourse production, and (3) the institutional effects and impacts on practice emerging out of discourses (Keller, 2011). To explore the processes of institutionalisation and transformation, Foucault's ideas of discourse as practice, problematisation, and "dispositif" are used (Foucault, 1984). Dispositif, often from French translated to "apparatus" means a by organisations and governments designed infrastructure, with the goal of fulfilling a particular purpose (Foucault, 1984).

Foucault, in this book "The Archaeology of Knowledge" (1970), takes discourse as a central concept that does not only represent external objects but constitutes them. SKAD takes on these concepts by looking at concrete data, including oral or written texts, to analyse how discourses and knowledge are structured and performative. To analyse this structure and performativity within the governance of synthetic biology for biodiversity conservation, I combine SKAD with theories on the politics of environmental knowledge.

3.3 Politics of environmental knowledge

The theories regarding the politics of environmental knowledge are linked to Foucault (1970) and Robbins (2011). Robbins takes knowledge as performative, arguing that since knowledge is situated, we must evaluate it based on its implications. As a result of this performativity, our representations of reality are what reality comes to be. Thus, "representations" are a key concept of these theories. Foucault argues that these representations become naturalised and seen as directly stemming from nature in itself. Representations of nature are selective, reflecting values, preferences, and priorities (Robbins and Bishop, 2008; Turnhout, Hisschemöller & Eijsackers, 2007).

3.3.1 Performative representations

Turnhout, Dewulf, and Hulme (2016) explain that there has been an increase in global knowledge-producing efforts to inform environmental governance. In knowledge for environmental governance, the selectivity of representations is argued to be purposeful, with the aim of being policy or economically relevant or impactful (Lövbrand, 2011; Turnhout, 2016; Halffman & Radder, 2015). This means that knowledge does not just inform policymaking but includes a further role of science being responsive to governance by packaging knowledge into categories that are relevant and fit for policymaking (Turnhout, Tuinstra & Halffman, 2019).

3.3.2 Measurementality logic

Turnhout, Neves, and de Lijster (2014) argue that biodiversity conservation governance, approximately since the 1990s, has been increasingly influenced by neoliberal approaches. The role of categorized science-based measurements forms the basis of this neoliberal approach. The concept of "measurementality" explains the logic when efficiency and effectiveness are used as neoliberal principles in governance (Turnhout, Tuinstra & Halffman, 2019). Even if the knowledge is produced by actors not supporting a neo-liberalised relation to nature, representations of biodiversity are often intended to be relevant and inform decisions. This can be seen in the expression of biodiversity in standardised knowledge of measurements and calculations, which facilitates comparison and exchange (McElwee, 2017; Turnhout, Tuinstra & Halffman, 2019). Turnhout, Neves, and de Lijster (2014) call this "measurementality logic" and base the logic on three discourses in conservation governance.

The first is technocratic discourse, resting on science providing neutral and needed input for policy. The second is managerial discourse, adding values of efficiency to policy-making. The last is policy discourse, arguing that knowledge must be usable and relevant. Turnhout, Neves, and de Lijster (2014) argue that these three discourses together create a system that privileges science-based techniques that, to ensure efficiency and relevance, should focus only on representing nature as ecosystem service. Even if this is not a diverse way of representing biodiversity, nature is increasingly seen to be made up out of ecosystem services in need of management, conservation, or exchange (Robertson, 2012). This is in line with Foucault's (2013) argument of a reorder of the relationship between humans, environment, and society. Knowledge framed in measuring techniques to be meaningful is then not technical, but a matter of practising politics (Behagel, 2012; Mahanty, Milne & Dressler, 2012).

3.3.3 Local and indigenous knowledge

Turnhout, Tuinstra & Halffman (2019) argue that the three discourses on which measurementality is based privileges science-based techniques. This is critical, especially since several studies show the need for a deep inclusion of local and indigenous knowledge. For example, Soberon & Peterson (2015) argue that biodiversity governance should be deeply rooted in participation of local actors and their knowledge, to successfully deal with the complex and diverse issues of biodiversity governance. This is due to indigenous and local knowledge systems being extremely valid and useful to enhance our understanding of the governance of biodiversity and ecosystems, creating a need for synergies across knowledge systems (Tengö, Brondizio, Elmqvist, Malmer & Spierenburg, 2014).

3.3.4 Post-normal science and strategic research in biodiversity governance

Lastly, it is of importance to link the concepts of post-normal science and strategic research to the politics of biodiversity knowledge. Rauschmayer, van den Hove, and Koetz (2009) argue that biodiversity governance on an EU level has been through three shifts: (1) a shift is from a top-down administrative way of looking at policy towards a more flexible and collective approach, (2) a shift towards post-normal and democratic types of science, and (3) a shift from a conservation focus towards more anthropogenic ecosystem's services approach. The three shifts reflect and incorporate the theories of strategic research and post-normal science.

Hessels & van Lente (2008) link the concept of strategic research, meaning produced knowledge with the aim of relevance, to performative knowledge. They argue that due to the roles of complexity and uncertainty within environmental governance, a reassessment is needed for the role of scientific research. Global knowledge influences what governance focusses on, who influences governance, and how governance supports already existing sources of power (Turnhout, Dewulf & Hulme, 2016). This means that there is nothing neutral about placing knowledge into categorisations to make it relevant for policy.

4 Methodology

This study relies on discursive methods, conducted in parallel with a close reading of literature and theory. Developing a strict methodological framework for analysis mainly based on theories related to Foucault, is beside difficult also not desirable (Bäckstrand & Lövbrand, 2019). Instead, it is argued that we should see theories and studies as analytical tools and as conceptualisations that can enhance the investigation of forms of governance (Walters, 2012). Before starting the data analysis and discussion of this thesis, guidelines for acquiring the data to answer the research questions are established, and the logic behind such methods explained.

4.1 Research design

To start broadly, I examine my research question according to the philosophical design. This design uses concepts, theories, and models as tools of argumentation to explore and challenge the relevance of logic in debates (Burton, 2000). Burton (2000) discusses three framings of analytical tools in this research design: (1) ontological, describing the nature of reality, (2) epistemological, studying the nature of knowledge, and (3) axiological, studying values and how those can be related to interests. I use discourse analysis as an approach, following the theory of this study. There are multiple approaches to using discourse analysis, but the core is explained by Dryzek (1998) describing the process of language constructing our understandings that condition how a phenomenon is defined and addressed. A key feature of this is a constructivist nature (Potter, 1997), that recognises many viable renditions of discourse. Due to the process of a depiction of reality being built up, the formulation of an argument in one way instead of another is crucial (Billig, 1991).

Discourse analysis is an approach that suits the aim of this research due to the characteristics of a critical reflection of how existing reality is perceived, providing is a good starting point for analysing the justifications used in the governance of synthetic biology for conservation. Harvey et al. (1996) explains that discourse analysis offers us tools to see how reality came about, including its implications, which allows me to analyse how knowledge in the governance of synthetic biology for conservation is understood and given meaning, as well as how the arguments are defined to form responsibilities for actors in the debate.

4.2 Data collection

4.2.1 Context of study

Research into biodiversity conservation usually focusses more on identifying strategies to cope with climate impacts, and less on how governance enables or constraints actions (Wyborn, Kerkhoff, Dudley, Guevara, 2016). Wyborn et al. (2016) argue for increased understanding of the implications of values, and the ability to engage with the governance of adaptation when it involves uncertainty, complexity, and change. The governance of biodiversity related to synthetic biology is a prime example of adaptation in the context of uncertainty, complexity, and change.

Projections of ecological change, including biodiversity loss, are argued to be determined by political processes and representations (Dunlop, Parris & Ryan, 2013; Stein et al., 2013). The role of knowledge, and its inclusion or exclusion, in political processes is interesting due to the implications it brings in governance (Leach & Davis, 2012; Wyborn, 2016). Turnhout et al. (2019) argue that environmental knowledge is next to partial, situated, and selective, also performative. This brings a great opportunity to gain insight into how biodiversity knowledge produces effects, in the context of governmental processes surrounding synthetic biology with the aim of biodiversity conservation.

International governance processes are the focus of my study for two main reasons. First of all, it is the level on which most debates are currently taking place. Second of all, if decisions were to happen, they would influence ecosystems and humans worldwide. This makes global cooperation and decision-making a needed and important topic. By including both private and public sphere engagement, I acknowledge biodiversity governance to be a collective process involving interactions of various actors.

4.2.2 Justification of sources

The analysis is based on four types of primary sources: (1) governmental documents at international level, (2) reports of international organisations, (3) synthetic biology roadmaps, and (4) scientific papers. Some considerations should be made when deciding on a selection of sources for analysis (Philips and Hardy, 2002). I selected the sources based on three main criteria. The first criterion for these sources is their international scale as explained in the context of study. Especially the UN CBD plays a key role in the development of these documents, due to their explicit role in the governance of synthetic biology for biodiversity conservation.

Another main criterion is that all sources should be developed from a governance perspective or with the purpose of influencing governance. Source types 2 to 4 mainly come from non-state actors. The reason for the inclusion of non-state actors is to enable a shift from "government" to "governance". Abbot (2012) describes that non-state actors can increasingly play an important role in the regulation of rapidly evolving technologies. Business organisations, environmental organisations, research organisations, and supranational organisations are often involved in environmental governance (Nasiritousi, Hjerpe & Linnér, 2016; Arts, 2006. As seen in Table 2, these are all represented in the analysis through the identification of these non-state actors described above producing knowledge for the governance of synthetic biology with the aim of biodiversity conservation. The sources are thus in accordance to the "Triple Helix Model", which assumes that industry, university, and government are increasingly interdependent and should be studied in co-evolution (Etzkowitz and Leydesdorff, 2000). Leydesdorff and Meyer (2006) further see the model as a forcing of researchers to take into account the three spheres together when researching the dynamics of knowledge production and innovation.

A last criterion is a focus on synthetic biology or related subjects, like genetic engineering and gene drives, for the use of biodiversity conservation purposes. A reflection on how synthetic biology influences the documents is necessary and can be read in Table 2. While every source includes a focus on synthetic biology or related subjects, the extent of the focus differs. In some of the sources, for example the older CBD documents, synthetic biology plays a smaller role than in others. In Appendix C, I discuss the role of synthetic biology and its relevance in this study for each of the 24 individual sources. These sources can be seen as an empirical site, allowing me to examine how knowledge is standardised, situated, and performative concerning the governance of synthetic biology for biodiversity conservation.

Table 2. List of (grouped) sources used in the analysis of this study, including their description and their relevance for analysis.

Instrument	**Description**	**Relevance**
1 -12. UNEP CBD Protocols, Reports, and Decisions	Includes proposals for new and emerging issues, protocols, reports, and decisions.	The governing body of the CBD is the COP, meeting every two years for decision-making and the review of priority subjects. Synthetic biology is one of those priority subjects. Due to the focus of this study on the connection between synthetic biology and international biodiversity governance, these sources are key for analysing governance of synthetic biology. The sources range from the CBD's first official decision on synthetic biology, to protocols creating larger legal certainty for the use of synthetic biology.
13. EU Commission Future brief	Synthetic biology and biodiversity future brief. 2016.	The document aims is to be an information service for policy on an international level, creating a governance perspective on this knowledge. This future brief provides expert forecasts of issues on the horizon, specifically based on synthetic biology for biodiversity conservation.

14 + 24. Scientific articles	Article on consolidated G20 synthetic biology policies Article giving advice on governance related to synthetic biodiversity conservation.	G20 are a group economically influential: together they make up 90% of GDP and 80% of world trade. This includes most trade and economic benefits of synthetic biology. The report puts together policies from these countries on synthetic biology and their role for sustainable development, including conservation. The other scientific article aims to highlight the advantages and possibilities of synthetic biology. More importantly, it also provides guiding principles for future governance of synthetic biology. As mentioned earlier, governance is increasingly expected to be science-based, and thus this article has a role in the governance of synthetic biology for the conservation of biodiversity.
15. Semiconductor Synthetic Biology	Roadmap for synthetic biology 2018	The National Science Foundation (NSF) and the SRC, a technology research consortium, together developed this roadmap for synthetic biology. Both are important non-state actors focussed on research, science and technology, and thus key to this analysis. The organisations also play an active role in putting this roadmap into practice by assembling a community to develop synthetic biology technologies.
16 - 18. European Strategy Forum on Research Infrastructures (ESFRI)	Strategic Report on RIs in Europe 2018. Land analysis on RIs in Europe 2018. Projects and landmarks on RIs in Europe.	The mission of ESFRI is to support a strategy-led approach to policy-making on research infrastructures and to facilitate multilateral initiatives leading to the better use and development of research infrastructures at an international level. This mission is highly linked to the governance of synthetic biology. The strategy report aims to reinforce the strategic goal of long-term engagements that carry out research and operation of infrastructures. The Landscape analysis report provides the current context of relevant infrastructures available to scientists and technology developers, including synthetic biology. The projects and landmarks report provides descriptions of projects, and describes the political support of ESFRI.
19. Engineering Biology Research Consortium (EBRC)	Engineering Biology: A research roadmap for the next-generation bioeconomy 2019.	The EBRC is a non-profit partnership between private and public actors with the goal of advancing engineering biology to address global needs. This research roadmap aims to address the research and application of engineering biology, including synthetic biology. Being a key example of how public and private actors are intertwined in the governance of synthetic biology, this roadmap is a source for analysis.
20. IUCN	Report on genetic frontiers for conservation: technical assessment 2019	The IUCN is a supranational organisation composed of both governments and civil society organisations, bringing together organisations and experts to conserve nature. This is another example of the close relationship between state and non-state actors in governance. The report aims to provide knowledge and information for policy. In July 2020, this report will provide the basis for the development of policy recommendations, thus making it an essential report for analysis.
21-23. Roberts, J. et al. Delborne, J. et al. Farooque, M. et al.	Workshop reports on synthetic biology governance: a Delphi study, a public engagement study, and a stakeholder perspectives study	The genetic Engineering and Society Centre in collaboration with the North Carolina State University, and with funding from the Sloan Foundation program on synthetic biology, workshops were hosted with large and diverse group dialogues and mapping exercises to evaluate the current and ideal governance of synthetic biology. These reports are the result of the workshops, and essential for analysis since they (1) showcase expert's view on what data and information is needed for governance, (2) describe public engagement in the governance of synthetic biology, and (3) the workshop collects information to inform decision-making about research, testing, and the potential deployment of technologies.

4.3 Data analysis

While coding usually takes place in traditional content analysis (Bryman, 2016), Potter and Wetherell (1994) argue that coding does not have to be part of discourse analysis itself but can be done to make analysis easier. Based on similar studies, including those of Gilbert, Gilbert, and Mulkay (1984) and

Bäckstrand & Lövbrand (2019), I created a discursive framework as seen in Table 3. In this table, according to three framing parameters, I developed questions for analysis.

Table 3. Discursive framework, in which framing parameters and questions can be used as an analytical guide. The three framing parameters follow the main research questions of this thesis.

Framing parameters	**Analytical questions**
Mode of argument	Which agents are defined to be responsible for the governance of synthetic biology for conservation? How are the roles of agents in the debate formed? How do these roles influence knowledge creation? What are the implications of these roles?
Representation	How are problems of biodiversity conservation defined? How does synthetic biology fit in those problem definitions? What are the values intrinsic in this representation? How does this influence the human – and non-human nature relationship? What are the implications of these representations?
Terms of debate	How are arguments formulated? What reasons inform and justify the use of synthetic biology for conservation? What kinds of knowledge are considered valid? Which principles justify particular forms of governance? What are the implications arguments and values?

To extract the data from the sources, all documents are first imported into EndNote, which allows for similarity and quick switching between sources. The analysis starts with a close reading of the sources, after which the segments of data are categorised through an initial use of the discursive framework, grouped into responsibilities, representations, and arguments. This enables the emergence of themes, as well as the significance placed on them. After further analysis, sub-themes emerge, as well as their scope and their relationships. The themes and sub-themes are placed on visual representations in the form of tables and figures, allowing to keep the integrity of the sources while analytically integrating the themes in relation to the theory.

4.4 Limitations

A first limitation related to my choice of study, and of discourse analysis as theory and method in general, is the difficulty of structure (Waitzkin, 1993). The discursive framework is a needed attempt, but even the framing parameters are sometimes overlapping and hard to separate. Due to the nature of the questions, it is difficult to keep the topics separate from each other within one box. However, I argue that the framework is not meant for providing a clear map of the governance of synthetic biology for conservation. Instead, it is a way of guiding analysis towards a better understanding of the results.

Secondly, discourse is often criticised for its contextual nature, through which the analyst has an important role in deciding how far to go with the inclusion of external factors (Schegloff, 1997). This means a limitation related to the researcher's bias, making my interpretations different from a researcher with other worldviews and experiences. While reducing this bias is hard, I aim to cope with this limitation by explicitly outlining my decisions and the justifications behind those decisions.

Lastly, the anti-realist inclination of discourse analysis is a source of controversy. It is argued that this type of theory and methodology makes the research, and reality itself, too abstract (Reed, 2000). The extensive use of the term "discourse" is included in this limitation, due to the considerably wide range of different understandings and applications it can have. Alversson & Karreman (2000) warn for the danger of discourse analysis becoming too broad to be meaningful. I attempt to mitigate this limitation in two ways: (1) I apply discourse analysis to a clear context, as can be read in section 4.2.1, and (2) I emphasize, as can be read in section 3.1, that it should be clear that discourse does not have a broadly agreed-upon meaning. The importance is that language is crucial to understanding the world, and discourse analysis approaches are the tools through which this is allowed to happen.

5 Analysis

The analysis follows the framework and the research questions, dividing this chapter into three main sections. Section 5.1 focusses on the responsibilities of agents in governmental discussions and describes the roles given to governmental organisations, scientists, and citizens. Then I identify and describe the representations of synthetic biology and conservation in section 5.2. In the last section, I analyse and discuss the way arguments are used, with a focus on knowledge generated for policy. Due to the importance of knowing where exactly the arguments come from, Appendix D shows all quotes used in this analysis and where you can find them. The analysis is conducted in close link with the theory, and implications are already discussed in each section of this chapter. At the end of each section, a summary will be presented in the form of tables to display the findings in a way that allows for a systematic reading, while at the same time exemplifying how the framework was used for analysis.

5.1 Mode of argument

5.1.1 Roles and responsibilities of actors involved in the governance processes of synthetic biology for biodiversity conservation

Governmental organisations

The sources show governmental organisations to have two main roles in the governance of synthetic biology for biodiversity conservation. The first is the responsibility to develop programs and assessments based on science and in accordance with the economy. This responsibility is communicated through encouragement: *"Parties are encouraged to cooperate on research and information exchange on any socio-economic impacts of living modified organisms"* (Source 1), or through stating it as a duty: *"To carry out scientific assessments concerning organisms, components, and products resulting from synthetic biology techniques"* (source 8). Source 12 also stressed the need for: *"urgent action to address the drivers of biodiversity loss, as well as those of climate change and land degradation, in an integrated matter, in line with the findings of the global assessment report on biodiversity and ecosystem services of the intergovernmental science-policy platform on biodiversity and ecosystem services* [IPBES] *to achieve the 2050 vision."*. Source 19, with the creation of a technical roadmap, hopes to *"establish a resource for the research and research-support community … that* *portrays the importance and impact of engineering biology tools and technologies"*, in which the research-support community includes policymakers and funding bodies. All of these sources shown the importance of governmental organisations to base decisions on science and to develop programs in accordance to the economy.

The second role of governmental organisations is to facilitate participation and provide access to information, with a focus on indigenous and local communities. Source 10 states that parties have the responsibility to: *"promote and enable public and multi-stakeholder dialogues and awareness-raising activities on the potential benefits and potential adverse effects of organisms, components, or products resulting from synthetic biology techniques."*, and the responsibility of: *"Involving all relevant stakeholders and with the full and effective engagement of indigenous peoples and local communities."*. Source 20 also describes it to be well established that: *"Indigenous and local communities are key actors in research, governance, and decisions around synthetic biology and engineered gene drive for conservation"*. Source 12 argues that the IPBES is to be used for advising to reach the *"enabling conditions"* of traditional knowledge and awareness, which includes communication and education.

Citizens and media

Citizens have the responsibility to get informed and involved in governmental processes related to synthetic biology for biodiversity conservation. The media is seen to influence this responsibility and is described to have the role to stop feeding into irrational denials of biodiversity loss and fears of synthetic biology. The responsibility of mainstream media comes from the critique that, to date, there has been too much focus on: *"extraordinary stories of de-extinction, neglecting the more nuanced benefits or risks for biodiversity and complex ethical and social implications."* (source 13). Another source highlights that scientists are not alone in their responsibility to be involved in policymaking: *"scientists are also not the only voices; society needs to be involved and may decide that some research should not proceed"* (source 20).

Scientists / Science

The roles of scientists can be categorised in two main responsibilities. The first is the responsibility to work interdisciplinary, embrace new technologies, and work towards solving issues of those new technologies. These related responsibilities are explicit in the sources. In terms of solving issues, source 19 states goals within synthetic biology applications. Within *"environmental biotechnology"* goals are ranging from addressing and mitigating climate change to controlling deployment of engineered organisms to improve ecosystem biodiversity. Under each of these goals, *"science aims*" are listed which conveys the responsibility of science towards achieving these goals. Examples of these science aims are to: *"enable and advance carbon sequestration from the environment"* and to *"improve engineering of select insects for safe, effective environmental deployment".*

As for the responsibility to work interdisciplinary, it is argued that a *"deeper collaboration between conservation scientists and synthetic biologists will be necessary to both develop evidence and to create the frameworks for understanding and using that evidence."* (source 20). Other sources argue for a wider collaboration beyond that of conservation scientists and synthetic biologists, emphasizing that *"broad interdisciplinary and ongoing engagement with a wide range of partners will be essential to guiding research trajectories in the most meaningful directions."* (source 19). Summing up this responsibility, source 24 argues that *"21st-century conservation philosophy should embrace concepts of synthetic biology, and both seek and guide appropriate synthetic solutions to aid biodiversity."*.

The second responsibility of scientists is the provision of measures and assessments on which decision-making related to synthetic biology applications for the conservation of biodiversity is to happen. Scientists are invited to continue to *"provide information in support of the process to develop the post-2020 biodiversity framework."* (source 12). Source 16 lists factors a research infrastructure needs to adhere to, including: *"identify and adopt measurable key performance indicators addressing both excellence of scientific services and sustainability*" and *"have resources ben policy adequate to guarantee effective operation*". The extent of this responsibility can even be seen in the aim of the documents and the organisations themselves. For example, the aim of source 13 is to provide *"the latest environmental policy-relevant research"* and the aim of source 20 is to serve *"as input to the development of policy recommendations"*. Source 16 mentions that the open research data system has grown from a need within the discipline to *"make possible a much higher level of interdisciplinarity and potentially a higher impact of solid scientific evidence into decision-making, planning, and strategy at a societal level."*. A summary of these findings can be found in Table 4.

5.1.2 Implications

Governance principles

Explanations and implications of the roles and responsibilities described can be analysed through reviewing the theory. First of all, the governance principles, as explained in section 2.3.2, can help explain the responsibilities of the governmental organisations. Principles of sustainable development, the precautionary approach, and consent of local and indigenous peoples can be linked to the responsibilities of governmental organisations. Before decisions are taken regarding synthetic biology for conservation, due to inherent characteristics of risk and scientific uncertainty, impact assessments are to be conducted and communicated with all actors involved. Citizens and local or indigenous communities are included in those actors and are seen to have a responsibility to be involved in the governmental processes.

Mode 2 knowledge production and post-normal science

Principles of "mode 2" knowledge production from Gibbons (1994) also apply, mainly to both of the identified responsibilities of scientists. One of the principles is transdisciplinarity, seen in the role of scientists from the conservation field and the synthetic biology field to work together to solve issues of synthetic biology applications for biodiversity conservation. Another principle is the "context of application", stating that knowledge is only produced when useful. This principle can be linked to the second role of scientists to provide measures and assessments about possible synthetic biology applications for biodiversity conservation, on which policy-making is to happen. Additionally, a link to post-normal science can be made, due to the core characteristic of post-normal science to be relevant for policy (Hessels & van Lente, 2008).

Relevance and impact

Furthermore, the first and third discourse on which the measurementality logic is based, technocratic discourse and policy discourse, can be linked to the identified responsibilities. The technocratic discourse states that science provides neutral and needed input for policy and the policy discourse indicates the priority of knowledge to be usable and relevant for policy (Turnhout, Tuinstra & Halffman, 2019). This dominant discourse for research to make any type of policy impact is dangerous, mainly because of the questions that aren't asked when aiming for making an impact, including: "What is it we are impacting?", "What are the consequences of that impact?", "Who benefits from the impact?", and "Who loses from the impact?".

Turnhout, Tuinstra & Halffman (2019) describe how relevance and impact of knowledge is reached by packaging knowledge into categories fit for policymaking. When relevance and impact for policy are focussed on in scientific research, other functions of knowledge production can be overlooked (Hessels & van Lente, 2008; Etzowitz et al., 2000). Due to the focus on scientist's responsibility to provide knowledge on how synthetic biology can help create or help limit categorised biodiversity services, there is less focus on other functions of knowledge production, including for example creating independent and critical scenarios of synthetic biology for biodiversity conservation.

Categorisation of biodiversity

Lastly, it is argued multiple times in the sources that the IPBES is an important actor when it comes to governmental organisations fulfilling their roles. Here, a link can be made to science being relevant when knowledge is packaged into categories fit for policymaking. Placing knowledge into categories that represent biodiversity as measurable ecosystem services to be relevant to policymaking is a key aspect of the IPBES. The responsibilities of actors are closely linked to how concepts such as synthetic biology and biodiversity are represented. These representations are discussed in the next section.

5.1.3 Summary of responsibilities

Table 4. Summary of findings for research question 1.

<table>
<tr><td colspan="5">RQ 1. What are the roles and responsibilities given by actors, by themselves or by other actors, in governmental discussions of synthetic biology for biodiversity conservation?</td></tr>
<tr><th>Category</th><th>Sub-category</th><th>Findings in sources</th><th>Theory</th><th>Findings</th></tr>
<tr><td rowspan="2">Governmental organisations</td><td>Progress based on science, in accordance with the economy</td><td>Policy action needs science-based. Source 1, 7, 8, 11, 12, 14, 19, 24</td><td rowspan="6">Principles of Mode 2 knowledge production: “transdisciplinarity” and “context of application

Post-normal science

Measurementality logic

Technocratic discourse

Policy discourse</td><td rowspan="6">Due to the inherent characteristics of risk and scientific uncertainty, impact assessments are to be conducted in collaboration with all relevant actors, including citizens, who have the responsibility to get involved.

Knowledge is only produced transdisciplinary and when considered useful by a group. Link to post-normal science due to the characteristic of knowledge to be relevant for policy. For example, the IPBES (a science for policy organisation) is seen to be a key actor for governmental organisations to fulfil their roles.

Placement of knowledge into categories that represent biodiversity as measurable ecosystem service to be relevant for policymaking.

Focus on relevance for policy or economy overshadows other functions of knowledge production.</td></tr>
<tr><td>Facilitate participation</td><td>Promote education, awareness, and participation. Source 1, 3, 7, 8, 10, 11, 12, 20</td></tr>
<tr><td rowspan="2">Citizens and media</td><td>Get informed and involved</td><td>Society needs to be involved. Source 20, 24</td></tr>
<tr><td>Stop feeding into fears and denials</td><td>Mainstream media to stop feeding irrational fears and show benefits as well. Source 13, 17</td></tr>
<tr><td rowspan="2">Scientists</td><td>Interdisciplinary problem-solving, embrace new technologies</td><td>Develop evidence and create frameworks for understanding and using that evidence by working interdisciplinary. Source 13, 18, 19, 20, 24</td></tr>
<tr><td>Provide measures on which decision-making is to happen</td><td>Research should aim to provide measures on which to make political decisions. Source 1, 10, 12, 13, 16, 17, 20, 24</td></tr>
</table>

Note. Appendix D provides the exact wording and full quote of the all the sources mentioned in the Table.

5.2 Representation

5.2.1 Representations of biodiversity conservation and synthetic biology

Biodiversity conservation

Current biodiversity conservation practices are seen to be deficient to a certain extent, thus creating a need for urgent action. The sources represent current biodiversity conservation practices as *"not slowing the overall rate of biodiversity loss."* (source 24). Due to biodiversity loss, conservation faces *"challenges of unprecedented severity that must be coherently and consistently addressed urgently"* (source 12).

Furthermore, biodiversity in itself is often represented as a service and a classification of nature. In source 6, the CBD focuses on the *"sustainable use"* of ecosystems. As mentioned before in the previous section, an important organisation mentioned multiple times by different sources is the IPBES, for example in source 12 when the organisation is argued to be able to help establish the *"use and value of nature"*. The IPBES aims to create scientific assessments for informing policy.

Synthetic biology

In the sources, it is evident that the concept of synthetic biology as a whole is seen as an issue with ethical and uncertain roots. For example, this is seen in source 6: *"Synthetic biology raises ethical questions around the level of predictability of its positive and negative impacts, and how to weigh anticipated impacts and the possibility of unexpected impacts."*.

Even though synthetic biology is represented as uncertain, it is also seen as an effective tool for conservation. The sources represent synthetic biology as being able to *"propose solutions to some of the greatest environmental challenges"* (source 13) and to be *"utilized towards solving the intractable problems of biodiversity conservation"* (source 24). Other sources supporting the representations explained here can be seen in Table 5 below. The full quotes of the supporting sources are listed in Appendix D.

5.2.2 Implications

Performative representations

It is important to first, in close link with the theory, contextualise the representations of synthetic biology and biodiversity conservation as performative. How terms and concepts are represented is argued to be purposeful, with as aim to be policy and economically relevant (Lövbrand, 2011; Turnhout, 2016; Halffman & Radder, 2015). This aim of relevance has been discussed in the previous section, including that this relevance is reached through the packaging of knowledge into categories fit for policymaking. The IPBES, again appearing in this section, is given the role of establishing biodiversity and the *"use and value of nature"*. The implication is that biodiversity is represented as being made up out of classifications and services, due to the relevance of these classifications and measures for policy and the economy. How this measurementality logic becomes apparent in the governance of synthetic biology for biodiversity conservation will be discussed in the next two subsections.

Synthetic biology as a preferred tool

A measurementality logic is conductive to synthetic biology due to the ability of synthetic biology applications to efficiently create a nature with, measurable, ecosystem services. For example, coral reefs can be represented as biodiversity consisting of various measurable ecosystem services. If the focus is mainly on the most effective and efficient way to ensure the services gained from the coral reef ecosystem, synthetic biology techniques focussed on adaptation would be preferable than other options. More specifically, enhancing thermal tolerance of coral reefs through inserting genes with antioxidant enzymes (Levin et al., 2017; van Oppen et al., 2017) or using a CRISPR-Cas9 gene drive system to reduce crown-of-thorns starfishes (Hall et al., 2017), are then viewed as more effective than say, mitigation approaches without synthetic biology focussing on reducing anthropogenically caused greenhouse gasses in getting the same services from biodiversity.

The discourse of representing biodiversity as an ecosystem service is key to the governance of this issue. Synthetic biology as a scientific discipline has, when focussing on biodiversity conservation, at its core an aim to create a nature with more ecosystem services. By representing biodiversity as service and classification of nature, and synthetic biology as a clear-cut tool and condition for the use and value of this nature, a way of seeing is produced in which synthetic biology is better at, and even needed to, reach set goals and getting nature's services.

Naturalisation

The representations of synthetic biology and biodiversity become naturalised, and as a result we as humans begin to view nature differently, leading to us living in and with a different nature. Hulme (2010) and Smith (2010) strongly relate this to the concept of neoliberalism, arguing that pricing nature's services, or humans' disservices to nature's services, are of doctrinal importance in policy, resulting in a climate policy dominated by market-based instruments. Hulme (2010) argues that two changes are needed: (1) a more in-depth exploration of climate politics and how it operates within and beyond government scales, and (2) to "re-express" contingencies of climate policy implementation, in particular neoliberal thinking and climate governance. Although knowledge was not Hulme's main focus when analysing climate policy, the understanding of how knowledge, power, and scale are inseparable in the relationship between humans and non-human nature are essential.

The context on which to perform ethical and just decision-making for an inhabitable world is changing rapidly, partly due to fast innovations in the technology of synthetic biology. The context is also changing on the level of society – with the creation of different views on technology and nature in itself – especially among the newer generation growing up with synthetic biology being a fact of life. The worldviews around technology and nature that we create have a powerful say in the outcome of decisions within environmental governance. While some argue that technology is an obstacle to experiencing nature (Lauv, 2011), others argue against there even being a distinction between experiencing nature and technology (Reuss & Cutcliffe, 2010). Although our understandings of nature and what is natural have always been changing, the pace of this change has accelerated, with a focus on the shift between nature and technology.

To clarify, I argue here that the power of knowledge goes beyond policymakers following scientific advice. It is about knowledge having the power to define and measurementalise nature and reorder the relationship between humans and non-human nature.

5.2.3 Summary of representations

Table 5. Summary of findings for research question 2.

<table>
<tr><td colspan="5">RQ 2. How are synthetic biology and biodiversity conservation represented in governmental processes?</td></tr>
<tr><th>Category</th><th>Sub-category</th><th>Findings in sources</th><th>Theory</th><th>Findings</th></tr>
<tr><td rowspan="2">Biodiversity conservation</td><td>Current practices deficient</td><td>"Conservation must be addressed urgently" Source 12

More efficient ways to respond to biodiversity challenges needed. Source 6, 24</td><td rowspan="4">Performative representations

Measurementality logic

Naturalisation

Reorder human and non-human nature relationship (Foucault)

Neoliberal policy (Hulme)</td><td rowspan="4">Representations of synthetic biology and biodiversity conservation as performative and purposeful, with the aim of policy or economic relevance.

Relevance reached through packaging of knowledge into categories fit for policymaking.

By representing biodiversity as service and classification of nature, and synthetic biology as a clear-cut tool and condition for the use and value of this nature, a way of seeing is produced in which synthetic biology is better at, and even needed to, reach set goals and getting nature’s services.

Example: enhancing thermal tolerance of coral reefs through inserting genes with antioxidant enzymes or using a CRISPR-Cas9 gene drive system to reduce crown-of-thorns starfishes, are then viewed as more effective than say, mitigation approaches without synthetic biology focussing on reducing anthropogenically caused greenhouse gasses in getting the same services from biodiversity.

Pricing nature’s services, or humans’ disservices to nature’s services, are of doctrinal importance in policy (neoliberal policy).

Although our understandings of nature and what is natural have always been changing, the pace of this change has accelerated, with a focus on the shift between nature and technology.

Knowledge having the power to define and “measurementalise” nature and reorder the relationship between humans and non-human nature, influencing governance.</td></tr>
<tr><td>Biodiversity as service and classification of nature</td><td>"Use and value of ecosystems" Source 6

"IPBES to establish use and value of nature" Source 12</td></tr>
<tr><td rowspan="2">Synthetic biology</td><td>Issue with ethical and uncertain roots</td><td>Raises ethical questions. Source 6, 13

"Recognition of scientific uncertainties" Source 5</td></tr>
<tr><td>Effective tool for conservation</td><td>Synthetic biology may propose solutions. Source 13, 17, 24

Technology as enabling condition for use and value of nature. Source 6, 12</td></tr>
</table>

Note. Appendix D provides the exact wording and full quote of the all the sources mentioned in the Table.

5.3 Terms of debate

5.3.1 Overarching term of debate: effective and efficient approaches to biodiversity conservation

The representation of current biodiversity conservation being deficient and needing urgent action works as a catalysator for the problem-solving narrative that focusses on efficient, effective, and immediate approaches to biodiversity conservation. Technological mastery is used as an argument to respond to and solve issues of, urgent challenges of biodiversity loss. Synthetic biology as an example of such technological approach and tool for effective and efficient biodiversity conservation can be found in many of the sources, for example: "*applications of synthetic biology aim at developing more efficient and effective ways of responding.*" (source 6). Arguments used for successfully developing these efficient and effective technologies centre around increasing collaboration, research, and expansion.

Collaboration, scientific research, and expansion for effective technologies

To successfully implement synthetic biology for conservation, sources emphasise the *"need for a coordinated, complementary and non-duplicate approach on issues related to synthetic biology under the Convention and its Protocols, as well as among other conventions and relevant organizations and initiatives."* (source 11), showing the argument of collaboration. Source 21 also adds to this argument by reasoning that ideal governance *"begins with efforts to obtain stakeholder buy-in."*. Collaboration between conservation scientists and biologists is deemed highly necessary (source 20), but engagement should also occur with NGO's, governmental organizations, universities, funders, and critical communities of interests (source 23).

An example of all three, collaboration, research, and expansion, can be found in source 12 when priority areas for governance are listed. One such priority area is *"technical and scientific cooperation work in support of the post-2020 global biodiversity framework"*. Within this priority area, two focal areas are identified. The first is science-based: *"the promotion of research cooperation to foster effective use of scientific information to support evidence-based policies, actions, tools, and mechanisms"* and the second is based on technological expansion: *"the development, transfer, promotion, and use of appropriate technologies, including indigenous and traditional technologies and knowledge to scale up solutions".* A summary of these findings can be found in Table 6.

Values

Values play a key role in what knowledge is considered valid. Drew Endy (as cited in Specter, 2009) asks the question: *"What if we could liberate ourselves from the tyranny of evolution by being able to design our own offspring?"*. This sentiment is shared among many synthetic biologists who see a pressing need to go beyond our current evolutionary system (O'Malley & Koonin, 2011). Since our ideas and decision-making on these issues are dependent on how people view and value aspects of for example technology, science, risk, and nature, values are of key importance.

In governmental processes of synthetic biology for the conservation of biodiversity, important values can be categorised. The values are all related to the arguments of efficiency and effectiveness for problem-solving. Next to the value of collaboration already discussed, values of affluence and progress can be identified in the sources. The value of affluence is reflected in synthetic biology since it is able to *"cause major economic shifts with positive and negative consequences."* (source 6). Economic well-being is a major component in the principle of sustainable development, and whether synthetic biology for conservation will be economically beneficial is seen as important. Wealth plays a key role, since synthetic biology could potentially ensure benefits from biodiversity at a lower cost than current biodiversity practices. This is an example of a modernisation dynamic found in the sources. Furthermore, some sources highlight the value of progress and the importance of embracing these technologies: *"The way forward is to acknowledge the potential benefit of new technologies, make measured decisions to integrate new technologies into conservation solutions, and implement ongoing oversight."* (source 24).

5.3.2 Implications

Measurementality logic

Several links to the theory can be made. First of all, the managerial discourse, in which the values of efficiency and effectiveness or important in policy, can be seen in the sources. Turnhout, Tuinstra & Halffman (2019) explain that the three discourses on which the measurementality logic is based on creating a system focusses only on representing biodiversity as measurable ecosystem service. Next to the representation aspects explained before, it is also argued that the system gives privilege to science-based techniques of knowledge production to ensure efficiency and effectiveness. The privilege to science-based techniques raises the question of how local and indigenous knowledge systems are included in governmental processes of synthetic biology for the conservation of biodiversity. It also brings us to a point of discussion in which a contradiction occurs between theory and data.

Local and indigenous knowledge systems

Nadasdy (2003) and Forsyth (2004) argue that we need to promote the rights of the holders of local and indigenous knowledge and change our understanding and definition of this knowledge. Similarly, Berkes et al. (2000) argues that we need to extend understandings of local knowledge beyond highlighting differences between local knowledge and science, to emphasize the value of local knowledge to biodiversity management. However, in governmental processes related to synthetic biology for the conservation of biodiversity, the inclusion of local and indigenous actors seen to be of high importance and value. For example, a key role of the Ad Hoc Technical Expert Group of the CBD is to: *"include a balanced representation of Parties from all regions and include representations of indigenous and local communities and all relevant stakeholders."* (Source 8). The value of local and indigenous communities is frequently referred to in the sources, often expressed in a full commitment to incorporating local and indigenous knowledge systems. The incorporation and value of this knowledge is a key principle not just in the synthetic biology for biodiversity debate but in general within UN CBD. As can be seen in Table 6, local and indigenous knowledge and its value for biodiversity conservation is emphasized and promoted in a great degree of the sources analysed.

Furthermore, Lahsen (2016) argues that the debate surrounding local and indigenous communities is framed as if little connections between science and indigenous and local communities currently exist. Participatory knowledge-making has been suggested as an alternative system for incorporating different types of knowledge. Lahsen (2016) argues this will problematise naturalised and taken for granted classifications and ways of working, and by doing so refuse the logics of measurementality - preventing premature consensus due to the allowance of a space for actors to enact their role however they see fit, and where all relevant knowledge holders can continuedly question and contest.

Lastly, following the arguments of this thesis, local and indigenous knowledge must also be understood as situated and performative, to be evaluated based on how it is produced and interpreted. The knowledge being local does not change the situation of the measurementality logic to make knowledge fit for policy implementation. It is likely that current connections between scientists and other communities are already in place, but that these are not seen or liked by the measurementality logic.

Post-normal science

A strong theoretical link to elements of post-normal science can be made. Specifically, the element of knowledge produced needing to have economic or political utility, and the element explaining that the competition for money precedes the competition for credibility in scientific knowledge production. Taking a broad perspective, science focussing on synthetic biology can lead to greater understandings of genomes and can help towards tackling the biggest environmental challenges. However, the vast majority of research within the synthetic biology field focusses on industrial and commercial applications including pharmaceuticals and chemicals as per neoliberal processes (Pei, Gaisser & Schmidt, 2012).

Additionally, even when synthetic biology is applied to biodiversity conservation, funding agencies more and more often require scientists to find external co-funding to get a research grant (e.g. the Dutch Science Foundation). This has an important reason, which is the shared value of interdisciplinarity and collaboration also seen in the sources. It is a rule that can be beneficial for creating a more intrinsic link between scientists and organisations who co-fund. However, it can also allow for increased inequality due to the fact that mostly wealthier companies are now able to use science for their work, while limiting scientific value to economic gains (Halffman & Radder, 2013).

Power

Science creates possibilities for bigger inequality by (1) serving to companies and actors already more powerful, and (2) creating science that feeds into already established policy-relevant terms. In the case of governmental processes of synthetic biology for biodiversity conservation, there are various standpoints one can have in relation to the ethical and social consequences of a neoliberal approach to biodiversity policy. However, whatever your standpoint is, the application of measurementality logics to biodiversity governance creates questions about its effects that should be addressed and evaluated. Haug et al. (2010) argues for this evaluation to be of a rationalistic and constructivist approach, preferable due to the strong focus on equity, coordination, and reflection on policy goals.

The implications go beyond the neo-liberalisation of nature and biodiversity in particular – it shows that certain representations lead to knowledge production that is applicable to policy and governance logics. Often, these logics are beneficial to groups already more powerful. Linking this back to the theory, Foucault explains the interconnection between power and knowledge production. This means it is not only knowledge production shaping the context of power, but also power shaping the context of knowledge production (Flyvberg, 1998). I argue here that knowledge within governmental processes about synthetic biology for biodiversity conservation influences what and whose arguments are seen to be relevant in governance, and additionally how that governance supports sources of power.

5.3.3 Summary of terms of debate

Table 6. Summary of findings for research question 3.

<table>
<tr><td colspan="5">RQ 3. Which reasons, arguments, and kinds of knowledge are considered valued for governmental discussions?</td></tr>
<tr><th>Category</th><th>Sub-category</th><th>Findings in sources</th><th>Theory</th><th>Findings</th></tr>
<tr><td rowspan="3">Argument: Effective and efficient approaches, thus technological mastery</td><td>Achieved through collaboration</td><td>Inclusion of indigenous and traditional knowledge. Source 1, 3, 8, 10, 11, 12, 14, 20

Need for international cooperation and discussions. Source 7, 11, 12, 20, 21, 22, 23</td><td rowspan="3">Modernisation dynamics

Sustainable development principle

Measurementality logic

Managerial discourse

Post-normal science

Interconnection power-knowledge (Flyvberg, Foucault)</td><td rowspan="3">Values of affluence and progress can be identified in the sources. Economic well-being as a component in the principle of sustainable development, and whether synthetic biology for conservation will be economically beneficial is seen as important. Synthetic biology could potentially ensure benefits from biodiversity at a lower cost than current biodiversity practices. Example of a modernisation dynamic.

Managerial discourse, in which the values of efficiency and effectiveness are important in policy, can be seen in the sources.

Measurementality logic gives privilege to science-based techniques of knowledge production, however, sources show the important value of including local and indigenous knowledge systems.

The knowledge being local does not change the situation of the measurementality logic to make knowledge fit for policy. Logics of measurementality may exclude current ways in which there is already a connection between science and indigenous/local communities. This framing of the need to create a connection gives priority to those already in power to decide how that connection is formed.

Elements of post-normal science: knowledge must have economic or political utility and competition for money precedes competition for credibility

Allows for increased inequality due to the fact that mostly wealthier companies are now able to use science for their work, and also limits scientific value to economic gains.

Scientific knowledge creates possibilities for bigger inequality by (1) serving to companies already more powerful, and (2) creating science that feeds into already established policy-relevant terms.</td></tr>
<tr><td>Achieved through scientific research</td><td>Promotion of research and scientific information to support evidence-based policies. Source 7, 12, 21</td></tr>
<tr><td>Achieved through expansion</td><td>"Development, transfer, promotion, and use of appropriate technologies, including indigenous and traditional technologies to scale up solutions" Source 12

"Must embrace new technologies" Source 24</td></tr>
</table>

Note. Appendix D provides the exact wording and full quote of the all the sources mentioned in the Table.

5.4 Summary and reflections on future research

Synthetic biology with the aim of biodiversity conservation is a prime example of an issue fraught with uncertainty, risk, and urgency, with the added complexity of involving contrasting values. In this thesis, I identified key hurdles apparent when providing knowledge for collective decision-making surrounding synthetic biology with the aim of biodiversity conservation and discuss what happens when knowledge for that decision-making only works when it is considered relevant. Relevance within the interaction of policy, knowledge, and society has become embedded in procedures not often questioned. This analysis carries an undertone of warning. If we do not create a knowledge system with a diverse inclusion, solutions implemented to deal with synthetic biology for biodiversity conservation can, and probably will, backfire because the complexity of the issues are not properly addressed.

However, the findings discussed in this analysis can also be viewed in a positive light. Acknowledging the diversity of knowledge by including other perspectives and knowledges can be an opportunity for more meaningful interactions between policy, knowledge, and society. A distribution of power more equal can be achieved by questioning the procedures of produced knowledge and opening them up for more diversity and accountability.

Further research should be conducted to explore how knowledge influences governmental processes surrounding synthetic biology for biodiversity conservation. First of all, this study can be complemented by a long-term research studying the progression of knowledge production for policy. Second of all, the results finding inclusion of local and indigenous knowledge systems in governance processes can provide a good opportunity to investigate how different forms of knowledge, including natural science knowledge, social science knowledge, and indigenous or local knowledge, become integrated in policy. What categories will structure the information coming from these sources? And how will these be interpreted to make knowledge fit for policy or the economy?

Lastly, there is an opportunity for analysis of the role of knowledge in governmental processes surrounding the intellectual property rights of synthetic biology for biodiversity conservation. Due to this study showing that knowledge-for-policy serves groups already more powerful, it would be interesting to see how this influences the property rights of synthetic biology techniques. There are various ways to go about applying intellectual property rights. One example is patenting the components, organisms, and products of synthetic biology. Another example is combining patenting the end organisms and products, while sharing the use of components needed for the development of synthetic biology organisms and products. Based on how the intellectual property rights of synthetic biology will develop in governance, innovation may be directed towards certain kinds of end-goals, serving to different kinds of groups. This creates an important research opportunity into the interplays between knowledge, power, and governance.

5 Conclusion

Initially, feelings of both hopeful curiosity and adrenaline-fueled caution pulled me into the field of synthetic biology applications for biodiversity conservation. Reading into the topic more, the risk, uncertainty, and opportunity involved make the international governance hard to navigate. Global cooperation and decision-making might make governance more complicated but is of high importance because decisions made would influence ecosystems and humans worldwide. This is especially true in a context where high-gain and high-risk technologies seem increasingly tempting in the hope of solving some of the urgent ecological problems that sustainability science aims to address. Soon after this interest into governmental processes of the issue, I began researching the role of knowledge in these processes, of great importance to the far-reaching influences and implications of the current knowledge production system.

In this study, I contribute to a wider understanding of the role of knowledge in governmental processes regarding synthetic biology for biodiversity conservation. This study shows the role of scientists to produce knowledge for governance, by providing measures and assessments that fit with how biodiversity and synthetic biology are represented. For example, representing biodiversity conservation as needing effective approaches, and synthetic biology as an effective tool for the use and value of services of biodiversity, knowledge production favours synthetic biology techniques. This is because synthetic biology is an approach able to create a nature with more measurable ecosystem services. I argue that the power of knowledge in this context is not merely knowledge informing policy, but knowledge having the power to (1) define our view of biodiversity, reordering the relationship between humans and non-human nature, and (2) serve companies and actor groups already more powerful.

In conclusion, this thesis warns against a narrow view of what produced knowledge is considered relevant for governance and against a knowledge production system more focused on policy-relevance than on credibility. The thesis also aims to show consequences on the solutions proposed, and on how we see our relationship with nature. Lastly, I also aim to show the need and opportunity for a fuller consideration of the roles of knowledge to prevent the danger of power and benefits related to synthetic biology to be monopolised by a small group, creating further inequality and injustice.

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Appendix A. CRISPR-Cas9 explanation

CRISPR-Cas9 is short for clustered regularly interspaced short palindromic repeats, with the associated nuclease 9 (Shalem et al., 2014). The National Human Genome Research Institute (NHGRI) (2020, para. 3) explains how CRISPR-Cas9 works in the lab. First, a piece of RNA with a guiding sequence is created, that then attaches to a target sequence of DNA. Secondly, the RNA binds to the Cas9 nuclease, after which the modified RNA sequence is used to recognize the DNA sequence. When the DNA sequence is recognised, the Cas9 nuclease cuts the DNA at the targeted location. Lastly, when the DNA is cut, the DNA repair machinery of the cell is used to make changes to the DNA by replacing an existing segment with the created sequence. This process is seen in Figure A1 below.

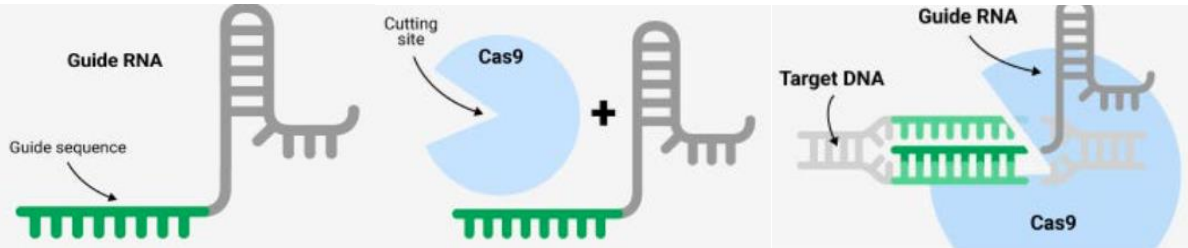

Figure A1. Visualisation of how CRISPR-Cas9 works in the lab. In the first picture, a guide RNA is created that matches the target sequence of DNA. In the second picture, the RNA sequence is added to a cell along with Cas9, which cuts DNA. In the third picture, the RNA homes in on the DNA sequence and Cas9 cuts it. The guide RNA and Cas9 leave, and now another piece of DNA is in place of the old DNA. Adapted from: “CRISPR, the gene-editing tech that’s making headlines, explained in one graphic” by D. Roach and T. Lewis, 2015, Business Insider, Issue of December 2.

While there are several approaches to changing and organisms DNA by altering the genetic material at particular locations in the genome (called genome editing), the CRISPR-Cas9 approach has generated the most excitement (NHGRI, 2020). This is because if the old approaches of genetic manipulation were like a map, CRISPR-Cas9 is like a GPS system – a technology that makes techniques of synthetic biology more efficient, precise, cheap and easy (Williams, Henao-Mejia & Flavell, 2016). However, as seen in Figure A1, by changing the genetic information of an organism, the edits will only be inherited by half of the offspring according to Mendelian inheritance, which is why the synthetic biology method “gene drives” is crucial to know about (Delborne et al., 2018).

Appendix B. Principles of governance of synthetic biology for biodiversity conservation

Because of the inherent existence of power dynamics in governance of synthetic biology for conservation of nature, there are some important principles of governance. These are: state sovereignty in 1972, precautionary approach, access to information, consent of local and indigenous peoples, and sustainable development (Redford et al., 2019).

State sovereignty

Decisions regarding genetic resources and biological diversity are made according to the principle of state sovereignty (Stockholm Declaration, 1972, Principle 21). However, on an international level, in response of the growing recognition that species and ecosystems are threatened, and with the added knowledge that biodiversity is of great importance and value, the United Nations Environmental Program (UNEP) summoned the Ad Hoc Working group of Experts in 1988 to explore a possible international convention on biological diversity (CBD, 2020). By 1992 the convention was opened for signature at the Rio Earth Summit, and to date 193 Parties have signed, of which the European Union is one (UN, n.d.). The governing body of the CBD is the Conference of the Parties (COP), meeting every two years for decision making and the review of priority subjects. Synthetic biology has been a such a priority, as seen in the early proposals for new and emerging issues, and later in the supplementary agreements "Cartagena Protocol on Biosafety to the CBD" in 2000 and "Nagoya Protocol on Access to Genetic Resources" in 2010 (CBD, 2012).

Precautionary approach

The reason for this broad debate on synthetic biology is the principle of the precautionary approach, stating that: "where there is a threat of significant reduction or loss of biological diversity, lack of full scientific certainty should not be used as a reason for postponing measures to avoid or minimize such a threat" (UN, n.d., para. 5). The "role of knowledge related to scientific uncertainty" is a key aspect of this principle (Wiener, 2018, p. 179) and directly related to synthetic biology governance (Zhang, Marris & Rose, 2011), and will be discussed more in-depth in the Theory section. Linked to this role of knowledge and information is the Aarhus Convention, stating the principle of access to information that (1) requires that any person has a right to environmental information held by public authorities,

(2) provides a right of the public to participate early in decision-making processes in relation to environment-related plans, programmes, and regulations, and (3) states that any person who considers their rights violated or their interests affected by an environmental decisions to have access to a court (Aarhus, 1998, 6-8).

Free and informed consent

Decision making regarding synthetic biology have the possibility of harming indigenous peoples and local communities. The principle of free and informed consent extends to apply to any decision making affecting the natural resources of indigenous peoples or communities (UN Declaration on Rights of Indigenous Peoples, 2007, art. 10). The Ad Hoc Technical Expert Group on Synthetic Biology (2017, para. 26) also states that synthetic biology technology development should include full participation of indigenous peoples and local communities.

Sustainable development

Lastly the principle of sustainable development, with the added intergenerational responsibility according to the Brundtland report, has relevance to synthetic biology applications. This is the basis of the Sustainable Development Goals, adopted in 2015, stating globally agreed on targets. Synthetic biology applications can provide a means to reach those targets (e.g. addressing invasive species could address the targets of marine and terrestrial conservation), but risks of synthetic biology could affect reaching the goals negatively (see Table 1 for more potential benefits and risks of synthetic biology applications).

Appendix C. Description, relevance and type of sources

All documents have the importance of being recent. Most from 2018 onwards. Exception is the EU and UN reports, which next to the recent reports also includes older ones, justification is to show the change and emergence of the issue.

Type of sources:

Source 1 – 13:	Governmental, on political level
Source 15 and 19:	Synthetic biology roadmaps
Source 16 – 18 and 20 – 23:	Reports from organisations
Source 14 and 24:	Scientific papers

Table C1. List of sources used for analysis, including description and relevance.

Instrument	Description	Relevance
1. UNEP CBD Cartagena Protocol	International agreement aiming to ensure save handling, transport, and use of living modified organisms resulting from modern biotechnology in 2000	Since this is an international agreement resulting from modern technology's effects on biological diversity, it is a key document for analysing governance of synthetic biology.
2. UNEP CBD COP 5.13	Decision adopted by the conference of the parties to the CBD at its tenth meeting in 2010	The Convention of Biological Diversity's first official mention and decision on synthetic biology
3. UNEP CBD Nagoya Protocol	International agreement on access to genetic resources and the fair and equitable sharing of benefits arising from their utilization in 2011	This protocol creates a larger legal certainty and transparency for users and providers of genetic resources. It aims at helping to ensure benefit-sharing in relation to the use and access to genetic resources. Thus, this is a key document in analysing the governance of synthetic biology.
4. UNEP CBD COP Note by Executive Secretary	Report on new and emerging issues relating to the conservation and sustainable use of biological diversity in 2012	Explains the thought process and the options of decision making on including synthetic biology in decision making
5. UNEP CBD COP 6.11	Decision adopted by the conference of the parties to the CBD at its eleventh meeting in 2012	The Convention of Biological Diversity's further elaboration and decisions on how synthetic biology is to be governed. It is thus a key document to analyse.
6. UNEP CBD report	Report on potential possitive and negative impacts of components, organisms, and products resulting from synthetic biology techniques on the conservation and sustainble use of biodiversity, and associated social, economic, and cultural considerations in 2014.	First report of the Convention on Biological Diversity that focusses solely on synthetic biology. This report aims to inform on potential possitive and negative impacts of synthetic biology on conservation and sustainable use of biodiversity. Its aim is to provide knowledge needed for decision making, and is thus a key document in the analysis of the role of knowledge in the governance of synthetic biology for conservation.
7. UNEP CBD report	Report on possible gaps and overlaps with the applicable provisions of the convention, its protocols, and other relevant	This report was released at the same time as the previous report on potential possitive and negative impacts of synthetic biology. The report also focusses on synthetic biology solely, this time in

		agreements related to components, organisms, and products resulting from synthetic biology techniques in 2014.	relation to possible gaps and overlaps with other agreements related to synthetic biology techniques. Since the aim is to inform for governance, it is a key document for analysis.
8.	UNEP CBD COP 7.24	Decision adopted by the conference of the parties to the CBD in 2014	The Convention of Biological Diversity's further elaboration and decisions on how synthetic biology is to be governed. It is thus a key document to analyse.
9.	UNEP CBD secretariat	Report on synthetic biology. Technical series No. 82 in 2015	Report from the UNEP CBD secretariat aiming to provide knowledge for informed governance of synthetic biology for the conservation of biodiversity. Especially the first part about impacts of components and products resulting from techniques within synthetic biology is key for analysis.
10.	UNEP CBD COP 8.16	Decision adopted by the conference of the parties to the CBD in 2016	The Convention of Biological Diversity's further elaboration and decisions on how synthetic biology is to be governed. It is thus a key document to analyse.
11.	UNEP CBD COP 14.19 synthetic biology	Decision adopted by the conference of the parties to the CBD in 2018	First decision fully on synthetic biology, instead of synthetic biology being included in "new and emerging issues".
12.	UNEP CBD report	Report of the subsidiary body on scientific, technical, and technological advice on its twenty-third meeting. 2019	Includes recommendation 23.7 on new and emerging issues relating to the conservation and sustainable use of biological diversity.
13.	EU Commission Future brief	Synthetic biology and biodiversity. Future brief. 2016.	The aim of the document is to be an information service. These future briefs provide expert forecasts of issues on the horizon, and this source is specifically based on synthetic biology. Since it is a forecast based on experts, the knowledge that is created here in order to inform the European Union. This creates a governance perspective on this knowledge, and is thus key to analyse in this research.
14.	Kolodziejczyk, B. Kagansky, A.	Consolidated G20 synthetic biology policies and their role in the 2030 Agenda for Sustainable Development 2017.	G20, a group existing of 19 countries and the European Union, are economically influential since together they make up 90% of GDP and 80% of world trade. This thus includes most trade and economic benefits of synthetic biology. This document puts together policies from these countries on synthetic biology and their role for sustainable development, including conservation. It is thus an important document for analysis of governance.
15.	Semiconductor Synthetic Biology	Roadmap for synthetic biology 2018.	The National Science Foundation (NSF) and the SRC, a technology research consortium, together developed this roadmap for synthetic biology. These are both important non-state actors focused on research/science and technology. As explained earlier, this is also part of the governance of synthetic biology for conservation, and thus key to this analysis. The organisations also play a key and active role in putting

		this roadmap into practice by assembling a community with the goal of developing synthetic biology technologies.
16. European Strategy Forum on Research Infrastructures (ESFRI)	Strategic Report on RIs in Europe 2018.	The mission of ESFRI is to support a strategy-led approach to policy making on research infrastructures and to facilitate multilateral initiatives leading to the better use and development of research infrastructures at international level. In this mission, you can see that the research they do are thus highly linked to the governance of synthetic biology. The strategy report aims to reinforce the strategic goal of long-term engagements that carries out research and operation of infrastructures - meaning a list of presented projects and their status.
17. European Strategy Forum on Research Infrastructures (ESFRI)	Landscape analysis on RIs in Europe 2018.	The mission of ESFRI is to support a strategy-led approach to policy making on research infrastructures and to facilitate multilateral initiatives leading to the better use and development of research infrastructures at international level. In this mission, you can see that the research they do are thus highly linked to the governance of synthetic biology. The Landscape analysis report provides the current context of relevant infrastructures available to scientists and technology developers. This includes synthetic biology.
18. European Strategy Forum on Research Infrastructures (ESFRI)	Projects & Landmarks on RIs in Europe 2018.	The mission of ESFRI is to support a strategy-led approach to policy making on research infrastructures and to facilitate multilateral initiatives leading to the better use and development of research infrastructures at international level. In this mission, you can see that the research they do are thus highly linked to the governance of synthetic biology. The projects and landmarks report provide descriptions of projects, but also gives information on the political support of ESFRI.
19. Engineering Biology Research Consortium (EBRC)	Engineering Biology: A research roadmap for the next-generation bioeconomy 2019.	The EBRC is a non-profit partnership between private and public actors with the goal of advancing engineering biology to address global needs. This research roadmap aims to be compelling to address the research and application of engineering biology, including synthetic biology. Since this is a key example of how public and private actors are intertwined in the governance of synthetic biology, this roadmap is a key source for analysis.
20. International Union for Conservation of Nature and Natural Resources (IUCN)	Report on genetic frontiers for conservation: an assessment of synthetic biology and biodiversity conservation: technical assessment 2019.	The IUCN is a supranational organisation composed of both governments and civil society organisations, bringing together organisations and experts to conserve nature. This is another example of the close relationship between state and non-state actors in governance. The report aims to provide knowledge and information for policy. In July 2020, this

		report will provide the basis for the development of policy recommendations, thus making it an essential report for analysis.
21. Roberts, J. et al.	Synthetic biology governance: Delphi Study Workshop Report 2015.	In collaboration from the genetic Engineering and Society Center and the North Carolina State Univeristy, and with funding from the Sloan Foundation program on synthetic biology, a workshop was hosted with large and diverse group dialogues and mapping exercised to evaluate the current and ideal goverance of SynBio. This report is the result of the workshop, and essential for analysis since it showcases expert's view on what data and information is needed for governance.
22. Delborne, J. et al.	Biotechnology, the American Chestnut Tree, and Public Engagement Workshop Report 2018.	In collaboration from the genetic Engineering and Society Center and the North Carolina State Univeristy, and with funding from the National Science Foundation, this workshop aimed to engage the public in the governance of the genetically engineered American chestnut tree and thus aims to show how public engagement is linked to the governance of synthetic biology. This makes it an interesting source for analysis.
23. Farooque, M. et al.	Exploring stakeholder perspectives on the development of gene drive mouse for biodiversity protection on islands. Workshop Report 2019.	In collaboration from the genetic Engineering and Society Center and the North Carolina State Univeristy, and with funding from the DARPA Safe Genes Program, this workshop report aimed to convene a group of stakeholders, scientists, and funders for an exploration of the development of synthetic biology. The workshop report collects information to inform decision-making about research, testing, and potential deployment of technologies, and thus plays a role in the governance of synthetic biology.
24. Piaggio et al.,	Is it time for synthetic biodiversity conservation? 2017.	This scientific article aims to highlight the advantages and possibilities of synthetic biology. More importantly, it also provides guiding principles for future governance of synthetic biology. As mentioned earlier, governance is increasingly expected to be science-based, and thus this article also has a role in the governance of synthetic biology.

Appendix D. Used quotes from sources

Table D1. Summary and additional sources of section 5.1

Values	Affluence	Source 1: "take into account the need for financial resources". Article 28.3 Source 6: "could cause major economic shifts" Section A.10 Source 15: "key challenge of synthetic biology: cost reduction" Source 21: "produce economically viable "suicide" gene traits" Page 4. Source 22: "efficient use of taxpayer funds" Page 7 Source 24: "most countries cannot sustain such [of current biodiversity conservation] economic costs" Page 102
	Progress and modernity	Source 24: "we must embrace new technologies" page 105 Source 24: "the way forward is to acknowledge … new technologies" Page 105
	Collaboration	Source 20: "deeper collaboration … will be necessary" Page 121 Source 21: "..if the process would be more collaborative…" Page 5 Source 22: "core value: collaboration" page 7. Source 23: "with whom should engagement occur?" Page 23
Representation	Synthetic biology as ethical and uncertain issue	Source 5: "recognition of scientific uncertainties" paragraph 3. Source 6: "raises ethical questions" Section A.12 Source 13: "raises complex ethical issues"
	Synthetic biology as tool for conservation	Source 6: "used to create gene drive systems … by suppressing populations" Source 12: "enabling conditions for use and value of nature: technology" Source 13: "may propose solutions to some of the greatest environmental challenges" page 3 Source 17: "to provide tools to better tackle areas of great social and environmental interests" Page 88 Source 24: "can be utilized towards solving the intractable problems of biodiversity conservation" Page 97
	Current biodiversity conservation as deficient, and needing urgent action	Source 6: "more efficient and effective ways to respond to challenges" Section A.4 Source 12: "must be coherently and consistently addressed urgently" Section 1.2.12 Source 24: "current conservation approaches are not slowing the overall rate of biodiversity loss" Page 97
	Biodiversity as service and classification of nature	Source 6: "sustainable use of ecosystems" Source 12: "Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services to establish the use and value of nature"

Table D2. Summary and additional sources of section 5.2

Problem solving & technological mastery	Through collaboration	Source 7: "discussions in international for a may be needed with a view of addressing the gaps identified in this note in an appropriate, consistent, comprehensive and adaptive manner." Page 9. Source 11: "need for a coordinated, complementary, and nonduplicate approach on issues related to synthetic biology under

		the Convention and its Protocols, as well as among other conventions and relevant organisations and initiatives." Page 1, number 7. Source 12: "promotion of research cooperation" page 47 Source 12: "including indigenous and traditional knowledge " page 47 Source 21: "begins with efforts to obtain stakeholder buy-in. ... including bench scientists, industry, DIY Bio, general public(s) representatives, government, investors, conservationists, and environmentalists." Page 15.
	Through research	Source 7: "discussions in international for a may be needed with a view of addressing the gaps identified in this note in an appropriate, consistent, comprehensive and adaptive manner." Page 9. Source 12: "science: promotion of research cooperation to foster effective use of scientific information to support evidence-based policies, actions, tools, and mechanisms. Technology: development, transfer, promotion, and use of appropriate technologies" page 47 Source 21: "a full risk-benefit, cost-benefit, or risk-risk analysis would be needed" page 5.
	Through expansion	Source 12: "development, transfer, promotion, and use of appropriate technologies, including indigenous and traditional technologies and knowledge to scale up solutions" Page 47

Table D3. Summary and additional sources section 5.3.

Responsibilities	Governments: to develop assessments and programs based on science and in line with the economy	Source 1: "parties are encouraged to cooperate on research and information exchange on any socio-economic impacts" Article 26.2. Source 7: "states have the duty to carry out an environmental impact assessment" page 5. Source 8: "to establish, or have in place, effective risk assessment" "to carry out scientific assessments" "to encourage the provision of funding for research into synthetic biology risk" Source 11: "scientifically sound case-by-case risk assessments" Source 12: "action in line with the findings of assessment report" Source 14: "develop effective and safe practices for commercialization of synthetic biology products" "policy developments need science-based data-driven approaches" page 6. Source 19: "establish resource for the research and research-support community, including policymakers and funding bodies, that portrays the importance and impact of engineering biology tools and technologies" Source 24: "call for the development of a robust decision-making, risk-assessment framework, and for research to be conducted on the application of synthetic biology to conservation issues" page 101
	Governments: to facilitate participation and access to information, with a focus on indigenous and local communities	Source 1: "all parties shall promote and facilitate public awareness, education, and participation" Article 23.1 Source 3: "aim of insuring that traditional knowledge is accessed with the prior and informed consent or approval and involvement of these indigenous and local communities" Article 7. Source 7: "applicable access requirements would apply" Source 8: "include representations of indigenous and local

		communities and all relevant stakeholders" Page 4. Source 10: "promote and enable public and multi-stakeholder dialogs and awareness-raising activities" "with the full and effective engagement of indigenous peoples and local communities" Page 2, section 9b. Source 11: "the prior and informed consent or approval and involvement of potentially affected indigenous peoples and local communities" "participation of indigenous peoples and local communities in the discussions and in the work on synthetic biology under the convention" Article 17 Source 12: "enabling condition: traditional knowledge" Source 20: "indigenous and local communities are key actors in research, governance, and decisions around synthetic biology and engineered gene drive for conservation" page 122.
	Citizens: to get informed and involved, to give up irrational denials and fears. Media: to stop feeding those fears	Source 13: "mainstream media coverage to date has focused on extraordinary stories of de-extinction, neglecting the more nuanced benefits or risks for biodiversity and complex ethical and social implications" page 30 Source 17: "to demonstrate effective use of resources and accountability for public money" "to demonstrate evidence of societal and economic benefits" page 89 Source 20: "scientists are also not the only voices, society needs to be involved" page 121
	Scientists: to work interdisciplinary, solve current issues of synthetic biology, and embrace new technologies	Source 13: "scientific community should openly debate the implications of their work and engage with society" page 30 Source 18: "operate in a multidisciplinary environment developing translational research" page 171 Source 19: "emphasize that broad interdisciplinary and ongoing engagement with a wide range of partners will be essential" "science aims" page 7 Source 20: "deeper collaboration between conservation scientists and synthetic biologists will be necessary to develop evidence and to create the frameworks for understanding and using that evidence" page 121 Source 24: "rapid, large-scale engagement of these two communities is urgently needed" "conservation philosophy should embrace concepts of synthetic biology" "conservation and synthetic biologists must be open and willing to educate themselves about their respective fields so as to identify ways to bridge the gap and achieve integration" page 105
	"Science" and research: to provide measures and assessments on which to make political decisions	Source 1: "based on available scientific evidence" Article 11.8 Source 10: "evaluate the availability of tools to detect and monitor the organisms, components, an d products of synthetic biology" Source 12: "continue to provide information in support of the process to develop the post-2020 biodiversity framework" Source 13: "provides the latest environmental policy-relevant research findings" Page 2. Source 16: "identify and adopt measurable key performance indicators" "have resources be policy adequate" "potentially a higher

		impact of solid scientific evidence into decision-making" "research infrastructures serve research and technology but also policy-making" Page 12. Page 18. Source 17: to inform future decision making and evidence for policy-making" Page 89 Source 20: "serve as an input to the development of policy recommendations" Page 123 Source 24: "answers to these questions lie in the scientific engagement of experts" "should be based on a series of guiding principles and with a robust decision framework to understand the pros and cons built on existing and new science to maximize biodiversity benefits and minimize biodiversity harm" Page 104, 105.