Master's thesis – master Sustainable Development

Adding monetary value to mangrove restoration projects through carbon credits

Case-study Building with Nature Indonesia

by

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Glossary

Building with Nature	= A design approach to undertake Nature-based Solutions for infrastructure related to water (Witteveen+Bos, 2022), in which nature is used to adapt to climate change risks, such as sea level rise, floods and increased waves
Carbon credit	= A certificate or permit that can be traded, representing one ton of CO_2 equivalent removed or reduced from the atmosphere
Carbon offset	= A removal or reduction of greenhouse gasses from the atmosphere, mainly CO_2, created to compensate for emissions produced (at another location)
Carbon offset credit	= The right to emit one ton of CO_2equivalent which is created by a carbon offset, meaning a reduction in GHG emissions or an increase in carbon storage is used to compensate for emissions that occur elsewhere
Certification standard	= Also called carbon standards or carbon schemes, provides criteria and guidelines that determine the requirements for carbon offset projects to be officially certified and considered genuine and legitimate carbon reduction activities
Compliance market	= Carbon markets that are created and regulated by mandatory regimes. The marketplace has a certain number of carbon credits that are issued per actor per year. It is mandatory for companies to comply to a yearly reducing cap set by regulators, where companies are allowed to trade their allowances
Voluntary Carbon Market	= The market that allows carbon emitters not included in the compliance market to offset their emissions, by buying carbon credits created through projects that remove or reduce GHG from the atmosphere

List of abbreviations

In this thesis abbreviations will be used for terms that are used frequently.

AGB = Above-ground biomass
AR = Afforestation/reforestation
BAU = Business-as-usual
BGB = Below-ground biomass
BwN = Building with nature
CCB = Climate, Community & Biodiversity standard
CDM = Clean Development Mechanism
CS = Certification standard (also called crediting scheme)
DBH = Diameter at breast height
ETS = Emissions trading system
ETS = European Trading Scheme
GHG = Greenhouse gas
GS = Gold Standard
MRP = Mangrove restoration project
NCS = Natural Climate Solutions
NDC = Nationally Determined Contributions
PES = Payments for ecosystem services
PV = Plan Vivo
SD VISta = Sustainable Development Verified Impact Standard
SeA = Sensitivity analysis
SOC = Soil organic carbon
StA = Stakeholder analysis
VCM = Voluntary carbon market

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Abstract

To achieve net-zero emissions goals, negative emissions are required. One prominent emission reduction mechanism is the Voluntary Carbon Market, which enables the trade of emission certificates while generating funding for offset projects. Carbon offsetting through the reforestation of mangroves possesses a significant potential for climate change mitigation, as their restoration efforts result in the substantial sequestration of carbon. Besides carbon benefits, restoring mangrove ecosystems also provides multiple co-benefits, such as coastal protection. This study has therefore examined how carbon credits can add monetary value to mangrove restoration projects, to increase project development. This was investigated through literature reviews, expert interviews, a stakeholder analysis, and a feasibility frontier. The study presents a comparison between three distinct certification standards that can generate carbon credits for mangrove projects, namely Gold Standard, Plan Vivo, and Verra. This research also identifies the key stakeholders involved in the mangrove carbon offset ecosystem and evaluates the cost-effectiveness of using a certification standard to generate carbon finance. It was found that average mangrove restoration projects are cost-effective over a 25-year period based on income from VCM credits alone, but require the inclusion of co-benefits to break-even with current mangrove restoration carbon prices if a 5-year payback period is required. Numerous challenges and risks were furthermore identified that hinder the development of such projects. Challenges exist in not overestimating carbon storage due to the inherent difficulty of accurately accounting for additionality, permanence, and leakage. Other challenges exist in the high costs, especially the high transaction costs for mangrove restoration offset projects, as well as low carbon prices in the volatile carbon market. Furthermore, a common inadequacy or insufficiency in stakeholder involvement was found in projects, whilst local stakeholder involvement was found to be crucial for effective project development. The findings were then applied to a case-study in Northen-Java, Indonesia, that applied the Building with Nature approach. The results found a total carbon storage potential of 111,211.6 tCO_{2e} and a carbon accumulation of 26.1 MgC/ha/year between 2013 and 2015. These results indicate that full financing of the case-study through carbon credits is not achievable, and additionally, maintaining environmental integrity cannot be guaranteed. Overall, this research serves as a valuable guide for mangrove restoration projects seeking to utilize the carbon market. It provides insights into the certification standards, the cost-effectiveness of these projects, and identifies potential hurdles that may arise.

Keywords*: Carbon credits, voluntary carbon offsetting, certification standards, Carbon sequestration, mangrove restoration*

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1 Introduction

1.1 Background and problem definition

To keep global warming well below 2 degrees Celsius and achieve the goals set by the Paris Agreement (2015), negative greenhouse gas (GHG) emissions are required (Gasser et al., 2015). This is necessary, as in the future there will still be a significant amount of emissions from difficult-to-decarbonize sources, as well as from the probability of exceeding the carbon budget (Smith & Friedmann, 2017). These emissions will have to be compensated for through CO_2 removal from the atmosphere. To achieve this, countries and non-state actors are setting increasingly ambitious emissions targets, where by 2021, two-thirds of the economy was covered by net-zero emission goals for 2050 (Tanaka & O'Neill, 2018; Black et al., 2021). Currently, however, private and governmental actors 'are far from achieving the climate change ambitions set by the Paris Agreement' (Miltenberger et al., 2021, p.1).

A mechanism that allows the trade of emission rights are carbon markets. These markets allow companies or individuals to buy emissions reduction certificates in the form of carbon credits from entities that reduce or remove GHG emissions. A distinction can be made between compliance carbon markets, such as the European Trading Scheme (ETS) and the voluntary carbon market (VCM). The key difference between them is that mandatory carbon markets are regulated and require covered entities to reduce emissions by law. This research has a focus on the VCM which, in contrast, is not legally mandated but self-governed by companies. The VCM therefore allows companies to purchase carbon offsets on a voluntary basis. One carbon offset is a removal or reduction of GHG emissions created to compensate for emissions produced elsewhere. A carbon offset can be traded on the VCM in the form of a carbon credit and is equal to one ton of CO_{2e}. The VCM is growing fast with the total value of transactions having passed 1 billion USD per year for the first time in 2021 (Nowak, 2022). Additionally, the forecast for the growth of the VCM is significant, and according to a report by Blaufelder et al. (2021), the global VCM could increase 15-fold to 50 billion USD by 2030 and 100-fold by 2050.

For a carbon offset project to represent quality and to maintain environmental integrity, which is defined by Spalding-Fecher et al. (2016, p.1) as: 'total global emissions should not increase because of the use of crediting mechanisms', certain criteria exist. Three important criteria to achieve this are additionality, permanence, and leakage. Firstly, a project has to be 'additional' when compared to a business-as-usual (BAU) scenario. Secondly, no 'leakage' from the carbon sequestration should be able to occur that can lead to unforeseen GHG emissions outside of the project's boundaries. Lastly, carbon sequestration has to be 'permanent' in order for the carbon to remain sequestered over longer periods of time (Locatelli et al., 2014; Thamo & Pannell, 2016).

To ensure that carbon offset projects meet these and other criteria, carbon certification standards (CS) exist which develop and approve standards. Followed by third party verification, which assesses whether projects comply with the aforementioned standards (Broekhoff et al., 2019). The whole process can be a time-consuming and costly process, and therefore it is questionable if certifying carbon offsets through CSs is efficient for every project (Wylie et al., 2016).

Although the VCM provides a significant amount of emission reductions, the system is a regular object of criticism. The VCM has been critiqued for not delivering real emissions reductions, for reducing the incentive of the private sector to invest in low-carbon technologies, and for enabling financial windfalls to emitters (Calel, 2013; Valiergue & Ehrenstein, 2022). The VCM is controversial for selling ‘junk credits’ that are not backed by real emission reductions. The criticism has spiked in recent months following an article from the Guardian claiming that 90% of rainforest avoided deforestation (REDD+) carbon offsets by the biggest certifier Verra, are unlikely to represent genuine carbon reductions (Greenfield, 2023). The article expands upon three recent studies that raise concerns about the effectiveness of forest offset conservation projects. These studies suggest that certain projects may overstate the risk of forest removal, leading to the generation of what is referred to as "phantom" carbon credits. This allows CSs, such as Verra, the organization held responsible for certifying such projects, to sell these junk credits. The debate is still developing, with Verra heavily defending itself (Verra, 2023). The criticism is however primarily focused on avoided deforestation carbon offsetting and not on reforestation methodologies, highlighting the importance of offsetting through reforestation (Greenfield, 2023). Still, the article caused, besides a drop in the generally cheaper avoided deforestation carbon credits, an overall drop in carbon prices and trust for the whole VCM (Yin, 2023). The identified weaknesses of the system highlight the volatility of the market and emphasize the need for improvements in existing methodologies.

Contrary, as stated by Miltenberger et al. (2021), the existence of carbon markets is beneficial from an environmental, social, and economic standpoint when compared to an absence of emission reduction mechanisms. They furthermore contend that the criticism on the VCM is not only resolvable but are unavoidable challenges that must be addressed on the path to mobilizing climate change ambition and achieving reduction targets. Therefore, market observers claim that a healthy, trusted, well-functioning VCM must be in place in order for major polluters to realistically commit to net-zero pledges and meet the growing demand for carbon offsets (Spilker & Nugent, 2022). The VCM has the potential to channel significant funds to climate protection and the regeneration of nature (Blaufelder et al., 2021), there is however much work is needed to ensure its success (Nowak, 2022).

One form of climate mitigation within the VCM that generates carbon offsets are natural climate solutions (NCS). NCS are a method for direct CO_2 removal and are actions through the conservation, restoration and improved land management of landscapes & wetlands that allow for increased carbon storage or the avoidance of GHG emissions (Osaka et al., 2021). The concept has emerged as the preferred option to remove GHG emissions from the atmosphere (Macreadie et al., 2021). Furthermore, NCS have the potential to be more cost-effective and scalable when compared to other technical options, such as direct CO_2 removal (Macreadie et al., 2021). NCS alone could provide 15 Gt CO_{2e} of mitigation and achieve 30% of the Paris climate goals (Streck, 2021). In light of this, it is evident that the Global South holds significant potential for NCS, due to the cost advantages associated with implementing such projects in these regions (Friess et al., 2022). Moreover, the utilization of carbon offset credits can facilitate the flow of capital from the Global North to developing countries, enabling the implementation of climate-action projects that may be economically unfeasible otherwise (Blaufelder et al., 2021).

The protection, conservation and restoration of blue carbon ecosystems is a promising type of NCS (Zeng et al., 2021). Blue carbon refers to the carbon stored in coastal and marine ecosystems, namely the carbon that is sequestered by mangrove forests, seagrass meadows and salt marshes. The protection, conservation, and restoration of blue carbon ecosystems could achieve carbon sequestration and avoid emissions of 3% of the annual global GHG emissions (Macreadie et al., 2021). Mangrove forests are the largest ecosystem out of blue carbon ecosystems (Macreadie et al., 2021), which are productive wetlands that grow on coastal intertidal zones. Mangroves sequester high amounts of carbon, mainly because of their high productivity of above-ground wood and below-ground root systems, as well as their ability to trap carbon rich sediments (Alongi, 2012). This makes them among the most carbon-dense forests in the tropics (Donato et al., 2011).

Besides carbon storage, mangrove forests offer a wide range of co-benefits, including coastal protection, biodiversity conservation, improved water quality, and support for fisheries (Lovelock et al., 2021; Vanderklift et al., 2019). These ecosystems play a vital role in supporting the livelihoods of local stakeholders who heavily depend on the natural resources provided by mangroves (Barbier, 2006). Consequently, restoring mangrove ecosystems holds the potential to enhance human well-being (Jakovac et al., 2020). Global mangrove areas have however seen a decline in size, experiencing a significant reduction of 50% between 1950 and 2000 (Alongi, 2002). This loss of mangroves has had a notable impact on current atmospheric CO_2 concentrations, as these forests currently store more than two years' worth of anthropogenic CO2 emissions (Elwin et al., 2019). Agricultural expansion, particularly for shrimp farming and rice paddies, is the primary driver behind mangrove loss (Thomas et al., 2017). Additionally, urbanization, logging, and climate change also contribute to the degradation of these vital ecosystems (Thomas et al., 2017). Given the high carbon content of mangroves, their restoration presents an efficient climate mitigation strategy (Adame et al., 2021).

1.2 Knowledge gaps

Despite the increased interest in blue carbon projects, there are few projects currently verified or being developed that produce blue carbon credits (Friess et al., 2022; Macreadie et al., 2021). An important driver for this discrepancy is the presence of market-related challenges that constrain the development of blue carbon projects (Friess et al., 2022). Examples of these challenges include high upfront costs, extensive time consumption, and a lack of cost transparency in the market (Friess et al., 2022). While other barriers have been extensively studied, financial barriers for blue carbon projects have received less attention, as financial mechanisms are considered poorly developed (Vanderklift et al., 2019). As a result, it is regularly unclear if projects are cost-effective, given the high transaction costs and investment risks associated with them. These market-related challenges are especially challenging for general small-scale mangrove projects (Friess et al., 2022). Thus, a knowledge gap exists in a further understanding of the comprehensive barriers and challenges, especially financial barriers, that hinder the development of mangrove restoration projects (MRP).

Furthermore, within the VCM, mangrove forests and blue carbon, in general, are still a novel topic. Blue carbon CS methodologies are relatively new and present challenges in their adaptation to existing CS methodologies, as coastal ecosystems possess distinct characteristics compared to other forest ecosystems. Differences exist in terms of dominant carbon pools, drivers of loss and degradation, and governance arrangements (Friess et al., 2022). Insufficient research has been conducted on these CSs, and no scientific literature exists that specifically compares the CSs within the context of mangrove ecosystems. While existing studies by Michaelowa et al. (2019) and Kollmuss et al. (2008) have examined the standards in a general sense, they do not address mangroves restoration, and the standards have changed since the publication of these studies. Therefore, additional research focusing on these standards within the context of mangroves is required.

1.3 Research goal and research questions

The primary objective of this research is to find how carbon credits can add monetary value to mangrove restoration projects. This will be done by addressing the market-related challenges, including costs associated with certifying mangroves project to generate carbon credits. The research further aims to assess the suitability and differences of various CSs for mangrove projects. In addition, this research aims to find the dynamics within the stakeholder field of carbon offsetting through an MRP. Moreover, this study aims to find when it becomes cost-effective to use such a CS, considering the regularly smaller size of MRPs, compared to typical offset projects. The gained knowledge will furthermore be applied to a case-study project in Indonesia, further discussed in chapter 2.4.3.

To address the identified knowledge gaps and achieve the objectives of this research, the following overarching research question was formulated:

How can carbon credits be of added monetary value to mangrove restoration projects?

The main question will be answered through the following sub-research questions:

- *1. What are the key challenges associated with the development of reforestation carbon offset projects and how does this relate to smaller (MRP) projects?*
- *2. Which stakeholders are relevant for carbon offsetting through mangrove restoration projects?*
- *3. How do the best suited certification standards for mangrove restoration projects compare?*
- *4. When does it become cost-effective for a mangrove restoration project to use a certification standard?*
- *5. How much carbon is stored in a mangrove restoration case-study project in Indonesia, and can carbon credits add value to a similar project?*

2 Theory

This chapter explains the theory behind the key concepts of this research, which will provide the background knowledge required for this study.

2.1 History of the Voluntary Carbon Market

As stated in the introduction, the carbon market serves as a mechanism to enhance the efficiency of global emission reductions. This market can be categorized into two main types: mandatory carbon markets, exemplified by the European Trading Scheme (ETS), and voluntary carbon markets (VCM). The mandatory or compliant carbon markets are part of a cap-and-trade system, meaning that each participant of the system is appointed a certain set of emission allowances each year (Kolmuss et al., 2008). The total number of allowances decreases annually towards a target, forcing the system to reduce emissions. Companies under a compliance system can then trade their allowances to meet their emission requirement or sell their unused emission. In addition, companies that do not meet their requirements are fined forcing the system to comply with emission reductions.

The Kyoto Protocol, formed in 1997, strived for the reduction of global GHG emissions. Following from the protocol, the world's first carbon finance schemes were developed, such as the Clean Development Mechanism (CDM). The CDM was the first offset mechanism that helped countries within a compliance market to achieve their climate goals by allowing investment in developing countries through carbon offsetting (Calel, 2013). The CDM promoted the sustainable development of the host country, and it supported the avoidance and reduction of global GHG emissions. As the CDM started to grow, it became an established compliance market and projects issued by the CDM could be traded within the ETS. Besides the CDM compliance market, many companies and governments started participating in parallel voluntary mechanisms (Benessaiah, 2012). In recent years the CDM has seen decreased activity primarily caused by the exclusion of the use of the CDM by the ETS, and because the integrity of the CDM was publicly debated (Watt, 2011). The mechanism did pave the way for the VCM, by providing a blueprint for voluntary standards, as many of the CSs are built upon the principles and methodologies proposed by the CDM (Ahonen et al., 2022).

2.2 Requirements for a carbon offset

To represent quality and to maintain environmental integrity, a carbon offset project has to satisfy specific criteria. In this context, summarized by Broekhoff et al. (2019), the project must be associated with GHG reductions that are:

- Additional
- Not overestimated
- Permanent
- Not claimed by another entity
- Not associated with significant social or environmental harms

A project has to be additional, meaning that the project results in abatements that would not have occurred in the absence of the project. Described by Murray et al. (2007) as:

> 'Additionality maintains that an offset credit is granted only to the extent that the associated amount of emission reduced or sequestered within the project boundaries is additional to that which would occur without the project, or under BAU conditions' (p.10).

In other words, the activity or project should be developed because of the carbon financing and should not have happened anyway (the BAU scenario). This is important because if a project claims GHG reductions which are not additional, no real emission reduction occurs, and emissions are then allowed to be emitted without a corresponding cut in emissions somewhere else. The projected effect is compared with a BAU baseline scenario (what would happen without the project), against which the baseline scenario of the carbon offset project is compared to assess additionality.

In addition, GHG reduction should also not be overestimated. One important factor to avoid overestimation is that the risk of leakage must be minimized. Leakage of a project can be environmental damage resulting directly from the carbon sequestration activities or indirectly if the activity is displaced to another location, potentially to other countries (Moilanen & Laitila, 2016). Direct leakage is easier to discover, it however remains challenging to account for indirect leakage caused by carbon offsetting, despite the attention in scientific literature (Thamo & Panell. 2016). In addition, it has been observed that carbon offsetting can cause other impacts besides GHG emissions, primarily impacting biodiversity and other ecosystem services (Moilanen & Laitila, 2016).

Another important aspect to generate acceptable carbon offsets is permanence. This means reducing the risks of removal of the carbon stored after the offset had been traded or sold. An offset project has to be durable, and it has to have the ability to store carbon long-term. Factors influencing the permanence of a project are risks such as land-use change or natural disasters. The latter risk is becoming more significant due to climate change as many ecosystems become less stable and weather patterns less predictable (Pan et al., 2022). The ability to measure, report, and verify emissions reductions is another precondition. The carbon offsets must be independently and accurately verifiable, without having to rely on the entity issuing them (Ullman et al., 2013).

Furthermore, offsetting should be seen as a three-step process and not as a miracle solution (Valiergue & Ehrenstein, 2022). First, offset buyers must map and quantify their carbon footprint, afterwards they develop and implement changes to reduce it, and only then, should companies or governments be able to buy carbon offset credits to compensate for their unavoidable emissions. This method can overcome greenwashing accusations, as only the unavoidable emissions are compensated (Valiergue & Ehrenstein, 2022).

2.3 Certification of carbon offsets

With the absence of governmental oversight, the voluntary offset market needs quality assurance of offset projects, in order to maintain credibility (Chen et al., 2021). With a lack of trust and credibility in offsets generating real emissions reductions, demand could decrease, and less capital could be directed towards offset projects (London Economics, 2022).

To ensure the quality and credibility of voluntary offsets certification standards (CS) are crucial. They define requirements for monitoring, reporting, and verification of different types of projects. Over time many carbon CSs have developed, each with differences in goals, services provided and approaches for measuring emissions removal and reductions. However, they all aim to provide project developers with quality insurance certification, and they further aim to provide carbon offset buyers with increased transparency and confidence in the integrity and credibility of certified offsets (Chen et al., 2021). As stated by Streck (2021) they all include criteria on:

- Defining project categories and eligibility
- Additionality
- Setting of reference levels or baselines against which emission reductions and removals are to be assessed
- Monitoring emissions and displacements
- Managing the risk of reversals through discounts and buffers
- Verification and certifications
- Sustainable development and co-benefits
- Participation and consultations

With stringent rules in place, CSs can provide sufficient assurance regarding the environmental integrity of carbon credits, meaning that projects helped to reduce net GHG emissions. These criteria and how they are incorporated into the methodologies within the CSs will be further discussed in part III. To confirm if projects comply with the standards, third party validation and verification bodies (VVB's) provide independent judgement. Figure 1 shows the simplified process for the certification from a project's design phase towards the issuance of certified credits.

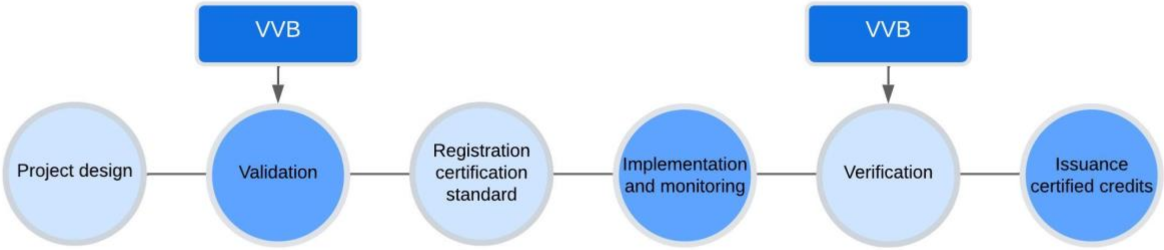

Figure 1: Simplified process from project design to issuance of certified credits.

Verra, formerly known as VCS, issues most carbon offsets out of the major standards, with a share of 67.6% in 2020, followed by the Gold Standard (GS) with 13.6% (Chen et al., 2021). In 2003 the GS was developed by the WWF, whereby the GS aims to issue carbon offset projects that include a higher level of sustainability and other 'carbon+' benefits (McEwin & McNally, 2014). Another CS is Plan Vivo (PV), which has a focus on including sustainable livelihoods for communities in carbon offset projects. Although these standards all include the same criteria, they have different methodologies and focuses. Within CSs, mangrove forests and blue carbon in general, are still a novel topic. The first methodology to quantify real GHG benefits for mangrove forest projects was developed by Verra in September 2020, after which Gold Standard and Plan Vivo developed methodologies and guidelines for mangroves as well.

2.4 Mangrove restoration

2.4.1 Mangrove forests and ecosystem services

Mangrove forests are most common in tropical and sub-tropical regions around tidal river deltas. They are characteristic for their rooting systems both above and below saline or brackish water. A mangrove forest hosts many advantages in the form of ecosystem services that promote human well-being directly and indirectly (Locatelli et al., 2014). One vital function of mangroves, is coastal protection, because they reduce erosion and shelter the shoreline (Lovelock et al., 2021). Improved coastal protection enhances economic activities such as coastal property and fisheries (Bryan-Brown et al., 2020). Mangrove root systems are efficient in dissipating wave energy and are therefore also a good defence against tropical cyclones and tsunamis (Massel et al., 1999). Indonesia is the largest contributor to blue carbon stocks, see Figure 2, as the country stores 17% of the global reservoir (Alongi et al., 2015). Mangrove forests store some of the highest densities of carbon among all ecosystems worldwide, resulting in a significant climate change impact when the ecosystem is removed (Adame et al., 2021).

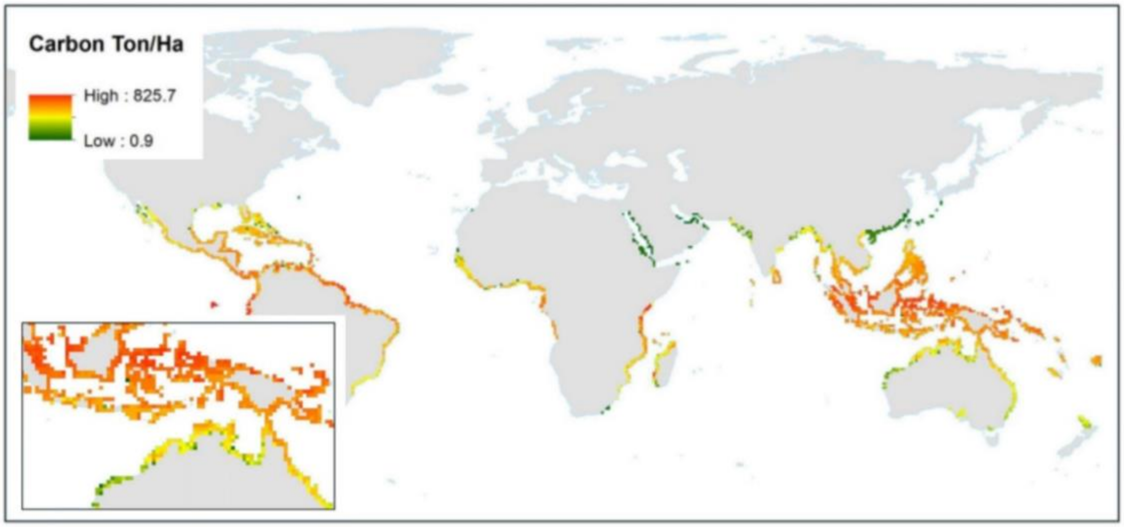

Figure 2: Average carbon stock in mangrove ecosystems in Carbon Ton/hectare, adjusted from Jakovac et al. (2020).

2.4.2 Status of mangrove forests

The large-scale decline of mangrove forests worldwide has caused many drastic impacts on local communities living near coastal areas. One of the main effects is the reduction in natural coastal protection by the former forests. This results in the sea moving inland year by year, which is amplified by rising sea levels due to climate change (Alongi, 2015). Other impacts are diminishing fisheries, increased social conflicts, reduced carbon sequestration capacity, and decreased nutrient cycling (Lovelock et al., 2022). Additionally, the removal of mangroves destroys the habitat of multiple species and thus results in a loss of biodiversity (Malik et al., 2015). Mangrove forests are still declining in size, the rate of decline is however decreasing, and a tipping point is expected (lovelock et al., 2022). The main driver for mangrove forest removal in Southeast Asia is the development of aquaculture (Richards & Friess, 2016). This entails the development of fishponds, for example for shrimp farming. Other drivers of mangrove removal are agriculture, forestry, and urbanization (Richards & Friess, 2016).

2.4.3 Mangrove restoration and the case-study

As previously mentioned in the introduction, there are two main types of carbon offset projects: restoration and conservation. The focus of this study lies on mangrove restoration projects (MRP), which can be distinguished between the planting of mangroves and the restoration of hydrology and sediment to facilitate the natural regrowth of mangrove ecosystems. The case-study project analysed in this research is located in Northen-Java, Indonesia, near the city of

Semarang. It is a finished project that followed the Building with Nature (BwN) principle, which is a design approach developed by a Dutch consortium to undertake Nature-based Solutions for infrastructure related to water (Witteveen+Bos, 2022). BwN projects use nature's strengths to cope with climate change risks like floods. The approach therefore aims to work with nature, rather than against it. The goal of the BwN project was to increase coastal protection through the regrowth of mangroves. Furthermore, the project is deeply engaged with local communities, knowledge institutes and governmental agencies aiming to address the root causes of coastal erosion in the area, providing multiple benefits for the local communities (Tonneijck et al., 2022). A pilot project was initiated in 2013, which paved the way for the official launch of the first phase of BwN project in 2015. The program continued its operations until its conclusion in 2020. (Winterwerp et al., 2020; Tonneijck et al., 2022). The initial phase of the project started near the village of Timbulsloko, which is located in the Coast I/II area. For this phase, the project did not use carbon financing mechanisms.

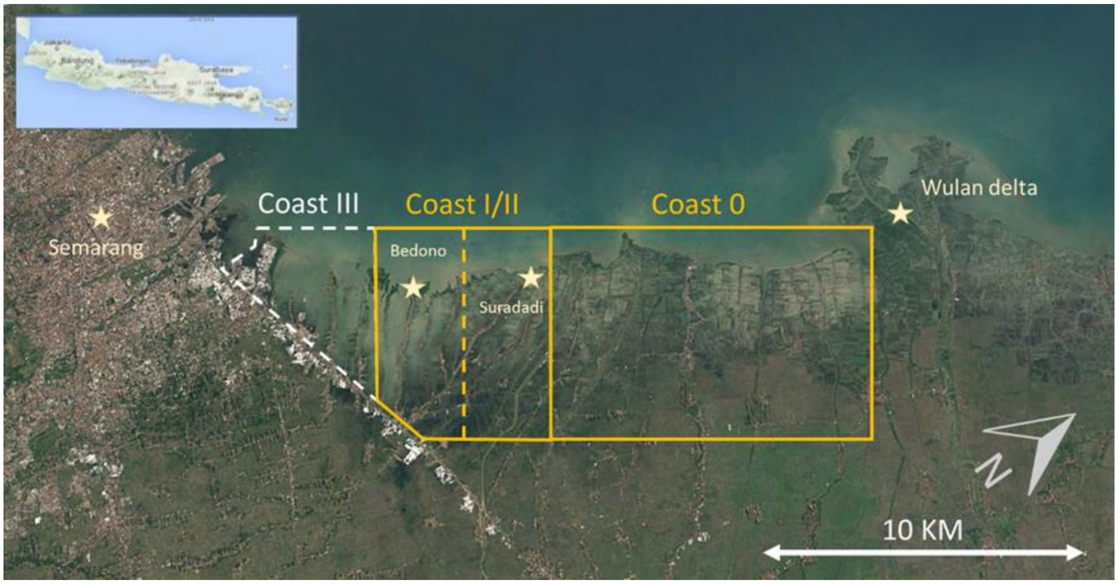

Figure 3: Building with Nature Northen-Java, Indonesia project (Witteveen + Bos, 2020).

The BwN project used for the case-study, has implemented a mixed approach through planting mangrove seedlings and the restoration of hydrology and sediment. In this region, a concerning issue arises from the feedback loop between the reduction of mangrove forests and increased erosion (Tonneijck et al., 2022). Once the mangrove forests vanish, the ocean soil levels decrease, exacerbating wave activity. These conditions make it exceedingly difficult for mangroves to return naturally. So, according to the BwN principle, the Dutch consortium, which includes Witteveen + Bos, implemented permeable structures designed that enable water passage while also facilitating the accumulation of sediment behind these structures (Tonneijck et al., 2022). Through this approach, the permeable structures mimic the natural functions of mangrove forests, see Figure 4. After the construction, seeds from nearby mangrove plants, can settle in the better-protected areas, and start to grow (Winterwerp et al., 2020). When new mangrove trees have grown, the permeable structures are relocated further into the sea, thus increasing the stretch of mangroves. Additionally to this, local inhabitants have also replanted mangroves to accelerate the process. This has resulted in a total area of 80.7 hectares of returned mangroves between 2013 and 2018 (Bijsterveldt et al., 2022). The aim of the project was to create and extend the existing mangroves further into the sea, creating a coastal protective greenbelt. For the BwN project, Witteveen + Bos has designed the permeable structures and has assisted in developing the program.

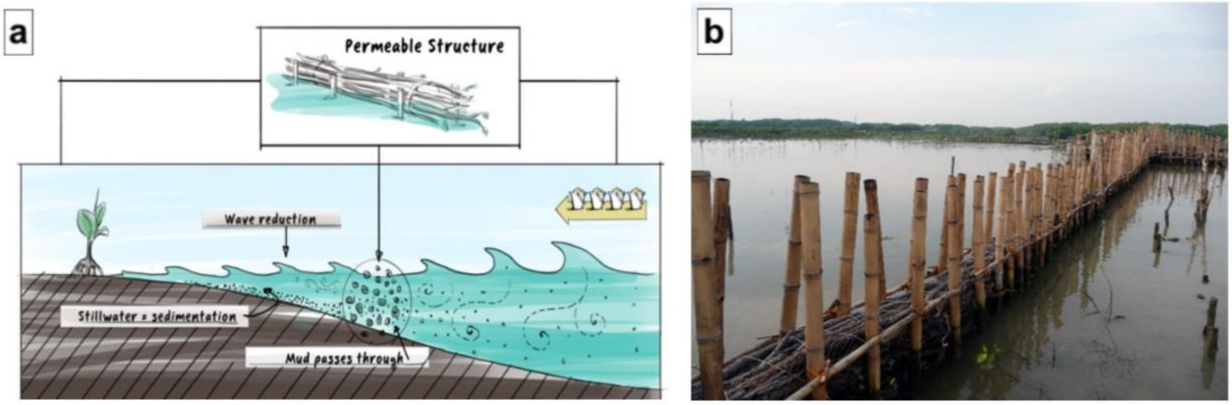

Figure 4: a) Construction of permeable dams that allow the re-growth of mangrove forests, retrieved from Deltares (2019). b) photo of the permeable dams near the village of Timbulsloko, retrieved from Witteveen + Bos.

3 Methodology

The research question of this thesis will be answered according to the five sub-research questions mentioned in chapter 1.3. This research was conducted by reviewing literature, interviews, a feasibility frontier, and a case-study. The research framework is presented in Figure 5. The study was divided into three phases, of which phase 2 was divided into five parts, namely parts I, II, III, IV and V. Each part represents a sub-research question in numerical order.

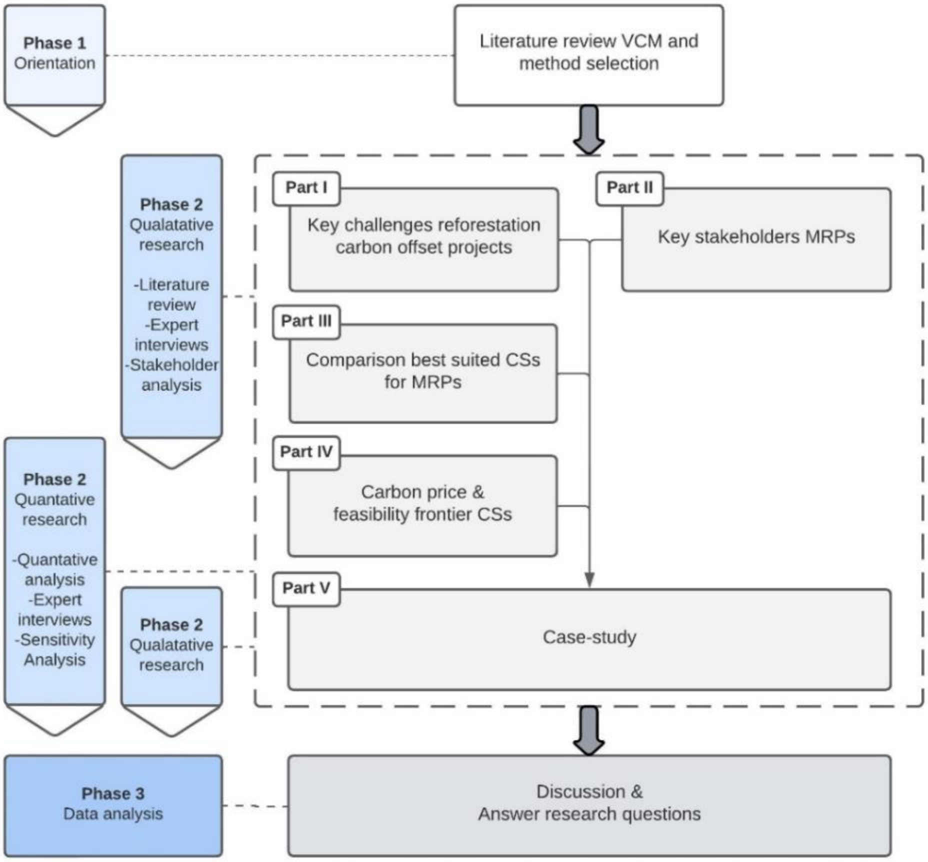

Figure 5: The research framework consisting of three phases, namely phase 1 consisting of the orientation phase, phase 2 consisting of the sub-research questions divided into 5 parts, and phase 3 data analysis.

3.1 I - What are the key challenges associated with the development of reforestation carbon offset projects and how does this relate to smaller (MRP) projects?

This chapter starts with a literature review to discover the key challenges associated with the development of a forestry carbon offset project. The first search term for the literature review has a focus on forestry AR challenges in general, instead of mangrove or blue carbon specific, as more literature is available on these topics

The below search term was entered into Google Scholar. Subsequently, relevant articles were selected through a snowball search approach. Snowballing enables the systematic expansion of the initial set obtained through the search term below by analysing additional sources referenced in these articles. Considering the rapid advancements in VCM, articles published prior to 2010 were excluded due to their reduced relevance. The key challenges were divided into three categories. The first category pertains to methodological challenges focussed on technical issues arising from carbon offsetting and challenges related to the methodologies and system of the CSs and VVB's. The second category are implementation challenges that are related to the practical aspects of the development of a forest offset project. Lastly, the category social and stakeholder challenges focused on the social sustainability of these projects.

1) ~Challenges 'Carbon offset' OR 'voluntary carbon offsets' OR 'voluntary carbon market' verification OR certification

Next, the below search term was used to explore the relationship between carbon offsetting and project sizes. Again, there is a focus on AR forestry projects in general, instead of a mangrove specific focus, because more literature is available regarding this. This chapter furthermore aimed to also find the relevant challenges associated with smaller reforestation carbon offset projects, as more literature is available when compared to a mangrove specific search. MRPs are regularly small in size when compared to other offset types (Friess et al., 2022). Among the five blue carbon projects fully approved by Verra, the average project size was 3,638 hectares, with the smallest project covering an area of 308 hectares (Verra, n.d.). In line with this, Lovelock et al. (2022) highlighted that small-scale projects are typically smaller than 1,000 hectares. Similarly, Friess et al. (2022) noted that blue carbon projects frequently fall below this threshold, exemplified by the 80.7-hectare case-study examined in this research. A snowball search approach was employed for the below search term. For this search term, solutions for the challenges were also examined in scientific literature.

2) ~Challenges 'Carbon offset' OR 'voluntary carbon offsets' OR 'voluntary carbon market AND ~project ~size AND ~small ~scale

The academic papers and books from the two search terms were reviewed to answer the sub-research questions. In addition to the literature, semi-structured interviews were conducted. This type of interview allows asking predetermined questions from an interview guide, accompanied by improvised follow-up questions based on the participant's responses (Kalio et al., 2016). The Interviews have captured information directly from stakeholders involved in the VCM, therefore Interviewing the stakeholders adds valuable insight and practical experiences that may not be readily available in scientific literature. The stakeholders that were interviewed can be found in

Table 1. The semi-structured interview and a consent form can be found in appendix A and B respectively. Out of the five interviewees. four signed the consent form and one person gave permission for the answers to be used anonymously.

Table 1: List of stakeholders interviewed in this research and their role within the VCM.

Person	Company	Type of company
Daan van de Kamp	Climate Neutral Group	End-to-end emissions reduction provided (including project development)
Daniel Balutowski	Sinkit	Developer and accelerator carbon removal solutions
Gregory Williams	vanOord	Maritime solution provider and blue carbon developer
Anonymous	NGO	Ecosystem restoration company and blue carbon developer
Elizabeth Francis	Fair Carbon	provides guides to implement blue carbon projects matched to the requirements of CSs

3.2 II - Which stakeholders are relevant for carbon offsetting through mangrove restoration projects?

In the second chapter, a stakeholder analysis (StA) was performed, as a tool to better understand the stakeholder ecosystem of carbon offsetting for MRPs. The goal of the StA, defined by Golder et al. (2005, p.1) is 'to develop a strategic view of the human and institutional landscape, and the relationships between the different stakeholders and the issues they care about most.' The StA gives further insight into which stakeholders are important to consider for effective MRP project development. Furthermore, understanding the complex stakeholder ecosystem can contribute to answering the remaining sub-research questions.

To conduct the StA, desk research was supplemented by semi-structured interviews. The interviewees from Table 1 were also asked questions for the StA, as the interviews for sub-research questions 1 and 2 were combined to save time. The interviewees were asked about the present stakeholders for carbon offsetting through MRPs and how they influence one another, see appendix A. Articles that were used are a market study on the voluntary carbon offsets by Chen et al. (2021) and a study by Thompson & Friess (2019) on stakeholder preferences for payments for ecosystem services (PES) for mangrove ecosystems. The outcomes of the StA include a market ecosystem map, visualizing all stakeholders involved and their relationships.

3.3 III - How do the best suited certification standards for mangrove restoration projects compare?

This chapter will make a comparison between the different CSs based on their methodologies and through the available data on their websites. In order to create a comprehensive overview of the standards and highlight their differences. These results give further insight in how to use the CSs to enter the carbon market for MRPs. Additionally, this chapter provides useful insights into the input variables for parts IV and V.

Three CSs were examined that are suitable for MRPs, which were selected on three criteria. The first criterion was found in part II, as the standards have to be ICROA-endorsed standards. ICROA is an organisation that provides quality assurance of CSs, third party verifiers and project developers. All standards considered have an ICROA accreditation label which represents adherence to the code of best practice. A second criterion for selecting the CSs is for the standards to have a separate mangrove methodology or to have developed mangrove projects. Lastly, the standards have to be globally applicable rather than limited to national or continental usage. Plan Vivo (PV), Verra and Gold Standard (GS) are the three standards that comply with the three criteria and are therefore further examined in this chapter and the rest of this study.

The standards are compared on afforestation and reforestation (AR) characteristics when specific data on mangrove restoration is missing. In addition, there is a focus on mangrove restoration instead of mangrove conservation. Furthermore, this part is divided into five different comparison categories. The first category compares the CSs in a general context, giving an overview of the standards. The second topic compares the standards on how their assessment processes, including validation, verification, monitoring, and reporting. The third category examines the standards' approaches to maintaining environmental integrity, with a specific focus on their incorporation of key elements such as additionality, permanence, leakage, and double counting. The fourth topic compares the standards on how to incorporate co-benefits and environmental criteria. Lastly, the standards were compared on their mangrove methodologies and their developed MRPs. The methodologies from the CSs that were consulted are Verra (2021), SD VISta, (n.d.), VCS (2017), Gold Standard (2022) and Plan Vivo (n.d.) The comparison will be shown through the use of tables.

3.4 IV - When does it become cost-effective for a mangrove restoration project to use a certification standard?

3.4.1 Feasibility frontier

3.4.1.1 Description

This part aims to determine when it becomes cost-effective to use the carbon market through CSs for MRPs, and to further analyse the to a lesser extent researched financial barriers that prevent project development. To assess this, the present value of the lifetime cost of a mangrove project using a CS was calculated. These costs were compared to the carbon credit prices required to finance the present value costs. To do this, an increasing number of total emission reductions were selected, representing different project sizes. Through this, the required carbon price to compensate for the present value cost could be found. The different emission reductions were furthermore translated to the required project sizes for the total emission reductions, by using the relation between project size and carbon storage.

These values were then displayed into graphs, to form the feasibility frontiers, with on the x-axis the required project size in hectares and on the y-axis the required carbon price in $/credit for a project to break-even. The graph thus shows the break-even price between the required carbon price and project area, in other words, the graph determines the minimum area of a project to be cost-effective. These values were compared to the average carbon prices of MRPs, which were examined through grey literature, scientific literature and information from the interviews. A decision was made to set the carbon prices at the same price throughout the years. A further explanation and assumptions can be found below. Additional assumptions that were made are listed in table appendix C4 and Excel was used to generate the feasibility frontiers and the formulas used can be found in appendix C5.

Two feasibility frontiers were constructed with different time periods for the three CSs examined in part III. The two time periods are 25 years and 5 years, see Figure 6 for the involved costs and carbon benefits for both time periods.

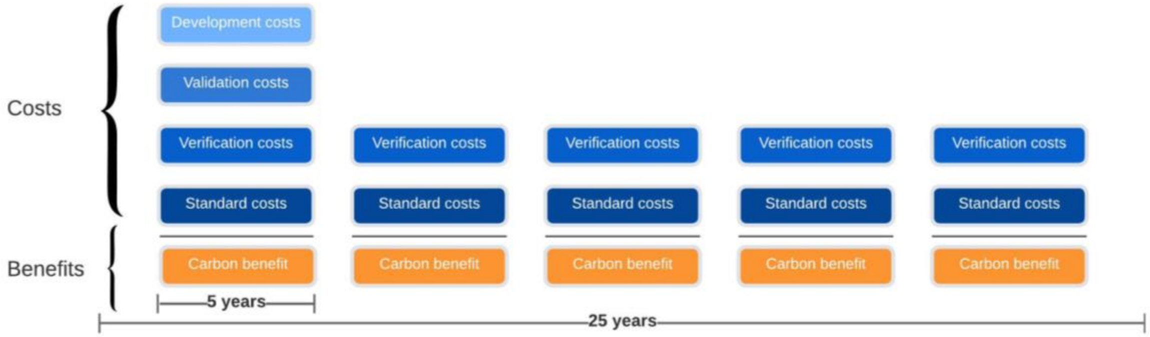

Figure 6: Costs and carbon benefits involved in the 5-year and 25-year feasibility frontier.

The first feasibility frontier was constructed for a project lifetime of 25 years with a 5-year return verification period. A 25-year project lifetime was chosen as this is a common lifetime used within CSs when looking into natural regeneration projects. As, the carbon uptake decreases at this time, as mangrove forests approach maturity (Howard et al., 2015; Kandasamy et al., 2021). A second feasibility frontier was constructed for the first 5 years of a project. A decision was made to further examine the costs of the first 5 years, as a project's verification commonly lasts for 5 years, after which CSs require a project to be re-verified. In addition, many companies, such as Witteveen + Bos, look at the profitability of a project in the first 5 years, on which they base their investment decisions.

3.4.1.2 Costs

The costs of the CSs, which were obtained from the standards websites, can be found in appendix C1. The costs of the standards were supplemented by the median development cost of mangroves globally of $4368 per hectare retrieved from Jakovac et al. (2020). This corresponds to a study from van Zanten et al. (2021), using restoration costs for mangroves of $3900 per hectare. An assumption was made that the development costs are the same per hectare regardless of the size. Table 2 shows what is included and excluded from the development costs in the article of Jakovac et al. (2020).

Table 2: Development costs for mangrove restoration included and excluded, retrieved from Jakovac et al. (2020).

	Type of cost	
Included	capital	planning
		purchasing
		land acquisition
		construction
		financing
	operational	maintenance
		monitoring
		Equipment repair & replacement
Excluded	Monetary restoration costs	
	Other opportunity costs	
	Costs from transactions	
	Time-lag	

All standards include different costs, as well as the requirement of validation and verification. In Table 3 the CSs and their different programs are visible and if they require validation or verification. The costs for validation and verification are difficult to retrieve because these costs differ between projects, therefore an estimation of these costs is used based on interviews, emails and literature (appendix C2).

Table 3: The certification standards examined for the feasibility frontier with their different programs and if they require validation and verification.

Certification standard	Program	Validation and verification
Plan Vivo	Micro (<10,000 tCO_2/yr)	No, Independent expert
	Macro (>10,000 tCO_2/yr)	Yes
Verra	VCS	Yes
	VCS + CCB	Yes
	VCS + SD VISta	Yes
	VCS + CCB + SD VISta	Yes
Gold Standard	Micro (<10,000 tCO_2/yr)	No, Gold Standards expert
	Macro (>10,000 tCO_2/yr)	Yes

To find the present value costs, a discount rate of 6% was used for yearly costs and for verification costs every 5 years in the 25-year lifetime scenario. Discount rates in literature and discount rates used by Witteveen + Bos differ between 2% and 10%, therefore a rate within this range was chosen (Dicks et al., 2020; Biasin et al., 2023). This is also in line with van Zanten et al. (2021), who use a 5,5% discount rate for mangrove restoration in Indonesia. From this the total cost of using a certification standard with validation and verification, if required, was then found.

3.4.1.3 Carbon

The costs in US dollars of the CSs were compared to the total carbon credits generated in tCO_2 and the project size in hectares. For the project lifetime of 25 years, the average global carbon storage of mangroves of 738.0 MgC/ha from Alongi (2020) was used. Regarding this, a study by Thura et al. (2022) examined the SOC stocks over a mangrove reforestation plot and found that within the first 25 years, SOC increases by 20% of the initial stock. Therefore, to find the amount of carbon stored, the global average mangrove initial carbon stock was subtracted from the average carbon storage of mangroves by Alongi (2020) and multiplied by the SOC increase over 25 years by Thura et al. (2022). Additionally, for the 5-year feasibility frontier, the growth per year was assumed to be linear. Furthermore, to determine the annual growth rate of 16.3 MgC/ha/year, the aforementioned average carbon stock increase of 408.7 MgC/ha, achieved by the MRP, was divided by its 25-year lifetime.

From this, the carbon price per credit, required for a project to break-even, was found by dividing the total present value costs by the total number of carbon credits in ton CO_2. The CSs all apply a buffer, found in part III, to counter risks. Therefore, not all CO_2 that is stored, is converted into sellable carbon credits, see equation 1. The carbon price is multiplied by the share of credits that can be sold, increasing the price per credit. Furthermore, a 20% profit margin was assumed to ensure a sustainable financial model. From this, the carbon price was visualized against the size of the restoration project area in hectares, with the line representing break-even prices.

$$(1)\ Carbon\ price\ \left(\frac{\$}{tCO_2}\right) = \frac{Costs_{total}\ (\$)}{Carbon\ credits\ (tCO_2)} * (100 + \%buffer + \%profitmargin)$$

Additionally, the minimum transaction costs associated with using a certification standard (CS) including validation and verification, were determined by setting the time period to 0 years, eliminating development costs, and reducing the project size to 0.

3.4.2 Sensitivity analysis

A sensitivity analysis (SeA) was performed to determine the extent and manner in which specific variables influence the outcome of the feasibility frontier. To conduct the SeA three amounts of carbon emissions reduction were selected for the 5-year and 25-year feasibility study corresponding to specific project sizes, see Table 4. These numbers were selected based on the observation that the feasibility frontier reaches an equilibrium after 150 hectares. This chapter is aimed at finding when it becomes cost-effective to use CSs, therefore 150 hectares was set as the default size.

Table 4: Sensitivity analysis emission reductions and representing project sizes.

	Low	Default	High	Unit
Project size	50	150	250	Hectares
5-year period emission reductions	14985	44956	74926	tCO_2
25-year period emission reductions	74927	224781	374635	tCO_2

Furthermore, the following variables were used, each with lower, default and higher boundaries, see Table 5. For the average development cost of mangroves, most project costs centre around the average mangrove restoration costs, therefore the lower boundary was set to 2200 \$/hectare and the higher to 6536 \$/hectare, corresponding to the range of costs from Bayraktarov et al., (2015). It should however be noted that more expensive outliers also exist, the study by Bayraktarov et al., 2015 found the most cost-effective project to be 786 \$/ha, and the least cost-effective project of 749215 \$/ha.

As can be seen appendix C2, the validation and verification costs are based on interviews, literature, and personal communication with VVBs. The costs given by these sources however vary widely, therefore the lower boundary was set through the lowest estimate of \$10,000 for validation and $10000 for verification. The higher boundary was set to $40,000 for both validation and verification, in line with the highest sums from the sources. The lowest discount rate used in literature and from Witteveen + Bos is 2%, therefore this was set as the lowest estimate. The higher boundary discount rate estimate was set with a similar difference between default and high, which is in line with higher discount rates used by Witteveen + Bos and found in scientific literature (Dicks et al., 2020; Biasin et al., 2023).

Table 5: Variables and the boundaries used in the sensitivity analysis.

Variables used	Low	Default	High	Unit
Average development cost mangroves	2,200	4,368	6,536	$/hectare
Validation	10,000	25,000	40,000	$
Verification	10,000	25,000	40,000	$
Discount rate	0.02	0.06	0.1	%
Average carbon storage mangrove	250	408.7	567.4	MgC/ha
Growth rate mangroves median	10.0	16.3	22.7	MgC/ha/yr

The difference between the lower and higher boundary and the default estimations for the three-project size, based on total emission reductions, were put forward in regression lines. These regression lines show the sensitivity of the variables. Furthermore, from the results of the feasibility frontier, it can be visible that PV and GS show similar trends, therefore a decision was made to exclude the PV micro and macro scenarios, to increase the clarity of the figures. Additionally, the VCS standard scenario was examined for the SeA and the other Verra programs (VCS+CCB, VCS+SD VISta, VCS+CCB+SDVISta) were excluded, as the results for the VCS standard would show similar trends as the other Verra programs.

3.5 V - How much carbon is stored in a mangrove restoration project case-study in Indonesia, and can carbon credits add value to a similar project?

The case-study will apply the knowledge gathered in parts I, II, III, and IV to a project near the village Timbulsloko in Indonesia. Firstly, the methods to calculate carbon storage will be discussed in this section. This will be followed by how these methodologies will be applied to the case-study area.

Secondly, the carbon storage was used to evaluate if carbon credits can be of added value to this MRP. To evaluate this, the feasibility frontier was adjusted to the case-study input variables to find what carbon prices are required for certain CSs. Then the additionality, permanence and leakage were discussed, as well as new regulations of the Indonesian carbon market.

3.5.1 Carbon storage case-study

3.5.1.1 Methods to calculate carbon sequestration mangrove forests

Firstly, to find the carbon stored in the case-study, the methods for calculating carbon storage in mangrove forests were examined. The important factors that need to be considered when calculating the carbon storage of mangrove forests are therefore highlighted below.

There are multiple methodologies in scientific literature available to accurately calculate mangrove carbon storage. One methodology regularly used in scientific literature and used by carbon offset projects to measure, monitor and report carbon stocks of mangrove forests is from Kauffmann & Donato (2012). Additionally, the Blue Carbon initiative (Howard et al., 2014) have constructed a methodology for assessing blue carbon stocks, using, and building on the methods proposed by Kauffman & Donato (2012). These methods are the bases for a list of the required information to calculate the carbon sequestration potential for the case-study, which is presented in appendix D. This showed which data is crucial to be available for the case-study and which data had to be assumed.

Carbon storage mangrove methodologies, such as Kauffman & Donato (2012) and Howard et al. (2014) calculate the above-ground biomass (AGB) through allometric equations that are able to capture the scaling relationships between tree form and function to calculate total biomass storage (Vorster et al., 2020). To calculate the biomass stored in mangroves it is most accurate to take field measurements and develop an allometric equation that best describes the biomass weight relation to diameter at breast height (DBH). However, it is also possible to calculate carbon storage through allometric equations from similar nearby species, from scientific literature or other offset projects, as the biomass stored in mangrove trees is primarily species, but also location specific (Analuddin et al., 2018; Howard et al., 2014).

In summary, the carbon storage of mangroves can be divided into four carbon pools (Howard et al., 2014):

- Aboveground living biomass (trees, scrub trees, lianas)
- Aboveground dead biomass (litter, downed wood, dead trees)
- Belowground living biomass (roots and rhizomes)
- Soil carbon which includes the dead below-ground biomass

From the CS comparison in chapter 4.3, it became evident that most projects and standards do not include all biomass types mentioned above. Most projects accordingly exclude shrub trees, lianas, palms and other non-tree biomass. These biomass types are excluded due to their small carbon storage impact and because of the high effort of measuring these biomass types. Multiple offset projects also exclude standing dead trees, litter and dead wood, but this tends to differ project-to-project. Excluding these smaller carbon storage biomass types adds to the overall conservativeness of the project's carbon calculations.

3.5.1.2 Carbon storage case-study Timbulsloko village

In-person, on-site measurement, following the measurement strategies from Kauffman & Donato or Howard et al. (2014) would have provided most accurate data. However, this study is limited to desk research. Therefore, the case-study data for carbon storage was extracted through a BwN study from Bijsterveldt et al. (2022) and a study from Ardhani et al. (2020). Both studies took field measurements in the case-study area, of which Ardhani et al., (2020) have followed the measurement methodology from Kauffman & Donato (20120. Through this, the carbon storage between 2013 and 2018 will be calculated, as this would represent the first 5-year verification period if the project would have applied for certification. Regarding this, the pilot project was developed in 2013 in the area near the village of Timbulsloko, after which in 2015 the BwN project was initialized until 2020.

Through the study from Bijsterveldt et al. (2022) the living biomass was calculated. The study provides data on mangrove regrowth in the area in hectares through high-resolution (< $1m^2$) satellite data, see Figure 7. The images that were examined are from 2005, 2010 and then on a yearly basis from 2013 to 2018. The study from Bijsterveldt et al. (2022) makes a distinction between planted mangrove trees and trees that regrew naturally because they consist of different mangrove species, visible in Figure 7. Furthermore, the study from Bijsterveldt et al. (2022) took field data measurements near the village from nine sites visible in Figure 8. This data consists of the surface area of the plots, the type of vegetation (planted or natural), species and diameter at breast height (DBH). Following from this, the study calculated the tree density (n ha^{-1}) and basal area (m^2 ha^{-1}) for the nine sites.

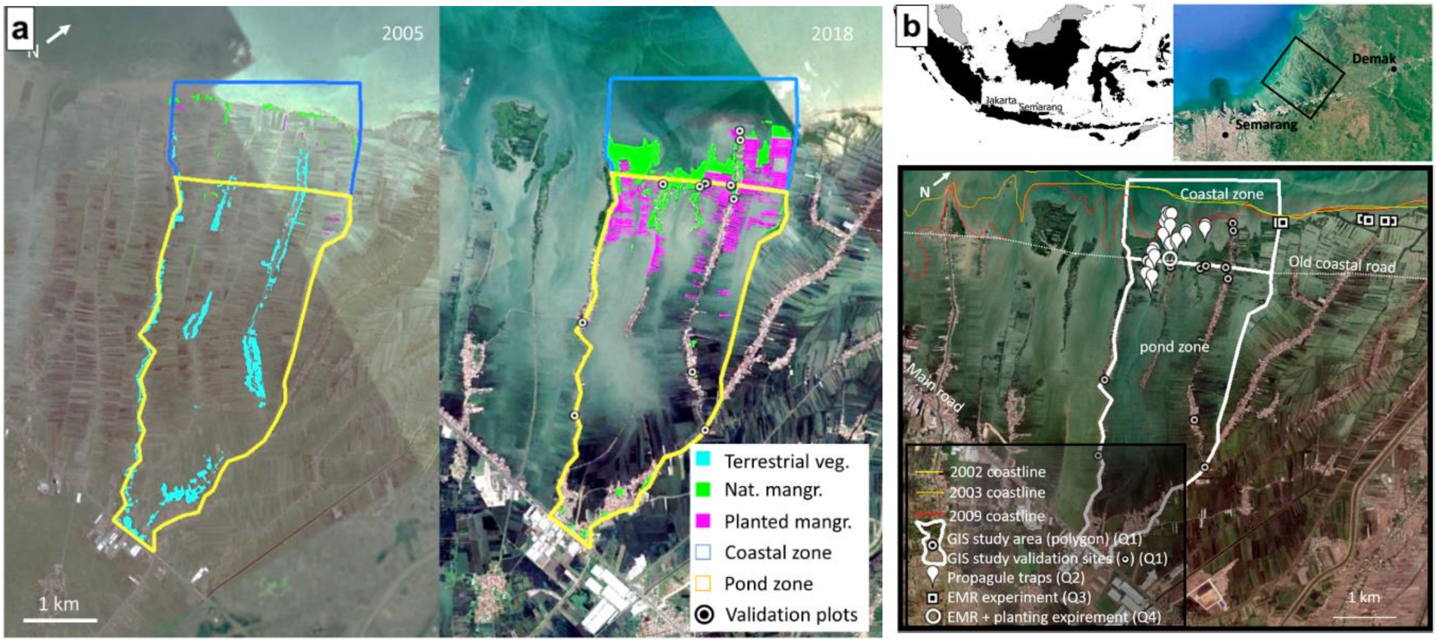

Figure 7: a) Study site from Bijsterveldt et al. (2022) showing the difference in mangrove cover between 2005 and 2018. b) Study site (in white) from Bijsterveldt et al. (2022) with the locations of the measurements near the village Timbulsloko in Indonesia.

A study conducted by Ardhani et al. (2020) has measured the ecosystems carbon stocks of mangrove forests behind the permeable dams, in the study area near the village Timbulsloko. The study has followed the methodology from Kauffman & Donato (2012) and provides specific data on below-ground biomass (BGB), deadwood carbon, SOC (2 meter soil depth) and AGB for the four groups in Figure 8.

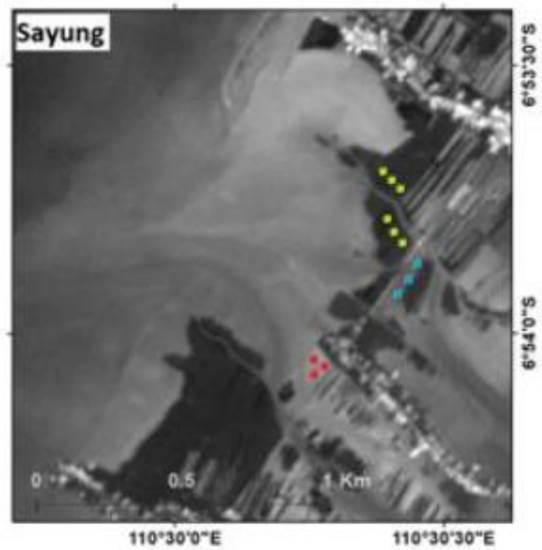

Figure 8: Study site Ardhani et al. (2020), yellow points demonstrate mangrove plots, red points express abandoned pond plots, and blue points symbolize productive pond plots.

Thus, the study from Bijsterveldt et al. (2022) provides the DBH, species type and surface area measurements for the plots in 2018. Through allometric equations the living biomass, also including roots, can be found. Kauffman & Donato (2012) and Howard et al. (2014) recommend using allometric equations for similar vegetive species and locations. Literature and documents of MRPs were examined to find the best suited allometric equations, shown in Table 6. For the Avicennia Marina species, AGB was used from Dharmawan and Siregar (2008), which encompasses all ABG biomass, including dead biomass and roots. No specific allometric equation of the Avicennia Alba was found. A study by Komiyama et al. (2005) has examined multiple mangrove species, including the Avicennia Alba, and came up with a general equation. Komiyama et al. (2005) also provide a formula for leaf biomass but excludes dead biomass. For this equation the diameter at lowest living branch is required, which is not included in the data from Bijsterveldt et al. (2022). Therefore, leaf biomass for the Avicennia Alba is excluded. The allometric equation of the Rhizophora Mucronata mangrove species is retrieved from a study by Kangkuso et al., (2018), and includes trunk, leaf and root biomass.

Table 6: Equations used for above-ground biomass wood in kg from Kauffman & Donato (2012). DBH is the diameter at breast height of a tree and ρ is the density of the tree.

Species	Above-ground biomass B (kg)	Source	Location	Considered
Avicennia Marina	$B = 0.1848DBH^{2.3524}$	Dharmawan and Siregar (2008)	West Java, Indonesia	Dead biomass, fresh biomass (felled), trunk, roots
Avicennia Alba	$B_{above} = 0.251\ \rho\ DBH^{2.46}$ $B_{leaf} = 0.135\ \rho\ {D_b}^{1.696}$ $B_{root} = 0.199\rho^{0.899}\ DBH^{2.22}$ $\rho = 0.506$	General equation Komiyama et al. (2005)	Trat, Thailand	Trunk, leaf, root
Rhizophora Mucronata	$B = 0.143 * DBH^{2.52}$	Kangkuso et al., (2018)	Sulawesi, Indonesia	Trunk, leaf, root

The allometric equation of the Avicennia Alba requires the density 'ρ' of wood, which was retrieved through field measurement data from Komiyama et al. (2005). For the Rhizophora Mucronata and the Avicennia Marine species, allometric equations do not require wood density to be known. Following from this, the average biomass per plot was calculated by adding the carbon stored in kg/tree of all trees and dividing it by the number of trees. A conversion factor of 0.47 was then used, commonly used in literature (Howard et al., 2014; Kauffman & Donato, 2012; Arifanti et al., 2019), to find the carbon stored in the biomass. After which it was scaled to a per-hectare basis in Mg/ha, to be able to report carbon pool estimates.

The SOC in Mg/ha can be taken from samples from Ardhani et al. (2020). Averages of the sample measurements from Ardhani et al. (2020) for SOC were used for the whole area in 2018, as

Bijsterveldt et al. (2022) have not taken SOC measurements at the plots. In eroded soil there is still carbon present, therefore the total SOC increase from the project was found by subtracting the SOC of abandoned plots from the SOC of measured plots in 2018. The total carbon in Mg/ha per plot can then be calculated by the following formula:

$$(2)\ C_{living}\ (C_{trunk} + C_{leaf}\ + C_{root}\,) + SOC - SOC_{abandoned} = C_{total}$$

The carbon stored from the plots in MgC/ha then had to be extrapolated to the whole area. The methodologies from Howard et al. (2014) and Kauffman & Donato (2012) take the average of carbon storage of all the measurements and multiply this by the total area. In the case-study there is a difference between planted and natural mangroves in carbon storage, of which the sizes in hectares of the different types are known. Therefore, the average of all carbon storage per plot for both planted and natural mangroves was calculated, by multiplying with the total area of planted and natural mangroves. Table 7 shows the total regrown area of planted and natural mangroves in the case-study area from Bijsterveldt et al. (2022).

Table 7: Regrown area of planted and natural mangroves in hectares in the case-study area.

Mangrove regrowth	Coastal	Pond zone	Total
Planted	21	32.9	53.9
Natural	40.5	13.3	53.8
Total	61.5	46.2	107.7

A buffer or uncertainty factor was then applied according to the findings in part III. This resulted in total carbon storage in 2018.

$$(3)\ C_{average,planted} * hectares = m_{C,tot,planted}$$
$$(4)\ C_{average,natural} * hectares = m_{C,tot,natural}$$
$$(5)\ \left(m_{C,tot,natural} + m_{C,tot,planted}\,\right) * \%_{buffer} = m_{C,tot}$$

The total CO_2 uptake was calculated by the ratio of molecular weights of carbon (12) and CO_2 (44):

$$(6)\ \left(\frac{44}{12}\right) *\ m_{C,tot} = CO_{2e\ total}$$

Furthermore, the carbon storage at full growth after 25 years was estimated through a study from Mulyana et al. (2021) who examined AGB, including roots, of a full-grown, same-species composition mangrove forest, nearby the case-study. Furthermore, the average SOC in Indonesia from Murdiyarso et al. (2015) were used to estimate total carbon storage in MgC/ha. This was then multiplied by the total project size, after which formula 6 was used, to find the total CO_2 sequestration.

3.5.2 The added value of carbon credits to the case-study

3.5.2.1 Feasibility frontier

The feasibility frontier was then applied to the case-study. The feasibility frontier was applied by adjusting the input variables according to the case-study data. This puts forward if using a certification standard is economically beneficial for the case-study, by comparing the required carbon price to the carbon prices found in part IV. For the 5-year feasibility frontier, the values from 2018 can be used, as the BwN project started in 2013.

For the growth rate of the mangrove, the total change in living biomass and SOC carbon stored was divided by the project lifetime of 5 years. This resulted in the growth of mangroves in Mg/C/yr. The development and maintenance costs were found through data supplied by Witteveen + Bos (2020). The construction cost of 122$/m and 50$/m maintenance costs were applied to the developed and maintained dams in length. The pilot project construction of 290m was added to this, extracted from Winterwerp et al. (2020). Additionally, costs for staff and socio-economic measures were added of 112,814 $/year for the start of the BwN project (Witteveen + Bos, 2020). An assumption was made that these costs were halved during the pilot phase, as the scale of the project was significantly smaller for that phase. From this total development and maintenance costs of 21,484 $/hectare were found for the first 5 years, in line with a cost-benefit study by Hakim (2015), who found a value of 20,934 $/hectare. This value was then applied to the case-study, an assumption was made that the development costs are the same per hectare regardless of the size of the project.

For the 25-year feasibility frontier, an estimation of the total carbon storage could be made through carbon storage calculation from nearby areas in scientific literature. An assumption was made that there would be no need for additional staff or socio-economic measures and that the existing socio-economic measures would be effective in incentivizing local inhabitants to sustain the mangroves through the income generated from the carbon benefit initiative. Based on the Witteveen + Bos data (2020) it is evident that within the first 5 years, all the dams had to be maintained, therefore for the 25-year frontier 5 maintenance rounds were included in the costs. A total possible carbon storage increase was found through a study from Mulyana et al. (2021) who examined AGB of a full-grown, same-species composition mangrove forest, nearby the case-study. For the SOC average values in Indonesia from Murdiyarso et al. (2015) were compared to the average values of the case-study area from Ardhani et al. (2022). The original SOC was subtracted from the average SOC in Indonesia to find the potential increase in carbon storage.

3.5.2.2 Environmental integrity case-study

The additionality, permanence, and leakage were then discussed. The project near the village of Timbulsloko has been finalized, therefore in this chapter additionality, permanence and leakage were discussed as if the project would have applied for certification in the past. Articles and data from the BwN project supplied by Witteveen + Bos will be used to examine this, as well as articles from literature and methodologies from CSs examined in part III.

3.5.2.3 New regulations Indonesian carbon market

This will be followed by focusing on new regulations from the Indonesian government that were recently released. Scientific literature from Oentang Suria & Partners (2022) and Sulistiawati & Buana, (2023) were consulted. Furthermore, grey literature from Mulder (2022) and Bahar et al. (2023) was consulted. Grey literature is consulted, as existing scientific literature on the topic is scarce due to the regulations being released recently. The implications of the new regulations will be elaborated, and it will furthermore be discussed how this affects the case-study or a future carbon offset project in Indonesia.

4 Results

4.1 I - Key challenges associated with the development of reforestation carbon offset projects

This chapter focuses on the key challenges associated with the development of reforestation carbon offset projects. Based on the literature review, this chapter identifies three primary categories of challenges associated with reforestation carbon offsetting. These categories firstly encompass the methodological aspects, secondly the implementation considerations, and lastly the social and stakeholder dimensions. Gaining a comprehensive understanding of the challenges and potential hurdles that arise during the development of such projects is crucial for ensuring effective implementation. By recognizing and addressing these hurdles, project planning and decision-making processes could be improved, leading to increased successful outcomes.

4.1.1 Methodological challenges

Key methodological challenges exist on the topics of additionality, leakage and permanence. Addressing these challenges is crucial to ensure the maintenance of environmental integrity and for carbon offsets to represent genuine emission reductions.

To begin with, additionality can be difficult to prove for projects, as different projects have diverse conditions, including species composition, ecosystems and habitats (Chen et al., 2021). The presence of these distinct factors poses a challenge in developing a universal framework to effectively demonstrate additionality, as each project operates within a unique context (Chen et al., 2021). This context-dependent nature also presents difficulties in assessing the baseline or BAU scenario, whilst it is a critical step in assessing a project's additionality (Chen et al., 2021). While every project is required to go beyond BAU, evaluating this varies among projects due to the diverse array of factors at play in each individual case (Pan et al., 2022). Establishing the baseline scenario or BAU scenario can be particularly challenging. As, developing the baseline scenario is regularly an inefficient and time-consuming process, further complicated by the inherent instability and potential variations of future conditions, particularly when considering the impacts of climate change. (Pan et al., 2022). Because of this, Pan et al. (2022) states that project developers tend to exaggerate the carbon sequestration of forest projects. Overall, the absence of a standardized framework for assessing additionality, combined with the project-specific nature of its evaluation, poses challenges for project developers in effectively demonstrating additionality.

Climate change also affects the permanence of forest offset projects, leading to methodological challenges. A changing climate can negatively influence a project’s ability to sequester carbon, due to natural or anthropological disturbances (Lovelock et al., 2022; Pan et al. 2022). As a result of climate change, nature is becoming less stable, thereby increasing the occurrence of unpredictable natural events, such as flooding, forest fires, and wind damage (Pan et al., 2022). Climate change, if not effectively mitigated, can affect the carbon sequestration capacity of trees and consequently influence the cost-efficiency of forest carbon offset projects (Grafton et al., 2021). Accounting for these future changes is proven to be difficult over longer timespans (Grafton et al., 2021; Pan et al., 2022), especially when considering common project permanence requirements of 100 years. Making accurately estimating carbon storage, which is already a challenging task due to the persisting complexities involved in calculating the diverse carbon pools associated with forest projects, even more difficult (Grafton et al., 2021). Another challenge to the permanence of projects exists in the uncertainty of governmental policy changes. A future government could for example change its climate policy and decide to harvest a carbon offset forest (Lovelock et al., 2022; Pan et al., 2022). Gregory Williams (personal communication, 2023) describes permanence as one of the largest challenges:

> *'We would all love to tell the future, but that's the challenge, how can you ensure that a project is permanent for 100 years? And how can you de-risk it enough to ensure that it's permanent for 100 years? Particularly if you're in a coastal setting where the dynamics of the coastline are going to change with changing sea levels and changing climatic forcing. The question remains how do you account for that risk?'*

Besides methodological permanence challenges, there are also leakage challenges for the development of a carbon offset project (Grafton et al., 2021). Leakage, especially indirect leakage is difficult to account for, as it can result from an activity shift and market behavior (Thamo & Pannell, 2016; Pan et al., 2022). An activity shift occurs when, for example, a landowner decides to harvest wood from a different location than the offset project land area from which they previously sourced their wood. Deforestation, for example, can occur in unexpected regions or even shift to a different continent, making it considerably difficult to track and account for (vonHedemann et al., 2020). Market behavior on the other hand refers to a project that causes a shift in supply elsewhere that would induce CO_2 emissions (Thamo & Pannell, 2016). Leakage, and especially indirect leakage is therefore difficult to identify and quantity and is frequently ignored within project development (Thamo & Panell, 2016). Not accounting for these emissions can overshadow real emissions reductions from carbon offset projects, and therefore exaggerate real emission reductions.

Another methodological challenge exists in the quality of carbon credits generated and the trust placed in them. Regarding this, additionality is the key methodological challenge to offset quality, according to interviewed experts and interviewees by Chen et al. (2022). The quality of carbon offsets is mostly influenced by if carbon credits represent legitimate permanent and additional carbon sequestration. This is connected to the recent quality concerns raised in The Guardian article (Greenfield, 2023), which questioned the permanence of avoided deforestation credits. Consequently, trust in the VCM has declined, leading to lower carbon prices overall (van de Kamp, personal communication, 2023). According to Gregory Williams (personal communication, 2023), trust is identified as the primary concern in carbon offsetting. He emphasizes the significance of ensuring that captured carbon genuinely represents emissions reductions. Gregory Williams further states that if people cannot trust that carbon offsets accurately reflect their impact, then the credits hold no value. Chen et al. (2022) furthermore state that low-quality offsets have caused harm to projects and have resulted in damaged reputations of offset buyers. Additionally, low-quality offsets could potentially be harmful to the climate, caused by non-additional credits. This leads to net positive emissions, as the compensated emissions are not compensated by any emissions removal. Chen et al. (2022) furthermore state that these low-quality offsets can have 'negative impacts on biodiversity, the integrity of local communities, and the health of the environment.' Daan van de Kamp (personal communication, 2023) states that there is no easy way in creating carbon offsets. He continues by saying that credits without third party verification or ex-ante sold credits are not advisable and says that there is not an easy, quick or cheap way to quantify carbon cycles.

All the interviewees highlight the challenge of low-quality offsets in the market, with three of them specifically pointing out the significant distinction between avoided deforestation credits (e.g. REDD+) and AR credits (personal communications, 2023). The problem with this is that while avoided deforestation credits and reforestation credits are grounded in different methodologies, they function within the same market. Therefore, when articles like The Guardian's publication (Greenfield, 2023) come to light, their influence extends across the entire market, affecting not only avoided deforestation credits but also other types of credits, including reforestation credits.

This is especially important as avoided deforestation credits are regularly the basis of critique, that avoided deforestation does not directly reduce atmospheric emissions; rather, it prevents potential emissions resulting from deforestation (Greenfield, 2023). Regarding this Daniel Balutowski (personal communication, 2023) points towards the carbon balance, with there being no net effect of avoided deforestation, whilst companies use these credits to justify their emissions. In addition, Gregory Williams (personal communication, 2023) believes that these projects lack additionality and do not truly reflect any emissions reduction. He asserts that avoided deforestation merely maintains the current state without bringing about any actual changes. Daniel Balutowski (personal communication, 2023) concludes that these projects are needed for nature and biodiversity conservation, but states that 'this complexity between maintaining biodiversity and ecosystem services plays a different role than what the carbon market allows for and what it should be.' He furthermore acknowledges the need for clearer differentiation between avoided deforestation and AR credits, although he highlights the inherent difficulty in achieving this distinction.

Avoided deforestation should however not be written off. Daan van de Kamp (personal communication, 2023) states that with current deforestation rates, it is like ‘sticking a plaster on a wooden leg’, as the deforestation rate is significantly higher than AR rates. Moreover, AR projects entail a substantial time investment to achieve full growth, incur higher costs, and raise concerns about whether they can attain the same biodiversity level as that found within a primary forest (Martin et al., 2021). This underscores the ongoing significance of conservation as a necessary action but also highlights the vulnerability in developing an offset project due to the coexistence of two inherently distinct offset methodologies within the same market.

Daan van de Kamp (personal communication, 2023) continues by saying that the methodologies within the carbon market have matured significantly in the last few years. He is convinced that these methodologies are strongly put together. Here Friess et al. (2022) say that the new CS methodologies from Verra, and other standards, are scientifically robust. Daan van de Kamp and Elizabeth Francis (personal communications, 2023) both agree that it is a good thing to remain critical on the VCM, such as the criticism from the Guardian article (Greenfield, 2023). He however does warn that this article criticized projects that are more than a decade old, and that projects and standards have improved significantly over time, whilst Elizabeth questions the science behind the article. Daan van de Kamp (personal communication, 2023) finishes by saying:

> *‘We just have to go for this, and we don't have time to perfect it all over again. Of course, there are always companies that will abuse it but that's with any system. Thus, not developing the VCM because of some mistakes, doesn't seem sensible to me.’*

4.1.2 Implementational challenges

In this chapter, the Implementational challenges will be discussed, which are challenges related to the practical aspects of the development of a reforestation carbon offset project.

The largest challenge for a project in this field is the associated cost. Regarding this, transaction costs are the largest hurdle for the development of a carbon offset project (Chen et al., 2022; Pan et al., 2022). These transaction costs arise from various factors, including the need for physical site visits, the remote locations of these forests, and the extensive documentation requirements. Cacho et al. (2013) and Elizabeth Francis (personal communication, 2023) describe the transaction, or upfront costs of search and negotiation to be a particularly large challenge, which encompasses various tasks such as finding suitable sites, land rights, providing training, drafting contracts, and estimating project offsets. Besides the development costs (Table 2), which encompass all initial costs, the high overhead costs of verifying and registries make it a challenge to generate funds for offsets (Williams, personal communication, 2023; Chen et al., 2022). Another reason why projects struggle with attracting finance is because of the time-lag between an initial investment and the earnings from the carbon credits (Blaufelder et al., 2021). It may take several years from the first phases of a project until the project sells its first credits. This is because of the lengthy processes of issuing and verifying offsets (Chen et al., 2022; Howard et al., 2015). There is typically a time delay of 3 to 5 years between the initial development phase and the ex-post emission verification and credit issuance (Rosales et al. 2021). Therefore, besides large development costs, it takes years for a project to receive earnings from carbon finance, increasing the risk for project developers and investors.

Another implementation challenge exists in the presence of low carbon prices. As highlighted by Chen et al. (2022) a significant challenge exists in the presence of low-cost credits in the carbon marketplace. Unlike tangible goods such as food or oil, some buyers within the VCM prioritize the acquisition of emission reductions over the quality of the offsets they purchase. Chen et al. (2022) furthermore state that these low carbon prices generally do not embody high-quality carbon offsets. Regarding this, Daniel Balutowski (personal communication, 2023) thinks that carbon buyers tend to buy cheap credits, as they do not see the difference between low-quality cheap credits and higher-quality more expensive credits; regardless of quality, the carbon buyer is sequestering a ton of carbon. He further argues that the availability of these cheaper credits creates challenges for high-quality projects to sell their credits at higher prices. This divergence underscores a clear division in the market, with one segment emphasizing the importance of high-quality offsets while another segment demonstrates lesser concern in this regard.

Besides the issue of low carbon prices, challenges with the high volatility of carbon prices exist. The exchange value of voluntary carbon credits is unstable and tends to fluctuate because of market uncertainties (van Kooten, 2017; Wylie et al., 2016). Due to the nature of carbon price fluctuations, carbon projects have smaller chances for development, because of the high transaction costs (Howard et al., 2015). Furthermore, fluctuating carbon prices discourage investors, as unstable carbon prices increase the risk and uncertainty of investment (Pan et al., 2022). Therefore, to account for the risk of fluctuating prices, higher carbon prices would be preferred, linking back to the challenge of low carbon prices. The recent criticism on avoided deforestation REDD+ carbon credits (Greenfield, 2023), has for example caused VCM credit prices to have dropped as a whole. The criticism highlights the challenge of fluctuating carbon prices, whilst it furthermore has a direct negative influence on the extent to which funding is available for nature restoration (Daan van de Kamp, personal communication, 2023).

A further challenge exists in the transparency of the carbon market. It is difficult to find related pricing information easily, as there is limited market transparency (Chen et al., 2022). Limited pricing data makes it challenging for carbon offset buyers to know whether they are paying a fair price, and furthermore for project developers to manage the risk they take without knowing the exact price of the credit they will generate (Blaufelder et al., 2021; Francis, personal communication, 2023).

Furthermore, for mangrove restoration, in addition to significant time, effort and high costs, finding an unbroken stretch of coastline proves to be quite challenging for the development of a reforestation project (anonymous interviewee, personal communication, 2023). The anonymous interviewee (personal communication, 2023) states that mangroves are predominantly located near coastlines, which are often densely populated areas. As a result, it becomes challenging to identify sufficiently sized project areas necessary for profitable mangrove projects. Furthermore, the interviewee stated that many potential sites have either already been developed or are beginning to be utilized by other project developers.

4.1.3 Social and stakeholder challenges

Social and stakeholder challenges are inherent aspects to generate carbon offsets from reforestation projects and must be effectively addressed to ensure effective development.

Howard et al. (2015) have addressed multiple challenges regarding this. Firstly, even in standards where co-benefits hold significant importance, stakeholders are sometimes inadequately or insufficiently involved. Whilst it is one of the most important aspects of a successful project (Francis, personal communication, 2023). Howard et al. (2015) also argue that multiple projects could have potentially engaged a more comprehensive and representative group of stakeholders who would participate in the consultation process. Furthermore, the methods employed, and the information provided regarding stakeholder inclusion inadvertently portrayed a passive role for the community, which resulted in local stakeholders hesitating to express themselves during larger meetings. These types of meetings are sometimes not able to convey complex concepts by simply presenting technical information. Additionally, there is evidence of unfair distributions when it comes to the allocation of benefits, as certain projects can perpetuate inequality and, in some cases, reinforce existing disparities. All in all, Howard et al. (2015) found that there were multiple design documents that were not compliant with the requirements of certain CSs but were validated anyway. Not all projects however encounter these challenges, and the CSs have furthermore improved significantly over time (van de Kamp, personal communication, 2023). It however does put forward that quality stakeholder inclusion remains a challenge for forest carbon offset projects. Where quality stakeholders' inclusion entails active management, transparent information sharing, equal benefit distribution, and ongoing feedback and monitoring mechanisms (Miltenberget et al., 2021).

Another more general challenge or critique on carbon offsetting is that of CO_2lonialism (carbon colonialism). This description suggests that developed countries exploit developing countries by leveraging carbon emissions offsets, allowing them to sustain their high-emission lifestyles without significant changes (Giscell, 2010). Ever since the Paris Agreement there is a risk of companies, governments and individuals continuing their high emissions lifestyles by compensating their emissions elsewhere. Hence, as emphasized by Trouweloon et al. (2023), a consensus is emerging that carbon offsetting should be carefully regulated and considered as a temporary and supplementary measure, rather than a substitute for other forms of climate action. This viewpoint challenges the approach of the CDM discussed in chapter 2.1, which aimed to address climate change by enabling emission compensation for companies while simultaneously providing financial support for developing countries. A problem with this, is that less privileged people in developing countries are predisposed to 'sell cheap' or 'sell blind' (Giscell, 2010). These people are vulnerable and exposed to contracts that do not represent their best interests (Corbera & Martin, 2015). This links with the concerns of quality stakeholder inclusion, and underscores the importance thereof, as these individuals lack access to transparent information, placing them at a disadvantage when making agreements.

The consensus of carbon offsetting to be used as a temporary and supplementary measure is emphasized by all interviewees, which state that carbon offsetting should solely be used by companies to compensate for nonreducible emissions. Daan van de Kamp (personal communication, 2023) sees potential for improvement in the VCM and believes that certain offset credits are currently being utilized by companies to mask their minimum efforts in reducing emissions. Daniel Balutowski (personal communication, 2023) disapproves of companies using the carbon market to justify omitting. Gregory Williams (personal communication, 2023) says that carbon offsetting should only be used if it's technically not possible to remove emissions at that moment. Emitters should therefore use offsetting as a last resort in order to address the criticism on the VCM of reducing the incentive for private sector investment in low-carbon technologies and preventing financial windfalls to emitters (Valiergue & Ehrenstein, 2022).

4.1.4 Trade-off quality and costs

As discussed above methodological challenges, implementation challenges, and social and stakeholder challenges raise concerns about the quality of offset credits. The problem with this is that in many cases the improvement of quality results in additional costs and time consumption, which are already a major challenge (Chen et al., 2021). The vast time requirements are evidenced by the significant time-lag of up to five years between project development and the first generation of carbon credits (Chen et al., 2021). Improving the challenges mentioned above, and possibly increasing the time consumption and costs, may therefore not be a feasible solution. There appears to be a trade-off between quality and costs, as well as between rigor and simplification (Chen et al., 2021; Thamo & Panell, 2016). This trade-off poses a further challenge to the effective development of a reforestation project.

4.1.5 Small size carbon offset projects

This part examines the relationship between project size and the development of forestry carbon offset projects. Searching for the influence of project size is relevant since numerous MRPs are comparatively smaller in scale when compared to other conventional projects certified in the VCM, such as typical forest conservation initiatives (Wylie et al., 2016).

Smaller-scale carbon offset projects are not exempt from the challenges discussed earlier in this chapter. Here, the largest hurdle faced by smaller offset projects is the issue of costs (Cacho et al., 2013). Even though smaller MRPs are more suitable for community management, they do not deliver landscape-scale benefits (Lovelock et al., 2022). Smaller-scale projects generally provide lower returns on investments (Vanderklift et al., 2019). For smaller carbon offset projects, defined as projects below 1000 hectares by Lovelock et al. (2022), it is more difficult to attain economies of scale and sell carbon credits at relatively lower global carbon prices (Wylie et al., 2016). This makes it more difficult to find buyers that are willing to pay higher prices for smaller offset projects (Wylie et al., 2016). Additionally, the development of carbon credits necessitates substantial administrative work (Wylie et al., 2016). This poses a challenge for smaller-scale projects, as they have access to fewer man-hours (Wylie et al., 2016; Taft, 2011). Lovelock et al. (2022) have summarized the potential benefits and problems associated with smaller and larger carbon offset projects, see Table 8. While Lovelock et al. (2022) found that smaller patches could deliver fewer ecosystem services, Elizabeth Francis (personal communication, 2023) argues that large projects are not able to provide equal co-benefits as small projects, such as effective stakeholder inclusion.

Table 8: A summary from Lovelock et al. (2022) on the potential problems and potential benefits regarding larger- and smaller projects.

Project size	Potential benefits	Potential problems
Larger projects	• Potential for rehabilitation and restoration of ecosystem services over large scales • Economies of scale • Attractive to investors • Can support high levels of biodiversity • Landscape scale ecosystem service provision	• Inappropriate biophysical conditions • Limited engagement with large number of stakeholders • Complex governance • Failure to address underlying causes of degradation • Monospecific plantings • Large but short-term investment
Smaller Projects	• Potential for rehabilitation and restoration of ecosystem services over large scales • Economies of scale	• Small patches may not deliver ecosystem services • Higher costs of implementation per area of habitat

	• Attractive to investors • Can support high levels of biodiversity • Landscape scale ecosystem service provision	• Unattractive, and often invisible, to investors • Limited biodiversity benefits

Transaction costs are thus the biggest issue regarding costs, as the initial costs are fixed in the majority of cases (Lee et al., 2018; Pan et al., 2022), because of this, landowners and project developers sometimes have little incentive to develop projects (Pan et al. 2022). A further problem with this is the risk for investors in these types of projects, as these projects require high investments without a high guarantee of receiving returns (Howard et al., 2015). As discussed at the Implementational challenges, the time delay is an issue for the investment in projects. This also links to the smaller offset projects, as the earnings from carbon credits are received after multiple years. Consequently, an investor must finance the significant upfront investment costs with limited assurance of project success (Howard et al., 2015). Therefore, projects are heavily reliant on donor funding (Howard et al., 2015).

Because of these transaction costs complications, community or smallholder-led projects are more interesting to generate carbon credits for smaller-scale projects (Wylie et al., 2016). These types of projects include higher costs, but they also generate multiple co-benefits that enable higher carbon prices, thereby facilitating the financing of such projects. This emphasizes the importance of the generation of co-benefits for the development of smaller-scale projects.

4.1.5.1 Solutions smaller scale projects

There are also solutions for smaller-scale projects to still enter the carbon market. One solution is to choose a CS suited for smaller-scale projects. In recent years PV and GS have developed standards for micro projects under 10,000 tCO_2, which do not require expensive third party validation and verification. According to Daan van de Kamp (personal communication, 2023), while these micro projects could potentially be less rigid, their small size and built-in buffer negate any concerns in this regard. Another solution for smaller projects is for multiple similar projects to aggregate together or coordinate efforts (Broekhoff et al., 2019; Chen et al. 2021). These projects then agree to a larger forest management plan and are able to apply to grouped certification (White et al., 2018). Multiple CSs allow for grouped certification, which reduces the costs considerably (White et al., 2018). The monitoring, reporting and verification and other transaction costs are significantly reduced through this, and furthermore, the time effort for landowners is reduced (Pan et al., 2022). Project aggregation can also increase the willingness to participate in the carbon market for small-scale forest holders (White et al., 2018). Additionally, because of the spread risk, project aggregation decreases the risk of reversal and the invalidation of credits (White et al., 2018).

For smaller scale reforestation carbon offset projects, it is essential to reduce associated costs. Pan et al. (2022) state that the development of program guidance and program standard documents is crucial for the reduction in information costs. Furthermore Pan et al. (2022) found that small-scale project developers can apply specific methodologies at the lowest cost, emphasizing the need for adjusted more specific methodologies. Another way to reduce the costs is by linking smallholders to institutions or local entities that are already equipped with the knowledge and facilities of carbon offsetting, reducing contracting costs (Pan et al., 2022).

In addition to this, efficiency gains can be made in the process of generating carbon credits, in turn reducing the costs and time consumption. More streamlined processes can improve carbon accounting, project development, and other certification requirements (Howard et al., 2015). Friess et al. (2022) state that the next generation of methodologies will focus on simplifying methodologies to enable quicker carbon storage estimations through conservative estimations. Furthermore, Blaufelder et al. (2021), found that the verification process can be streamlined, and verification methodologies can be strengthened. Another solution for small-scale carbon offset projects is for upfront ex-ante carbon credits sales. Implementing this approach makes it possible to alleviate investment costs. However, engaging in the sale of carbon offset credits before carbon sequestration introduces inherent risks. (Howard et al., 2015).

In the future, innovative technologies and techniques furthermore have the potential to significantly reduce costs. Regarding this, the increased use of satellites is promising to reduce efforts for monitoring and verification (Pan et al., 2022). For mangrove forests remote sensing has seen an increased capacity to monitor the extent of carbon stocks (Campbell et al., 2022). Another improvement could be community-based monitoring instead of monitoring by a third party verifier. Co-benefits are increased through this approach and this type of monitoring is more affordable and efficient (Pan et al., 2022).

4.1.6 Conclusions and trade-off quality costs

As discussed in this chapter there are multiple challenges that have to be taken into account when developing a reforestation carbon offset project. The key messages and challenges from this chapter are summarized below.

Methodological, implementation, and social and stakeholder key challenges:

- Methodological challenges exist in adequately addressing additionality, permanence and leakage. In order to produce quality and trusted caron offsets which are not overestimated
- Costs, especially the initial transactions costs, are the largest implementation challenge

- The market’s high volatility and the time-lag between investment and returns pose challenges and require a project to account for these financial risks
- Stakeholders are sometimes inadequately or insufficiently involved

Smaller-scale project's key challenges and solutions:
- Costs are a major challenge for small size projects, especially transaction costs
- Solutions to this are the use of CSs that allow micro projects, aggerated certification and possible efficiency gains

4.2 II – Relevant stakeholders for carbon offsetting through mangrove restoration projects

In order to better understand the stakeholder environment for a carbon offset project through mangrove restoration, a stakeholder analysis was conducted. This is relevant for projects, as stakeholders can significantly impact the overall success and outcomes of an initiative, in this case, including carbon offsetting into MRPs. The StA contributes to parts III, IV and V by providing a deeper understanding of the stakeholders and their roles, enabling their interests to be better taken into account. Figure 9 shows the relevant stakeholders through a VCM mangrove restoration ecosystem map. The figure shows the key stakeholders and how they relate to one another.

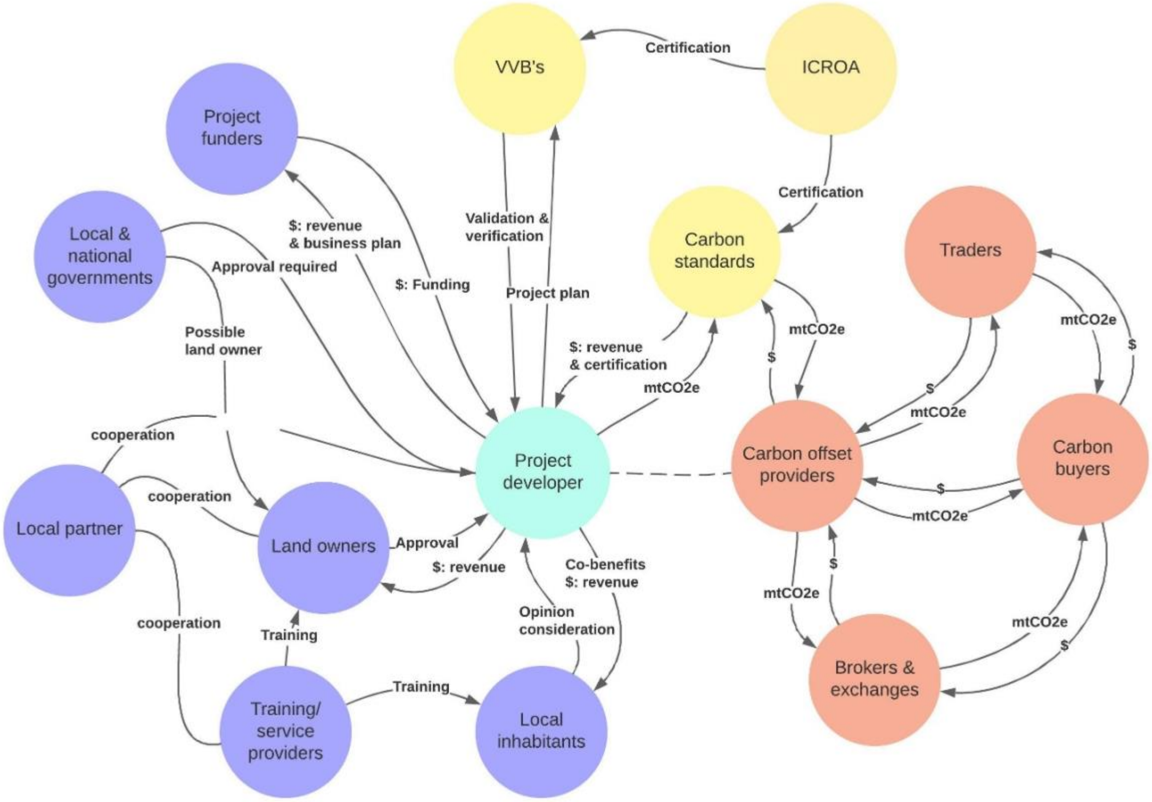

Figure 9: Mangrove restoration VCM key stakeholder ecosystem map. Lines represent relations between stakeholders. $= money transfer, mtCO$_{2e}$= transfer of CO$_2$ rights. The colours represent different roles in the ecosystem, namely financial stakeholders (red), local stakeholders (blue), certification stakeholders (yellow), and project developers (turquoise).

All interviewees (personal communications, 2023) highlight that local stakeholders are crucial for the development of an MRP. They have multiple roles, such as landowners, land users, or nearby inhabitants. Where Gregory Williams and Daan van de Kamp (personal communications, 2023) emphasize that for MRPs landowners are of high importance. The participation of local stakeholders is essential for the successful restoration of mangrove ecosystems. As described by the Interviewees (personal communications, 2023), they hold knowledge and expertise of the local area, they pose land ownership, they are directly affected by a change in management, and because effective community engagement can be beneficial for the project's success. Furthermore, a portion of the generated carbon revenue is directed towards supporting and benefiting these stakeholders.

In relation to this, an anonymous interviewee (personal communication, 2023) highlights that a significant number of people live near the coastlines in close proximity to MRPs. As a result, the significance of fostering effective community involvement and consideration becomes even more important. Gregory Williams (personal communication, 2023) compares this to general carbon offset forest projects, such as conservation projects, and says that population densities are significantly lower in these cases when compared to coastal areas. This increases the importance of quality stakeholders' consultation for MRPs, which is already a challenge according to findings in chapter 4.1.3. Furthermore, Daan van de Kamp (personal communication, 2023) highlights that the proper management and documentation of land ownership are essential prerequisites for project certification. Without thorough attention to these aspects, a project may not meet the necessary requirements for certification.

Additionally, an anonymous interviewee (personal communication, 2023) underscores the importance of mapping local stakeholders and taking into account their alternative sources of income in the context of mangrove forests. For instance, in situations where local inhabitants depend on shrimp farms for their livelihoods or depend on illegal logging, it becomes critical to plan and establish new income opportunities, which embody higher profits than the earlier jobs. Through this approach, the risk of reverting to previous practices that could jeopardize the restored mangroves is reduced. Daniel Balutowski (personal communication, 2023) furthermore puts forward the importance of locals for MRPs, as they have knowledge of the area, which can be useful for the implementation of restoration measures. Therefore, project developers work together with a local partner that knows the area (van de Kamp, personal communication, 2023). These local partners furthermore work with training and service providers, which speak the native language, to educate locals (van de Kamp, personal communication, 2023). Furthermore, local and national governments have to approve the projects and approve that sequestered carbon can be accounted for in another country.

To generate quality and reliable carbon credits the project developer has to certify the project through a CS. These standards, such as Plan Vivo, Verra or Gold Standard, provide methodologies and guidelines. They furthermore retire credits in their respective registries. To guarantee that a standard's requirements are met, third party VVB's first validate if the project's design, methodologies and plans are eligible for the standard. Then later in the process, VVB's verify the performance of the implementation of the projects. This step involves on-site visits to take measurements, as well as stakeholder interviews, to ensure the projects claimed environmental and social benefits are valid. The CS and the VVBs can in turn be certified by ICROA, which when certified, proves a code of best practice. This ensures that accredited 'organisations, and their clients, undertake carbon management strategies that lead to ambitious and impactful climate action' (ICROA, 2023).

Carbon offset providers then offer the certified credits for sale. Carbon offset providers, such as the Climate Neutral Group or Southpole can also function as project developers, whilst they also assist companies to reach their carbon reduction emission goals. Additionally, carbon offset provides, traders and brokers to sell carbon credits to carbon buyers, although credits can also be traded through carbon exchanges.

4.3 III – Comparison certification standards for mangrove restoration projects

In this chapter, three CS that are suited for MRPs were examined and compared. This chapter will therefore provide a comprehensive overview of the CS and the differences between them.

4.3.1 Carbon certification standards most suited for mangrove restoration projects

4.3.1.1 General

The CSs differ between their crediting periods. PV has a 10-year minimum project length to a maximum of 50 years, whilst Verra has a minimum of 20 years to a maximum of 100 years. GS has the longest minimum crediting period of 30 years. Climate Focus (2023) has constructed a VCM dashboard aimed to promote transparency within the market, by providing data on the number of credits issued through NBS. When looking at the total NBS credits issued, Verra has issued 92.9% of all credits from 2020 until April 2023. PV has issued 1.4% and GS 1.0%. Hence, Verra produces a substantial share of the total credits issued.

Table 9: General comparison of the Certification standards.

	Plan Vivo	Verra	Gold Standard
Crediting period	10-50 years	20-100 years	30+ years
Credit used	PVC (verified vPVCs, Reported rPVCs, Future fPVCs	VCU (with CCB and SD VISta additionally)	CERs
Market Share NBS	1.5%	91.5%	1.0%
Total NBS registered projects	28	262	47
Total NBS registered projects share	5.4%	50.3%	9.0%
Project area	Developing countries	Global	Global
Pricing credits per standard	Not available	Not available	$18 and $59 / credit, 2 reforestation projects

The share however changes when looking at the number of projects per standard. Regarding this, Verra produces 50.3% of the total number of projects, whilst PV and GS develop 5.4% and 9.0% respectively. Therefore, it can be stated that Verra produces more carbon credits per project and that their projects are larger sized than PV and GS for NBS projects. Furthermore, GS is the only standard that provides data on project prices, with one reforestation project being $18 per credit and the other $59 per credit (GS Marketplace, n.d.). PV and Verra do not provide carbon prices, indicating the low transparency around carbon prices found in chapter 4.1.

4.3.1.2 Assessment types and reporting

Both PV and GS exempt projects with annual CO_2 emissions of less than 10,000 tCO_2 from the requirement of utilizing a VVB. PV instead accepts validation and verification to be conducted through an internal process overseen by the PV foundation with the help of an independent expert. GS allows small-scale carbon offset projects to be validated and verified by an internal procedure within the standard. Both these standards therefore bypass expensive external validation and verification minimizing financial pressure from the auditing process.

Table 10: Assessment types comparison of the certification standards.

	Plan Vivo	Verra	Gold Standard
Validation and verification	VVB required projects > 10,000 tCO_2 /year, otherwise verification and verification by PV foundation and an independent expert. VVB's must be approved by Plan Vivo.	VVBs that meet the eligibility criteria from Verra. Specific for different methodologies and has to apply to VCS *methodology requirements*, VCS *program guide* and the VCS *standard*	For GS first a preliminary review by Sustaincert is required. After which third party validation is required for macroscale projects. Followed by Sustaincert project design review and then third party verification. <10,000 tCO_2/year microscale projects, GS internal validation and verification.
Verification period	Every 5 years	Not specified	Every 5 years
Monitoring plan and reporting plan	Monitoring plan required on progress indicators, namely expected carbon, livelihood and ecosystem benefits. Monitoring report yearly. A summary of the progress indicators must be included in each annual report and shared with other stakeholders	Monitoring plan required (specific for methodologies) on GHG information system, for roles & responsibilities and contribution to sustainable development. No specified frequency	Extensive monitoring plan and reporting plan required, based on *Safeguarding principles assessment*, *SDG impacts assessment* and *Stakeholder consultations*. Verified monitoring report every 5 years
Ex-ante or ex-post carbon credits	Both, fPVCs are available to buy, but can only be retired until fPVCs are converted to vPVCs	Ex-post	Ex-post

Furthermore, while PV and GS explicitly require verification every 5 years, the specific verification frequency remains unspecified for Verra. Nevertheless, many projects choose to align with a 5-year verification period when seeking Verra certification. Additionally, all considered standards require monitoring plans to be developed. Issuing credits is performed ex-post for Verra and GS, whilst PV allows future credits (fPVC) to be bought ex-ante. These credits cannot be retired until the carbon is stored, serving as a mechanism to support early carbon financing for projects to overcome high early transaction costs.

4.3.1.3 Environmental integrity

All three crediting schemes have detailed additionality requirements, the implementation thereof however differs on a project-to-project basis. Furthermore, Verra has a specific additionality document for tidal wetlands, including mangrove forests. In general, there are four main types to assess additionality which may be required individually or in combination:

1) Regulatory surplus: the project cannot be mandated by any statute, law or other regulatory framework
2) Positive list: project must demonstrate that it meets all of the applicability conditions
3) Barrier analysis: identification of potential barriers of a projects implementation and ways to prevent these barriers
4) Investment analysis: show that the project is not financially viable without carbon financing

Table 11: Environmental integrity comparison of the certification standards.

	Plan Vivo	Verra	Gold Standard
Additionality	Regulator surplus (beyond common practice) and barrier analysis	Regulatory surplus and positive list or CDM tool. Specific additionality methodology for tidal wetlands	Through CDM tool or a positive list
	Financial/economic barriers Technical barriers Institutional/ political barriers Ecological barriers Social barriers Cultural barriers	Regulatory surplus and Positive list or CDM tool: 0. Preliminary screening, 1. Identification of alternative scenarios, 2. Barrier analysis, 3. Investment analysis, 4. Common practice analysis	Positive list or CDM tool: 0. Preliminary screening, 1. Identification of alternative scenarios, 2. Barrier analysis, 3. Investment analysis, 4. Common practice analysis
Permanence	Non-permanence buffer used	Non permanence risk tool	Compliance buffer and 15-meter-wide buffer strips along water courses
Buffer used	10%-20%	Min 10%	20%
Leakage	An approved methodology must be used to assess leakage. If needed, leakage risk measures must be implemented	Required to use leakage methodology regarding three points: Market leakage ,activity-shifting leakage and ecological leakage	Detailed formulas required for modelling unit on Collection of wood, timber harvesting, agriculture and livestock
Double counting	Third party registry	Registry system	Registry system
	Double counting requirements specified	Projects have to apply to Paris agreement article 6	Extensive double counting requirements

For both PV and VCS, it is necessary to conduct a regulatory surplus analysis, which excludes projects being required by any statute, law or other regulatory framework. The second step for a VCS project is to apply to 7 points from a positive list. A second approach to prove additionality for VCS is through the 4-step mechanism from the CDM methodology, consisting of alternative scenario identification, investment test, barrier test and common practice test. PV goes one step further by requiring project developers to provide evidence that the barriers identified will not hinder the implementation of the alternative scenarios identified, and furthermore to identify and overcome all barriers that are identified. Additionality can be approached in two ways for GS either through the old CDM methodology or through a positive list, by complying with three set requirements and half of the extra set requirements.

To ensure a project's permanence the crediting schemes require non-permanence buffers. For PV the buffer ranges between 10% and 20% of the total carbon sequestration. For GS the buffer is set at 20%, and for Verra, it is calculated by a non-permanence risk tool which is minimally 10%. The latter risk tool requires an extensive risk assessment and therefore increases the data requirements of the Verra standard. The Verra risk analysis is the most comprehensive of all the standards, although all standards adopt similar mechanisms (Pan et al., 2022). Most PV and GS projects use a buffer of 20%, whilst the average buffer used for Verra is 12,5%. The three crediting schemes furthermore all include leakage requirements, and regarding this, Verra and GS have specific requirements for leakage. Whilst PV states that an appropriate methodology must be used. In order to prevent double counting, all standards include registries that assign unique serial numbers to projects. All standards furthermore require conservativeness for calculating CO_2 reductions to enhance environmental integrity. This means that when data is inconclusive, conservative assumptions have to be made in order to prevent over-crediting (Michaelowa et al., 2019).

All standards promote a high level of environmental integrity within their standards. PV and GS have a more in-depth additionality requirement, especially PV when compared to Verra. Furthermore, PV and GS account for larger buffer pools on average than VCS. Therefore, based on the methodologies GS and PV tend to uphold a higher form of environmental integrity.

4.3.1.4 Environmental criteria and co-benefits valuation

The three standards have distinct goals and core principles. PV is a standard that prioritizes key principles such as alleviating poverty, rehabilitating and safeguarding ecosystems, and enhancing local capabilities. As a result, this standard focuses on combating climate change by promoting sustainable livelihoods. On the other hand, the GS places sustainability at its core. Projects adhering to this standard must exhibit the highest level of environmental integrity and contribute to sustainable development.

VCS on the other hand, is a standard that aims to generate meaningful environmental and social value at scale, whilst also contributing to the advantages of such projects. It is a standard focussed on carbon benefits and scalability. The overarching company Verra has furthermore developed two other standards, namely the climate, community & biodiversity standards (CCBS) and the sustainable development verified impacts standard (SD VISta). These standards can be used in conjunction with, or separately, from the VCS standard. The latter is focused on certifying the SDGs, thereby providing benefits to local communities and smallholders, and promoting biodiversity conservation. In contrast, the former is aimed at advancing the SDGs and delivering benefits to people, their prosperity, and the planet. In other words, the CCB standard is focused on the certification of the co-benefit performance of forest projects (Lee et al., 2018). These two standards provide a rating that acknowledges non-carbon benefits, thereby enhancing more favourable carbon credit pricing of such projects. More than 80% of projects using the VCS standard have added the CCB label (Maguire

Table 12: Environmental criteria and co-benefits of the certification standards.

	Plan Vivo	Verra			Gold Standard
		VCS	CCBS	SD VISta	
Core principles	Three core objectives: 1. Alleviating poverty 2. Rehabilitating and safeguarding ecosystems 3. Enhancing local capabilities	To generate meaningful environmental and social value at scale, and contribute to the advancement of these programs globally	Promoting land use projects that contribute to climate change mitigation, provide benefits to local communities and smallholders, and promote the conservation of biodiversity.	Certify sustainable development goals. Advance the SDG's and deliver benefits to people, their prosperity and the planet	A projects sustainability is a core requirement. Projects that reduce carbon emissions should have the highest levels of environmental integrity and contribute to sustainable development
Environmental requirements	Besides carbon benefits projects must promote ecosystem & biodiversity benefits and livelihood benefits, executed through an ecosystem and biodiversity baseline that has to be improved over the project's lifetime. Furthermore, environmental, and social screening is required to reduce potential risks.	Project must demonstrate how it contributes to sustainable development, by contributing to at least three SDG's. Project should not harm environment.	Project must supply detailed climate scenarios and a net positive climate impact. Additionally, the project must supply biodiversity scenarios and net biodiversity impacts	Not present. Different for every SDG.	Evidence must be provided that the project has net-positive ecological impact on soil, water, biodiversity and climate. Furthermore, it is specified that evidence must be given of the usage of; no chemical products, appropriate waste disposal, buffer strips, no genetically modified species, native species and species planted that are adapted under changing climate conditions.
Social requirements	Projects must demonstrate social benefits. A livelihood baseline must be developed that must improve considering potential project participants and other local stakeholders. Also considering gender equality, women's rights, age equity and cultural heritage	Project activities must not negatively impact local communities. Any negative socio-economic impact must be identified and addressed, by engaging with local stakeholders	Multiple requirements for community improvement on net-positive impacts compared to a baseline, no harm to the well-being of other stakeholders and impact monitoring	Multiple criteria for the demonstration of impacts on people, their prosperity and the planet. Net-positive impacts on well-being of all directly impacted stakeholders and on natural capital and ecosystem services affected by the project	Projects must demonstrate net-positive socio-economic impacts. Several requirements for good and fair working conditions. All stakeholders must be invited for consultation and workers should come from nearby areas.
Stakeholder consultation	All stakeholders that could influence or could be affected by the projected need to be mapped. Stakeholder engagement plan required with a participatory design and free prior & informed consent	Local stakeholders should be consulted prior to the project to increase stakeholder participation. Must develop ongoing communication mechanisms.	Stakeholders have to be involved through full and effective participation. This includes access to "information, consultation, participation in decision-making and implementation, and free, prior and informed consent."	Stakeholders have to be involved on an ongoing basis. They shall have access to adequate and timely information. With criteria on anti-discrimination, worker relations, grievance redress procedures and access to information	Specific and detailed stakeholder consultation and engagement requirements necessary. Main goals are to engage stakeholders and to identify potential environmental, socio-economic risks and positive contributions. Whilst constructing an ongoing mechanism for feedback in consultation with stakeholders

et al., 2021). It is however worth noting that they have extensive data requirements and increased costs.

Both Plan Vivo and GS have strict environmental requirements. Projects must demonstrate environmental benefits. On top of that, for the GS it is necessary to comply with an extensive list of environmental requirements. Verra requires a project to be of added value to three SDGs and to not harm the environment, whilst the supplementary CCBS standard has multiple strict environmental requirements. For SD VISta the requirements depend on the different SDGs. Therefore, for PV and GS environmental requirements are stricter than for VCS without CCB or SD VISta.

The standards all include environmental criteria; however, they incorporate the co-benefits in varying ways. PV projects are required to include ecosystem and biodiversity benefits, as well as livelihood benefits. Their projects have to set ecosystem, biodiversity and livelihood baselines, which have to improve over a project’s lifetime. GS projects have to report and map their environmental and socio-economic impacts and come up with counter measurements if applicable. VCS projects have to report net-positive community benefits and biodiversity benefits. In this regard, SD VISta provides greater clarity on the inclusion of co-benefits. When a project successfully meets the SDGs, then it has the opportunity to apply a label marker, thereby enhancing the market value of the project unit. The standards do not mention exact price increases of carbon credits when co-benefits are valued or not. Despite the lack of co-benefit valuation in the standards, co-benefits are a key reason why some stakeholders participate in the carbon market (Hamrick and Gallant, 2017), and furthermore are the reason for higher market values of co-benefit rich carbon credits (Goldstein and Ruef, 2016; Hagger et al., 2022). Therefore, it is likely that the co-benefit valuation is determined per project and that they are dependent on carbon market prices, and furthermore on what buyers are willing to pay for certain carbon project credits.

Lastly, all standards require extensive stakeholder consultation and mapping. Local communities should be included in project development and stakeholder consultation plans should be developed prior to the project start. Chapter 4.1.3 however found that multiple challenges exist in effective and quality stakeholder inclusion. Hence, there seems to be a disparity between the established standards methodologies and the practical execution of projects.

4.3.1.5 Mangrove restoration projects and methodologies

Both PV and Verra have developed MRPs and are currently developing new projects. GS has not developed carbon credits from MRPs and does not have a project under development. The GS furthermore does not consist of a specific mangrove methodology but has an adjusted AR methodology for mangrove forests. The AR methodology can be used with an addition of 1.8 tCO_2/ha/year for SOC accumulation, however transparent and verifiable own-found values are also acceptable. Verra has a comprehensive methodology (VM0033) for blue carbon projects, whereas, PV does not have a specific methodology for mangroves. Out of the three developed projects, however, two use similar allometric equations as the methodology from Kauffman & Donato (2012) to calculate the stored biomass, and the other uses the methodology. From the four pipeline projects, three use Kauffman & Donato (2012) for their carbon calculations and monitoring, while the other is unspecified. One important requirement for PV projects is that 60% of profits has to be redirected to the local community, and for GS 15% of the profit has to be redirected to cover variable foreign exchange fees.

Table 13: Comparison of methodologies for mangrove restoration certification standards.

	Plan Vivo	Verra	Gold Standard
Avoided or reforestation	Both	Both	Reforestation only
Mangrove restoration projects	3	5	0
Projects being developed	4	17	0
Earnings	Minimal 60% to community	Not specified	15% to cover variable foreign exchange fees
Mangrove methodology	-	VM0033	Methodology for AR GHGs emissions reduction & sequestration
Details	No separate methodology, 1 finished and 3 pipeline projects use Kauffman & Donato (2012), other unspecified	Extensive blue carbon methodology	No separate methodology, uses reforestation methodology and implies an extra 1.8 tCO_2/ha/year for SOC accumulation, unless other value can be justified

Verra includes all types of mangrove biomass in their methodology; however, projects may decide not to include certain biomass categories. VCS-certified projects tend to exclude litter and deadwood biomass. The GS does not include non-tree biomass, harvested wood and litter. GS however does include tree biomass, standing dead trees, where SOC is optional. PV does not explicitly mention in their standard which biomass is included or excluded. However, the developed projects under PV do not include non-tree biomass, harvest wood, or litter & dying dead wood. These projects choose to exclude these biomass types due to their relatively moderate carbon impact and difficulty to measure. Excluding these biomass types adds to the overall conservativeness of the project's carbon calculations. Additionally, most projects include SOC in their carbon calculations.

Table 14: Crediting schemes Inclusion or exclusion of biomass for mangrove forest

	Plan Vivo	Verra	Gold Standard
Tree biomass	Yes	Yes	Yes
Non-tree biomass	No	Yes	No
Soil organic carbon	Varies	Yes	Optional
Harvested wood	No	Yes	no
Litter & dying dead wood	No	Yes	Litter no, standing dead wood yes

4.3.2 Conclusions

Verra (VCS), Plan Vivo and the Gold Standard are all suited standards for MRPs. They however differ in their goals and approaches. The key findings can be summarised as follows:

- VCS is a standard focussed on scalability with environmental criteria in sight, CCB and SD VISta can be used on top of the VCS standard, having a larger focus on environmental and socio-economic criteria.
- All standards have high environmental integrity criteria (additionality, permanence and leakage)
- Both PV and GS have a high environmental focus with PV having a larger focus on local communities and alleviating poverty, the GS aims to have the highest level of environmental integrity.
- Verra does include mangrove tree biomass, harvested wood, litter and dead wood in their methodology. Most projects and other standards however excluded these categories to improve conservational estimations

4.4 IV - Cost-effectiveness of certification standards for mangrove restoration projects

The feasibility of using the three examined CSs and their accompanied programs has been examined for a 25-year period and a 5-year period. To do this, the carbon price and the minimum project size are compared. This shows the break-even price, which is when the revenue of carbon credits is equal to the total cost of using a CSs also including development cost. The area above and right of the line represents an economically viable combination of carbon prices and project size, whilst below and left of the line represents unfavourable project size and carbon credit combinations.

The feasibility frontier can be useful for project developers to gain insight into when generating carbon credits through a CS becomes feasible. It should however be noted that the frontier does not indicate when a company or project developer can start making a profit through a CS, as company dynamics are not taken into account. These costs, for example, entail buffer costs for project risks or taxes.

4.4.1 Carbon prices

To get a grip of the carbon prices calculated from the feasibility frontier it is useful to know at what price carbon credits sell for. Carbon prices can differ significantly (Hamrick et al., (2018). Ecosystem Marketplace (2021) has tracked carbon prices within the VCM and found that between August and November 2021, the average carbon price was valued between \$3.13 and \$4.73 per credit. Daniel Balutowski (interview, 2023) working for a carbon removal project developer, estimates average carbon prices between \$5 and \$15 per tCO_2 for projects within the VCM. Hamrick et al. (2018) furthermore state that prices can be as low as \$0.5 per tCO_2 and as high as \$50 per tCO_2. This is dependent on multiple variables such as the type of project, conservation or AR projects, and the inclusion of co-benefits. One outlier was however found in chapter 4.3.1.1 of a GS reforestation project of \$58 per tCO_2.

Mangrove forest carbon prices are on average higher than other voluntary carbon offset prices, because of the included co-benefits and higher measurement costs (Jakovac et al., 2020). Table 15 summarizes the carbon prices found in this research. The project certified through PV in Madagascar is selling carbon credits at prices of \$20 per tCO_2 for a relatively small volume project focusing on environmental and social benefits (Beers et al., 2019). Therefore, for a project to sell above-average VCM carbon prices, co-benefits have to be included and reported. From the table it can be derived that mangrove carbon credits sell between \$18 and \$40, depending on the quality of the credits.

Table 15: Carbon prices of blue carbon or mangrove restoration projects.

Person or source	Carbon credit price	Type	Source
Daan van de Kamp	\$30-\$40	Mangroves	Personal communication (2023)
Elizabeth Francis	\$20-\$32	Mangroves	Personal communication (2023)
Anonymous interviewee	\$20	Mangroves	Personal communication (2023)
Plan Vivo Madagascar project	\$20	Mangroves	Beers et al. (2019)
QCI	\$20 - \$40	Blue carbon	Quantum Commodity Intelligence (2022)
Latleef (2022)	\$18 - \$25, highest \$32	Mangroves	Latleef (2022)

Additionally, carbon prices are expected to increase significantly in the future (van de Kamp, personal communication, 2023). As a report from EY (2022) expects carbon prices to increase to \$80-\$150 per tCO_2, compared to current prices of \$25 tCO_2. This increases the profitability of offset projects, paving the way for currently unfeasible projects to become viable and profitable in the future.

4.4.2 Feasibility frontier 25-year project lifetime

From the 25-year lifetime feasibility frontier it can be concluded that using CSs for carbon financing for MRPs can be achieved with relatively low carbon prices, see Figure 10. The PV micro program and the GS micro program have the relatively highest feasibility for projects to use a CS. It should however be noted that for PV the independent expert costs are unknown and therefore PV micro would likely show a similar trend to GS micro. They both show a relatively fast equilibrium between the carbon price and project area, as the development cost becomes an increasingly bigger factor in the total price when the total carbon storage increases. The feasibility frontier shows that the programs without validation and verification have break-even prices at 50 hectares between \$4.7 per credit for PV micro and \$5.8 per credit for GS micro. Both these programs do not exceed project sizes larger than 166.8 hectares with the input variables of this study, as otherwise, the projects would exceed the 10,000 tCO_2 per year threshold for micro scale projects. Furthermore, the initial costs without validation and verification are significantly less, therefore the feasibility frontier shows an increased steepness when compared to the other programs. The other programs that include validation and verification all approach carbon prices of \$6 per credit for project sizes of 100 hectares.

Therefore, these break-even prices of \$6 per credit compared to average carbon prices in the VCM from chapter 4.4.1, demonstrate that MRPs can be developed for relatively low carbon prices for a 25-year lifetime. Especially when compared to average MRP prices between \$20 and \$40 per tCO_2. Therefore, it can be concluded that on average the development and utilization of a CS is profitable for a 25-year lifetime.

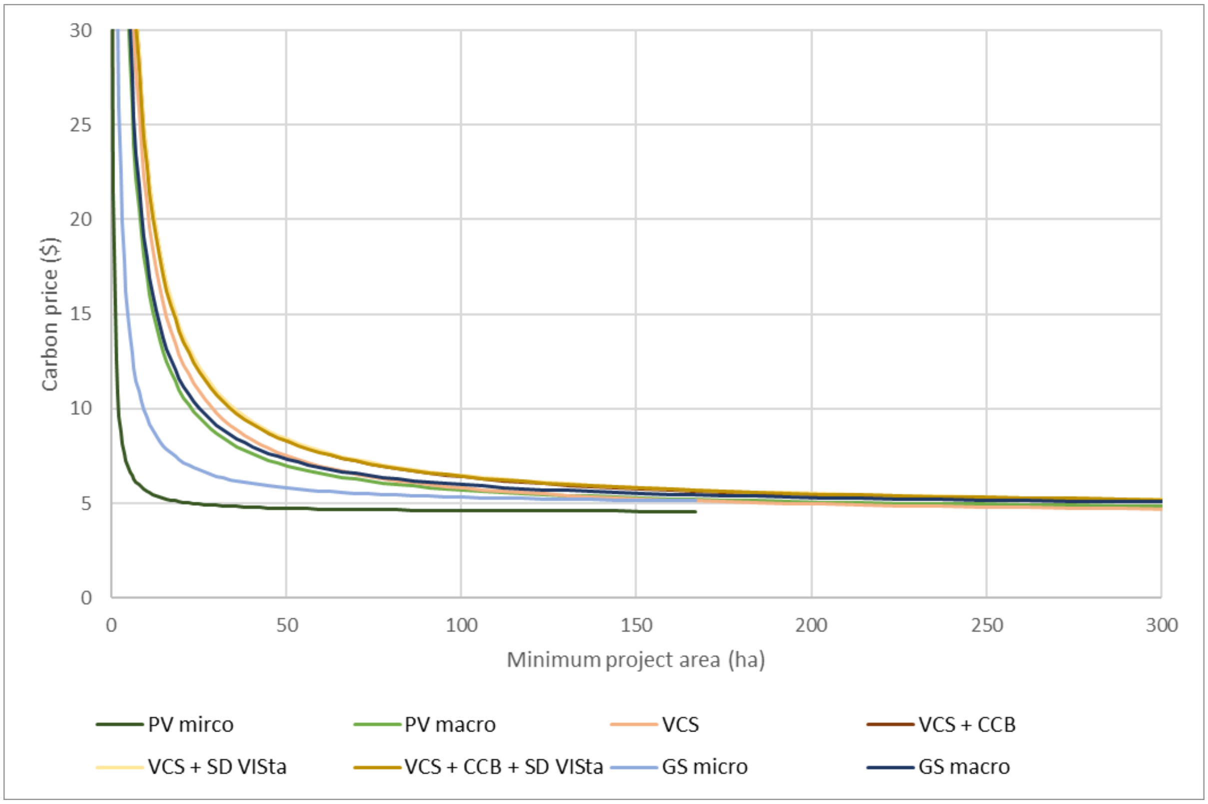

Figure 10: Feasibility frontier of developing a mangrove restoration project and certification through a certification standard, 25-year lifetime.

In Table 16 the carbon price and present value of the total cost is presented over a period of 25 years. PV micro and GS micro demonstrate the lowest present value costs, whilst Verra represents the highest total present value costs. The minimum cost of a 1000-hectare project for all CSs approaches $5,000,000.

Table 16: 5-year period, total present value price of projects using a certification standard, prices per $1000.

Crediting schemes		Size (hectares)			
		1	10	100	1000
Plan Vivo	Mirco	18.0	63.4	517.2	5055.5
	Macro	148.1	192.8	639.9	5110.7
Verra	VCS	195.3	237.1	653.2	4765.9
	VCS + CCB	202.9	245.3	668.1	4840.8
	VCS + SD VISta	202.9	245.3	668.1	4840.8
	VCS + CCB + SD VISta	197.6	240.7	670.3	4895.4
Gold Standard	Micro	54.8	100.2	554.0	5092.3
	Macro	146.1	189.4	623.0	4959.0

4.4.3 Feasibility frontier 5-year project lifetime

The feasibility frontier of developing an MRP and utilizing a CS change significantly when a first 5-year period is examined. Both the micro programs of PV and GS do not exceed project sizes larger than 166.8 hectares, with the input variables of this study, as otherwise, the projects would exceed the 10,000 tCO_2 per year threshold of micro scale projects.

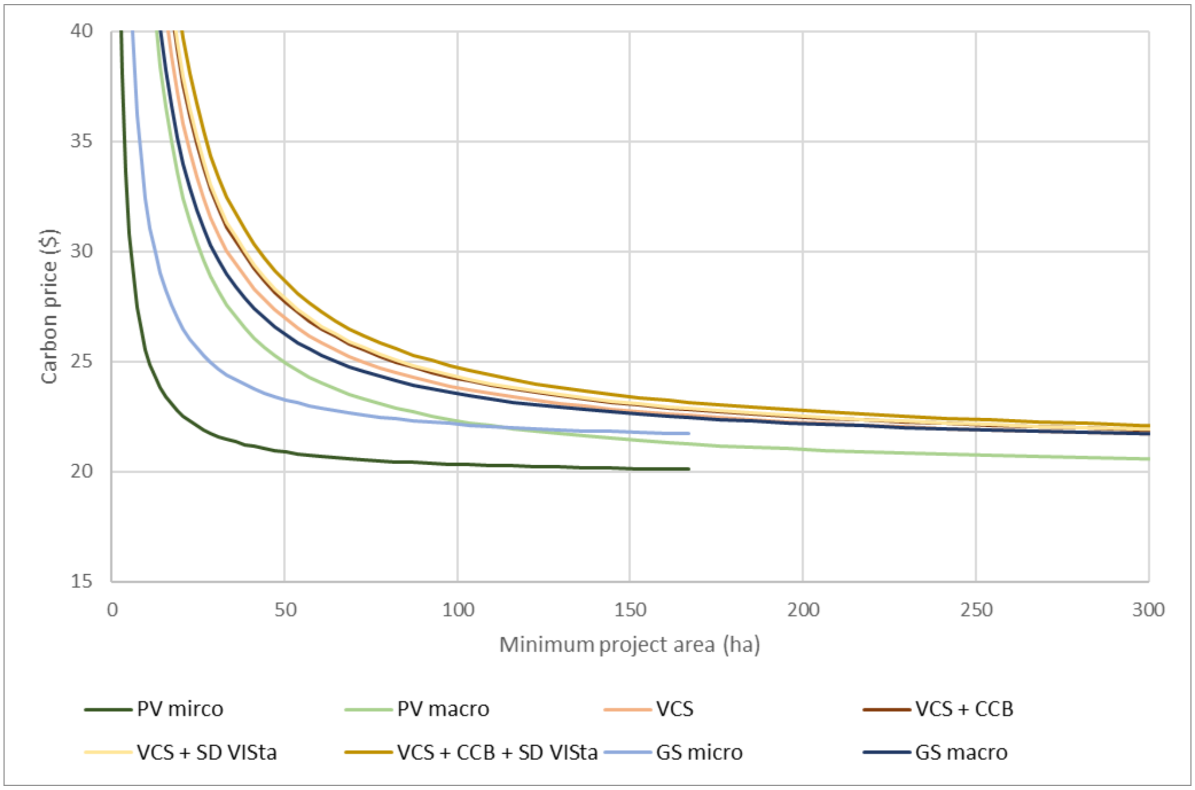

Figure 11: Feasibility frontier of developing a mangrove restoration project and certification through different certification standards, first 5 years.

The PV CS is the cheapest standard. PV micro CS reaches an equilibrium after around 100 hectares of 20 $/ha, these would however be slightly higher if the independent expert would have been included. PV Macro scale project costs reach an equilibrium of 21 $/ha at around 200 hectares. When compared with the average carbon prices then this aligns with the minimum carbon prices of restored mangroves. It should however be noted that in chapter 4.3.1.5 it was found that 60% of earnings have to be returned to local communities, and 15% have to be reserved for taxes at the GS CS.

The cost associated with the development and use of the Verra CS exhibits a moderate increase when CCB or SD VISta are added to the VCS standard. Carbon prices have a larger range for smaller project sizes when compared to larger sized projects. All Verra programs however show similar trends in their feasibility frontiers. Furthermore, Verra is relatively more expensive than PV and GS for smaller projects, certifying through VCS alone costs $24 per credit for 100 hectares.

For a 1000-hectare project, the required carbon price ranges at $21 per credit, in the range with the lowest sold mangrove restoration carbon prices.

The GS for micro projects demonstrates a relatively low required carbon price for smaller mangrove projects when compared to the other CSs. Projects between 100 hectares and maximum size for micro projects, reach equilibrium break-even prices of 22 $/ha. For macro projects, a break-even equilibrium is reached between 200 hectares to 300 hectares of 22 $/ha. Table 17 shows the total price of using a CS for different areas of mangrove forest for the first 5 years of a project.

Table 17: 5-year period, total present value price of projects using a certification standard, prices per $1000.

Crediting schemes		Size (hectares)			
		1	10	100	500
Plan Vivo	Mirco	17.5	58.0	463.2	4515.9
	Macro	64.3	104.7	508.6	4547.8
Verra	VCS	71.9	111.4	509.7	4489.5
	VCS + CCB	79.4	119.1	518.7	4512.0
	VCS + SD VISta	80.9	120.6	520.2	4513.5
	VCS + CCB + SD VISta	88.4	128.2	529.2	4535.9
Gold Standard	Micro	28.5	69.0	474.3	4526.9
	Macro	62.5	102.6	503.8	4516.0

Figure 12 presents the minimum transaction costs for each CS without the development costs of the mangrove restoration area. As stated in chapter 4.1 transaction costs are a significant challenge, especially for small projects. This table shows that PV micro and GS micro have minimum transaction costs of $12,950 and $14,500 respectively, because of the exclusion of a third party VVB. Verra, PV macro and GS macro programs range from $58,000 to $74,500 for the CS alone.

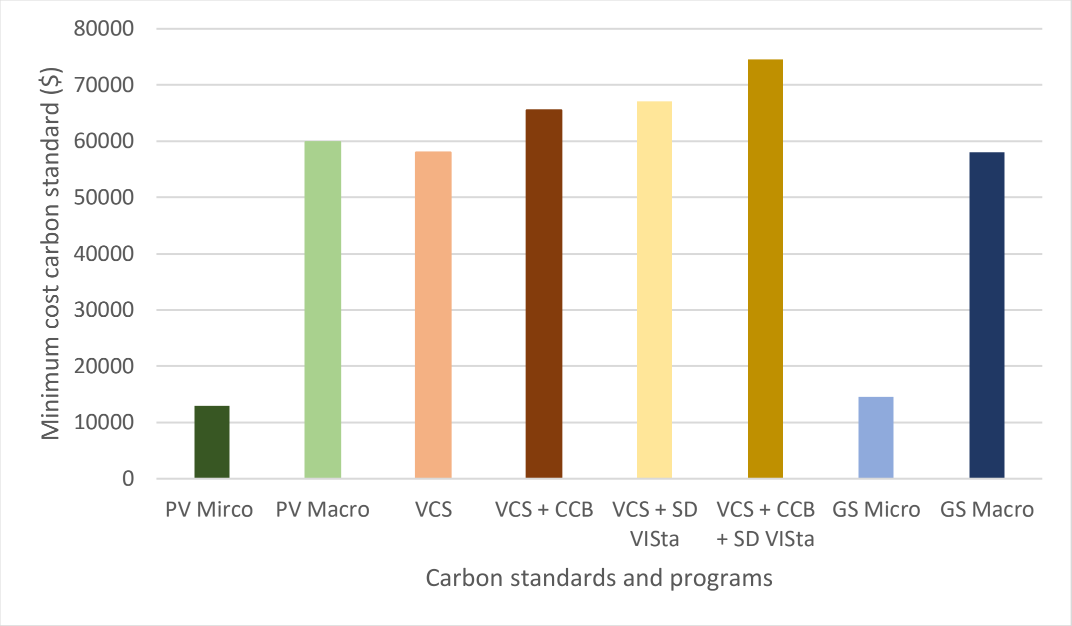

Figure 12: Minimum transaction costs of using a carbon certification standard and the different programs.

The higher production of carbon credits for a project furthermore corresponds with increasing CS prices, as the encounter fees per credit. Consequently, this necessitates considering not just the minimum prices associated with the CS, but also the amplified costs of project development and the augmented price of carbon credits due to increased production. Therefore, for larger projects, the minimum transaction costs become increasingly higher. Consequently, a substantial amount of funds has to be allocated to the transaction costs of a project. Even though the feasibility frontier shows viable break-even prices with current carbon prices, the transaction costs remain a significant hurdle for the development of projects.

4.4.4 Sensitivity analysis

The 5-year and 25-year feasibility frontier sensitivity will be discussed in comparison to each other. Per variable the 5-year feasibility sensitivity is shown above, and the 25-year feasibility sensitivity below. Additionally, the graphs on the left represent the Verra VCS CS, the middle depicts the micro GS program, and the graphs on the right represent the GS macro program. The SeA provides valuable insights into the effects of the underlying assumptions made for these variables.

In Figure 13 the sensitivity of the development cost is depicted. The figure shows a relatively large positive influence of the development costs, as larger project sizes significantly increase the total costs compared to the normal scenario. Therefore development costs are an important factor to consider for the total feasibility to finance a project through the carbon market. All CSs demonstrate similair trends. Additionally as depicted in Figure 13, it is evident that the development costs exert a greater influence during the 5-year period. Moreover, the size of the project correlates positively with the impact of the development costs; larger projects are influenced more by the development cost.

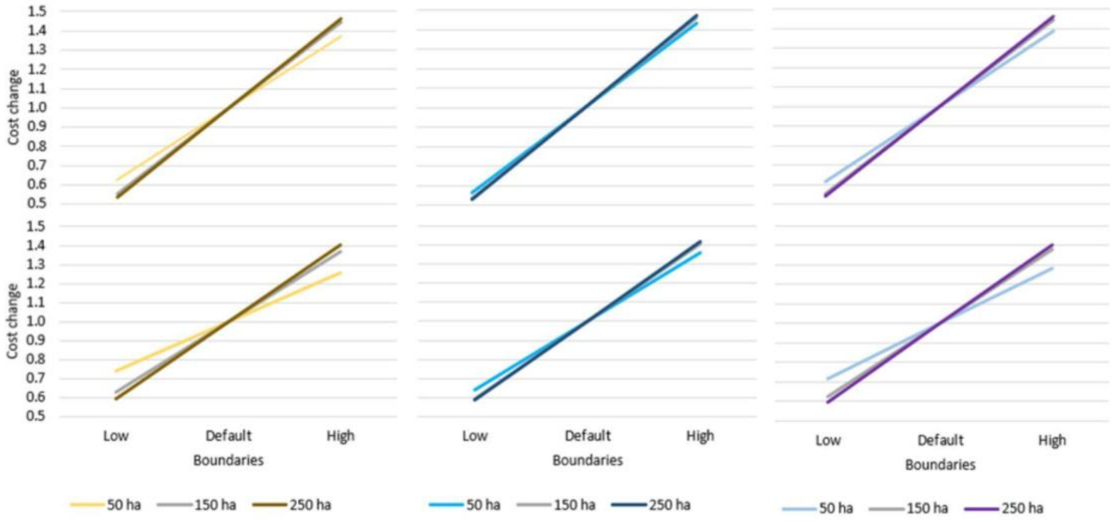

Figure 13: Sensitivity analysis development costs 5-year feasibility frontier sensitivity above and 25-year feasibility frontier sensitivity below. Left graphs: VCS, middle graphs: GS micro, right graphs: GS macro.

The influence of the validation costs is relatively low when compared to other variables. For the 5-year period, the sensitivity analysis reveals that the larger-sized 250-hectares scenario demonstrates a slightly less steep trend than the smaller-sized 50-hectare scenario. Therefore, higher validation costs have a larger effect on smaller mangrove carbon offset projects. For the 25-year period, validation has a relatively small influence on the total costs.

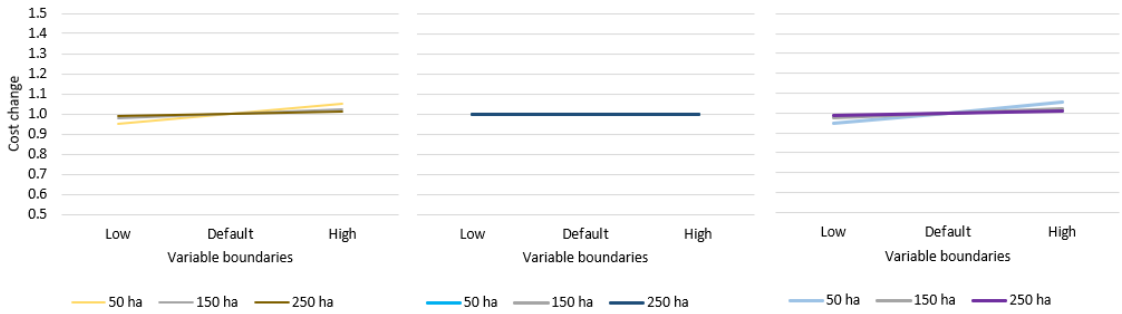

Figure 14: Sensitivity analysis validation costs 5-year feasibility frontier

The 5-year period verification costs have the same low positive sensitivity as the 5-year validation costs, as the costs are the same at the beginning of the project. For the 25-year period, changes in verification have a larger positive influence, and for smaller projects, the change in costs has a larger impact. Validation and verification costs are not included in the GS micro program and therefore do not have an effect.

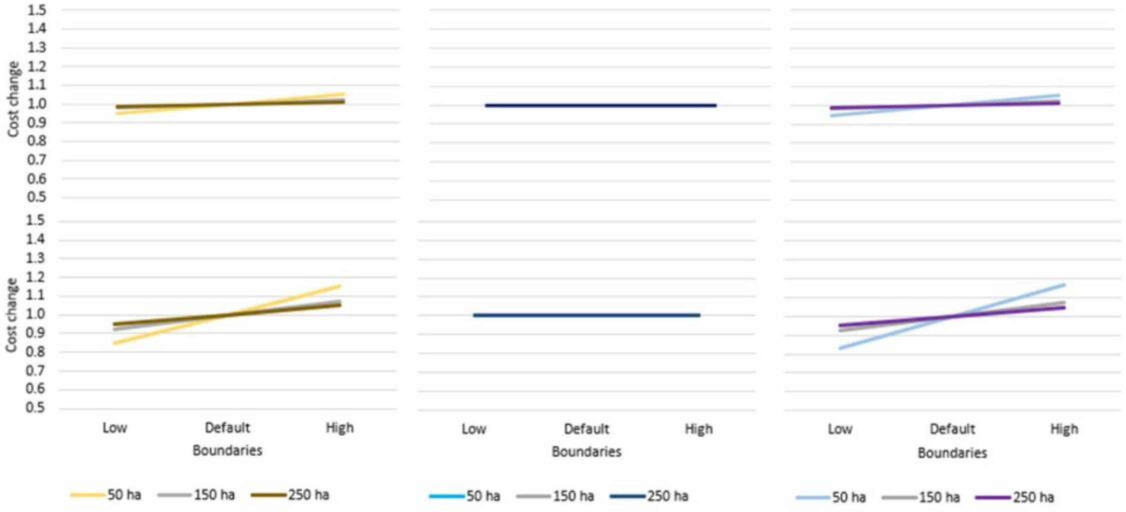

Figure 15: Sensitivity analysis verification costs 5-year feasibility frontier sensitivity above and 25-year feasibility frontier sensitivity below. Left graphs: VCS, middle graphs: GS micro, right graphs: GS macro.

The discount rate has a negligible effect on the 5-year period feasibility frontiers. The effect however changes for the 25-year period, as it has a slight negative influence. When the discount rate becomes higher, the costs decrease. Smaller project sizes are more affected by discount changes, with VCS having the largest sensitivity towards a change in discount rate, and GS macro having the lowest effect.

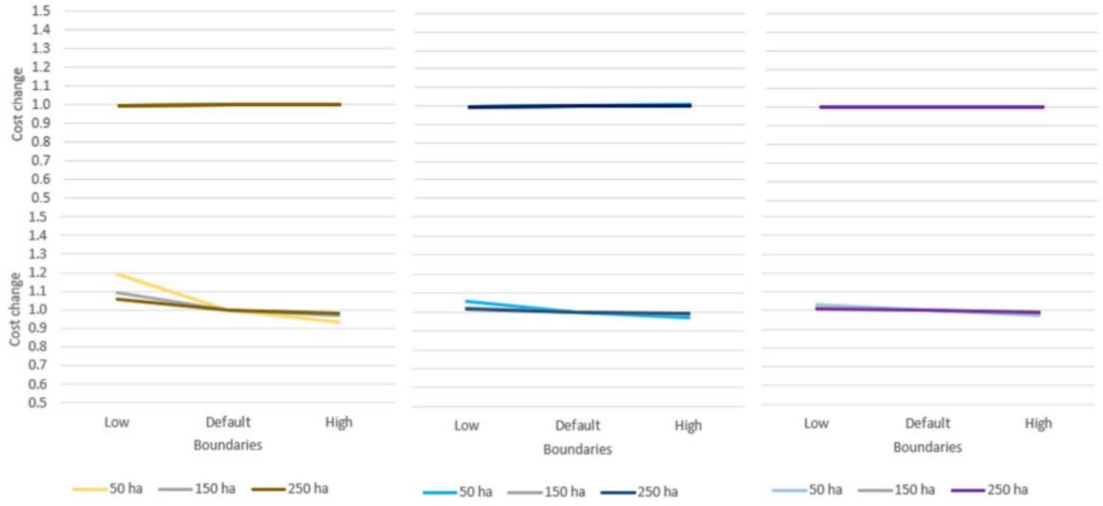

Figure 16: Sensitivity analysis discount rate 5-year feasibility frontier sensitivity above and 25-year feasibility frontier sensitivity below. Left graphs: VCS, middle graphs: GS micro, right graphs: GS macro.

The growth rate (for 5-year period) and total carbon storage (for 25-year period) show the largest sensitivity out of the discussed variables. A higher growth rate or carbon storage results in a lower overall cost. Another finding is that larger projects are more affected, regarding a change in total costs, by a change in growth rate than smaller project sizes. Additionally, the effect on the change of total costs of a change in growth rate for the 5-year period is larger than for the total carbon storage for the 25-year period.

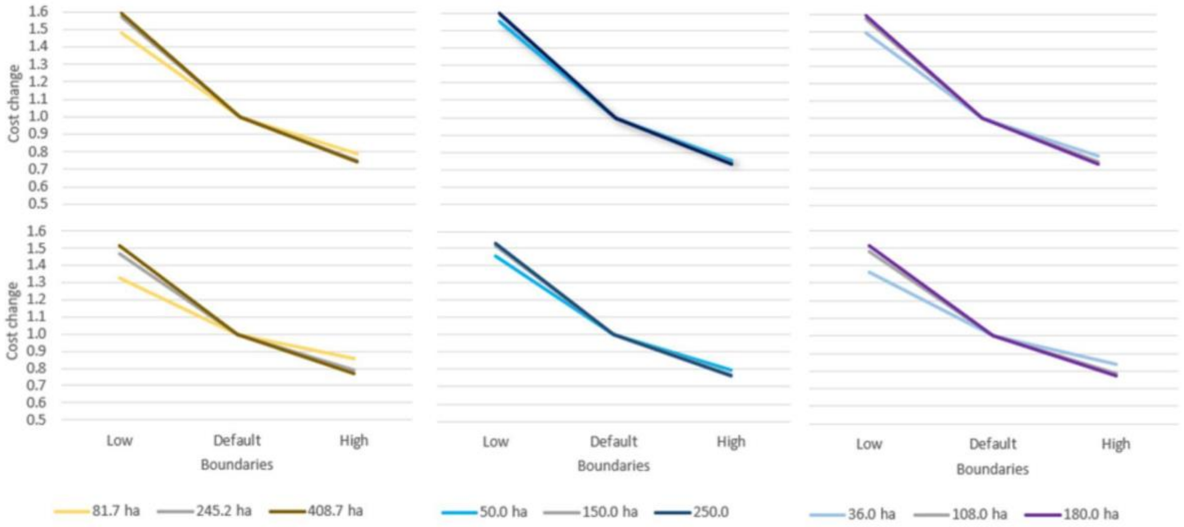

Figure 17: Sensitivity analysis growth rate for 5-year feasibility frontier and total carbon storage for 25-year feasibility frontier. sensitivity above and 25-year feasibility frontier sensitivity below. Sensitivity analysis discount rate 5-year feasibility frontier sensitivity above and 25-year feasibility frontier sensitivity below. Left graphs: VCS, middle graphs: GS micro, right graphs: GS macro. Left graphs: VCS, middle graphs: GS micro, right graphs: GS macro.

Table 18 shows an overview of the general sensitivity of the discussed CSs; VCS, GS micro and GS macro programs. The development costs and the growth rate have the largest influence on the outcome and show the highest sensitivities. Both the growth rate and development costs have the largest sensitivity for the 5-year period. In contrast, the sensitivity of verification is relatively low for the 5-year period, but more moderate for the 25-year period. Validation has a relatively low sensitivity and a change in the validation costs therefore has a fairly small impact on the total cost change. The validation sensitivity is higher for the 5-year period. The discount rate has a neglectable sensitivity for the 5-year period but has moderate sensitivity for the VCS and GS macro standards. In appendix C6, an overview of the other CSs and their sensitivities is shown, extrapolated for the standards or programs that have similar formulas.

Table 18: Relative sensitivity of the discussed variables. When the variable boundary is high and the cost change increases it is a positive impact (+) on the cost, when the variable boundary is high, and the cost change decreases then it is seen as a negative impact (-) on the cost. The larger the impact the higher the sensitivity of the variable. NP = not present.

Variable	5-year period			25-year period		
	VCS	GS micro	GS macro	VCS	GS micro	GS macro
Development costs	+++	+++	+++	+++	+++	+++
Validation	+	NP	+	+/-	NP	+/-
Verification	+	NP	+	++	NP	++
Discount rate	+/-	+/-	+/-	-	-	+/-
Growth rate	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -

4.4.5 Conclusions and considerations

Over a projects lifetime it can be concluded that using a CS for carbon financing is economically profitable. This however changes significantly when looking at the 5-year period with minimum prices of $20 per credit. These break-even carbon prices are just above the lowest mangrove restoration prices of $18 on the market. Hence, it is essential to take into account co-benefits and other factors that contribute to the increase of carbon credit prices in order to ensure feasibility of these projects. The challenge of transaction costs also found in chapter 4.1 however remain a challenge for the development of a project. The main conclusions can be summarized as:

- Prices for MRPs range between $18 and $40 per credit, and credit prices are expected to increase in the future
- The 25-year period feasibility frontier shows cost-effective credit prices for all CSs
- For the 5-year period feasibility frontier, all CSs are more expensive than average carbon prices within the VCM, with the prices of the standers being within the $18 to $40 average range
- PV micro and GS micro are the most feasible programs for smaller project sizes for both a time periods, as no VVB is required
- Transaction costs of the CSs are relatively high, especially for the programs where validation and verification are required
- From the SeA it can be concluded that the development costs and the growth rate have the largest impacts on the costs of a project

4.5 V – Case-study

4.5.1 Carbon storage case-study Timbulsloko

The planted trees, without SOC, have an average carbon storage of 21.9 MgC/ha, whilst the natural regrown mangrove show an average carbon storage of 29.8 MgC/ha in 2018. Therefore, naturally regrown mangrove trees store more carbon than planted mangrove trees. It was furthermore found that the average carbon storage per year for the case-study area, including SOC was 26.1 MgC/ha/year. This value is higher than the median growth of 16.3 MgC/ha/year in carbon storage used for the 5-year feasibility frontier, from a study by Alongi (2020). This growth is higher than the average mangrove growth, particularly when taking into account that the permeable structures and coastal protection measures were implemented over multiple years, instead of simultaneously. Therefore, the growth above describes the average growth between 2013 and 2018 and not the specific growth per hectare per year over 5 years. When considering the growth per hectare at the oldest coastal protection structures, the average carbon uptake of mangroves would likely be higher. A reason for this could be that little sediment is trapped without the dams, whilst this contains most of the carbon in mangrove ecosystems (Alongi, 2012). This is supported by the fact that 81% of the carbon stored in the case-study ecosystem originates from SOC.

It was furthermore found that the case-study represents a total regrown area of 80.7 hectares, based on data from Bijsterveldt et al. (2022). This area of regrown mangroves accounts for the replanting efforts, the impact of permeable dams, and other efforts. The total additional carbon storage after the construction of the first permeable dam from 2013 to 2018, is 13502.1 MgC, which is 49,507.7 tCO_{2e}. The total carbon storage per hectare in 2018 was 786.2 MgC/ha. After 25 years the total carbon storage per hectare is estimated to increase to 1021.0 MgC/ha. This translates to a total carbon storage increase of 111,211.6 tCO_2, thus the same amount of carbon credits.

4.5.2 Feasibility frontier and required carbon price

From the allometric equations it was found that the growth of carbon storage per year is 26.1 MgC/ha/year, significantly higher than the average 16.3 MgC/ha/year global growth from part IV. This is primarily due to SOC accumulation in the first 5 years of the case-study. One possible reason for this phenomenon is that the implementation of permeable dams can lead to sediment retention, resulting in a significant and rapid increase in soil organic carbon (SOC) levels when compared to a degraded situation.

Furthermore, because of the higher carbon growth per year, the micro programs of PV and the GS, with a threshold of 10,000 tCO_2/year are exceeded at a project size of 103.8 hectares. This is larger than the case-study area of 80.7 hectares, and therefore the micro program could be utilized for the case-study.

Figure 18 demonstrates the feasibility frontier for the case-study area for the first 5 years of the project until 2018. The red dotted line shows the minimum carbon prices required for the 80.7-hectare case-study. The significantly higher development prices of the case-study; 21483.8 $/hectare compared to 4368 $/hectare global median prices from Jakovac et al. (2020), cause the minimum carbon prices to be significantly higher than for the global 5-year feasibility frontier from chapter 4.4.3.

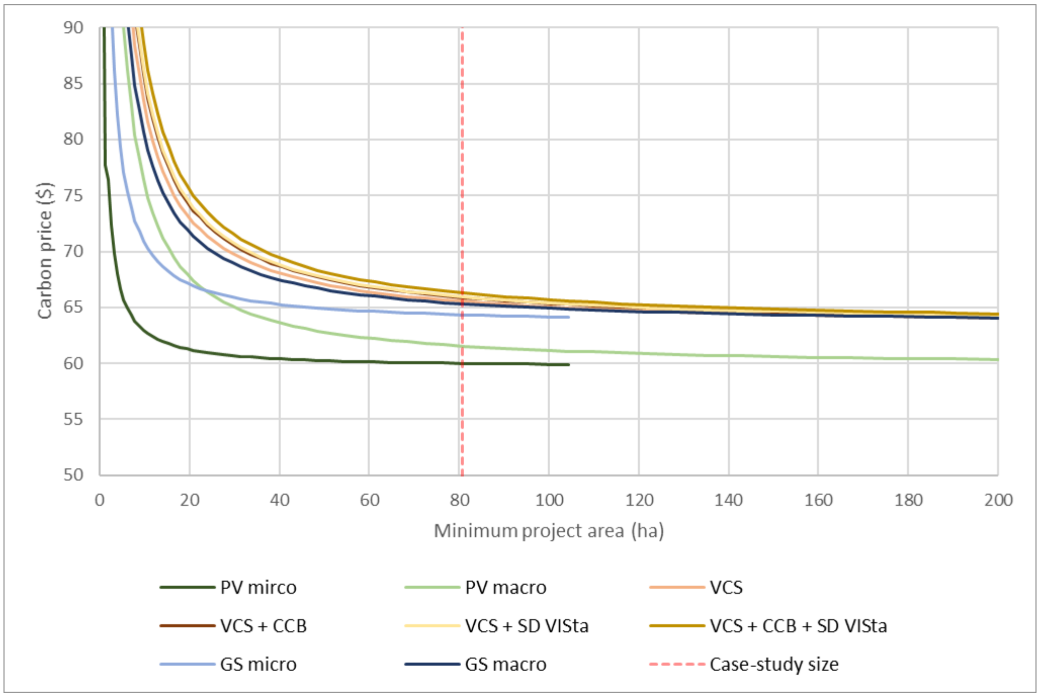

Figure 18: Case-study f*easibility frontier of developing a mangrove restoration project and certification through a certification standard, 5-year lifetime.*

Common carbon prices of MRPs were found in chapter 4.4.1, which put forward mangrove restoration carbon credits prices currently ranging between $18 and $40, depending on the quality thereof. The calculations of this study show minimum carbon prices from 60 $/credit for PV macro to 66 $/credit for VCS including CCB and SD VISta.

Figure 19 shows the feasibility frontier of the 25-year lifetime. When looking at this period, it is evident that the average growth of carbon per year is less than for the 5-year period. This effect is higher when compared to the lower development costs per year. Spreading the costs of the development of the project caused the break-even prices to be significantly lower than for the 5-year period. Minimum prices of 41 $/credit for PV micro and maximum break-even prices of 47 $/hectare for VCS with SD Vista and CCB added, are required to break-even.

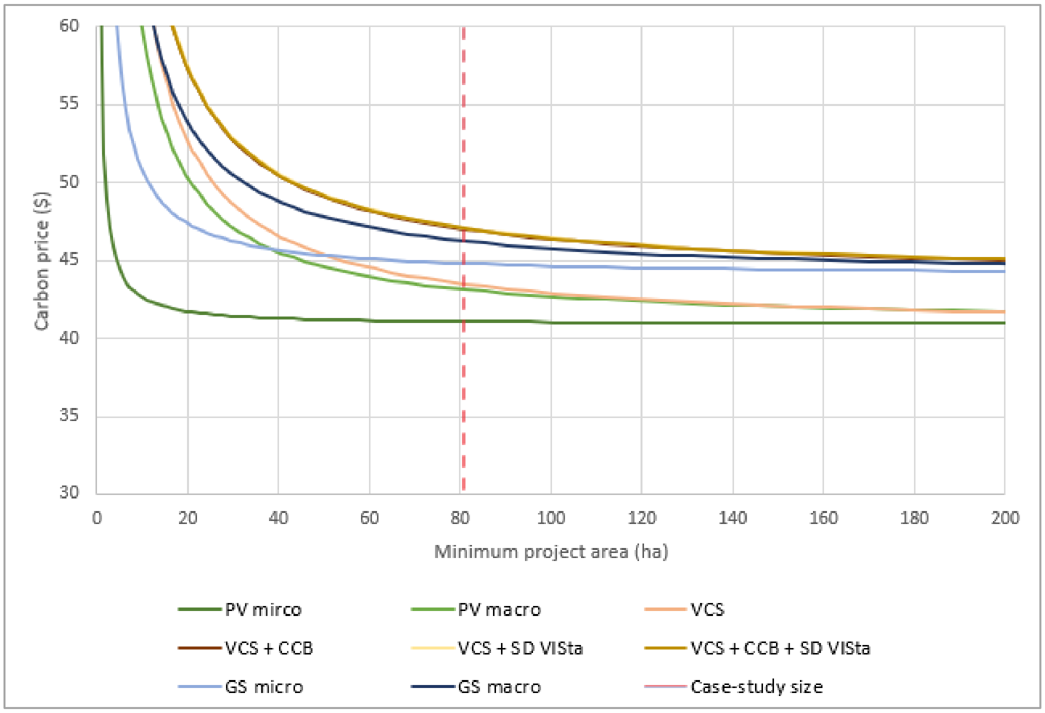

Figure 19: Case-study feasibility *frontier of developing a mangrove restoration project and certification through a certification standard, 25-year lifetime.*

In conclusion, the credit prices of the 5-year feasibility frontier and the 25-year frontier are relatively high when compared to average carbon prices, especially for the 5-year frontier. For Both time periods, it is not possible to finance the full project through the carbon market with current mangrove restoration carbon prices. With the total carbon storage of the case-study, it would be possible to apply for PV and GS micro scale projects. The high prices require the inclusion, creation and reporting of generated co-benefits. Furthermore, the substantial carbon growth observed within the initial 5-year period acts as a buffer for the comparatively higher development costs associated with the project.

4.5.3 Environmental integrity case-study

This chapter will examine if the case-study project could have passed the quality and environmental criteria of additionality, permanence and leakage. When examining the additionality requirements from the CSs discussed in part III, it is evident that the case-study project has the potential to prove additional with some minor adjustments and extra documentation. When, however, considering the broader concept of additionality, some uncertainties arise.

For the regulatory surplus additionality requirement, necessary for the PV standard and VCS standards, the project has to prove that the project is not developed because of any enforced legislation or official policies. For the case study, no information was found, that indicates that this issue poses a problem. Furthermore, the barriers that have to be overcome for the barrier analysis required for PV are generally met. Because the project actively collaborated with local communities, government agencies, and knowledge institutions to tackle the underlying factors contributing to coastal degradation and the approach furthermore aimed to provide holistic solutions that yield numerous advantages for the coastal communities involved (Tonneijck et al., 2022). Moreover, carbon financing could improve the already positive cost-benefit assessment, further increasing local cooperation and motivation for the project's development (Witteveen + Bos, 2022). A last type of additionality assessment is a positive list, required by the Verra and the GS. The case-study would pass these requirements, if certain achievable conditions would be met, such as the minimum planting of 5 different native tree species (Gold Standard, 2021). Therefore, when looking at the CS methodologies the case-study could pass the additionality criteria for a quality offset.

A problem, however, occurs when looking at the broader meaning of additionality. As described by Broekhoff et al. (2019) and Pan et al. (2021) a project is not additional if the GHG reductions would have occurred in the absence of the carbon offset market. They continue by saying that a project is not additional if the project would have happened anyway. A project is therefore additional when the project could not have happened without the earnings from the offset credits. This is the situation for the case-study, as the project happened without carbon financing. Therefore, the project itself cannot be additional. If the project were however to be developed with the assistance of carbon financing, it could potentially qualify for additionality. However, this situation brings attention to a challenge associated with additionality. A project that could have proceeded without relying on carbon financing could potentially modify its financial approach and suddenly meet the criteria for being considered additional. Regarding this Antes et al. (2011, p. 237) state that a 'projects compliance with additionality criteria has more to do with the documents' wording than with the project itself.'

The permanence of the case-study project is another challenge, as is questionable if the permanence of the case-study can be guaranteed. Firstly, a challenge exists for the permanence of the restored mangrove in the danger of illegal logging, as this has been an important reason for the removal of the mangroves in the past (Damastuti et al., 2023). The carbon financing could however provide an incentive for local inhabitants to protect the restored mangroves, as it would generate a steady income and other co-benefits. The largest challenge to ensure the project's permanence is the increasing erosion. This is because the project area experiences an annual sea level rise of 5.5 mm, along with land subsidence occurring at a rate of 2-3 cm per year. (Damastuti et al., 2023). Where, certain local universities have reported even higher rates of subsidence (Tonneijck et al., 2022). Excessive groundwater extraction by the city of Semarang is responsible for the land subsidence issue. While a roadmap was developed to tackle the problem, it was beyond the scope of the BwN project to effectively address the issue (Tonneijck et al., 2022). Without effective land subsidence management, the case-study cannot guarantee the mangroves' permanence. Therefore, the current risk seems too high to generate trusted permanent carbon offsets.

There is no specific mentioning of leakage from the BwN articles (Tonneijck et al., 2022; Witteveen + Bos, 2020). Leakage can however be reduced by the implementation of activities that increase productivity or provide alternative resources. Therefore, for the project it would have been important for the new land use to be more profitable for local inhabitants than the alternative land use. The already positive cost-benefit analysis with additional carbon financing could potentially result in little leakage, assessing this however is difficult with the available information (Witteveen + Bos, 2020).

4.5.4 New regulations Indonesian carbon market

In order for Indonesia to achieve their Nationally Determined Contributions (NDC) set to achieve the Paris Agreement (2015), the country has proposed two new framework regulations, called PR 98/2021 and MOEF 21/2022. The new regulations propose new rules for the carbon offset market. One requirement from the Indonesian government is that emission trading is only allowed for certified carbon offsets and offset projects are obligated to apply carbon buffers pools (Oentang Suria & Partners, 2022).

Firstly, as described by Oentang Suria & Partners (2022) trading can only be carried out when the countries' ministries have constructed a strategy or plan for achieving the NDC target. Furthermore, all carbon trading must be registered and authorized by the Indonesian government, and international trading is permitted exclusively upon the country's attainment of its NDC (Oentang Suria & Partners, 2022). Especially the last regulation generates complications for carbon offset projects in Indonesia, such as the case-study. It is, therefore, more difficult to internationally trade Indonesian-generated carbon credits, and furthermore, the credits traded on the Indonesian market are expected to sell for significantly lower prices domestically in Indonesia (Bahar et al., 2023). Because of this, carbon offset projects can count on lower returns (Bahar et al., 2023). Developing a carbon offset project, furthermore, requires additional effort, further expanding the already problematic time consumption and associated costs to develop a project, discussed in chapter 4.1 (Oentang Suria & Partners, 2022).

Because of this, the Indonesian carbon market has seen decreased activity and investors are hesitating to invest in new projects (Mulder, 2022). Currently, it is uncertain how these new regulations will influence the development of the Indonesian carbon market (Mulder, 2022). As stated by Oentang Suria & Partners (2022), the success of current nascent schemes will rely significantly on the regulatory and supervisory capabilities of the Government, particularly the MOEF and other relevant ministries. More clarification is however required, as details of the implementation of the regulations are missing (Sulistiawati & Buana, 2023).

In conclusion, because of these new regulations, it is waiting for further clarification until new projects can be developed under CS in Indonesia. It is however clear that additional work is required, and projects have mandatory certification requirements. Recent announcements from the Indonesian government, however, send a positive signal that they have the intention to open up to the international carbon market, but multiple details remain unaddressed (Christi & Mecca, 2023). Therefore, it is currently unadvisable to start developing a carbon offset project like the case-study in Indonesia.

4.5.5 Conclusions

This chapter found the carbon storage in 2018 in the case-study area and estimated total carbon storage for a similar project after 25 years. Furthermore, it can be concluded that a similar project like the case-study cannot break-even through carbon financing with current carbon prices. Furthermore, the case-study does not pass permanence requirements and its additionality is questionable. Moreover, the impact of recent regulatory changes in Indonesia remains unclear, making the country presently unappealing for project development. Encouragingly, Chapter 4.4.1 reveals that carbon prices are projected to rise, enhancing the viability of comparable projects in the future. The main findings of this chapter can be summarized as:

- The average carbon storage increased by 26.1 MgC/ha/year between 2013 and 2018 , higher than global averages
- The total regrown area is 80.7 hectares, which has removed 38647.7 tCO_{2e} and is small enough to apply for micro scale project certification
- The case-study project has the potential to meet the additionality criteria for a quality offset; however, a future similar project has to rely on carbon financing to prove additional
- The case-study cannot guarantee permanence, and is therefore not suited for carbon financing
- High uncertainties, caused by new regulations, make the Indonesian carbon market unattractive for project development

5 Discussion

This chapter will further reflect on the results from chapter 0 in order to be able to answer the sub-research questions and the main research question. Next, the limitations of this research will be discussed, along with recommendations for future research.

5.1 Interpretation of results

5.1.1 I - Key challenges associated with the development of reforestation carbon offset projects and their relation to smaller (MRP) projects

To begin with, this research has shown that multiple challenges exist when considering the development of a reforestation carbon offset project. The chapter underscored the controversial history of the VCM and its susceptibility to criticism from both the media and the scientific community (Calel, 2013; Valiergue & Ehrenstein, 2022). Firstly, from the methodological challenges it was found that carbon storage calculations tend to be overestimated because of the difficulties with accurately assessing additionality, permanence and leakage. These challenges show the inherent issues related to carbon offsetting. The estimation of carbon stocks is however likely to improve over time as inventories, allometric equations, measurement technologies and root: shoot ratios will improve (Haya et al., 2023).

Besides methodological challenges, there are multiple implementational challenges that exist for the development of AR projects. Challenges arise from high transaction costs, particularly the initial expenses, volatile carbon prices, and the time-lag between investments and carbon earnings. Projects are compelled to factor in these implementational complications and risks, resulting in the need for higher anticipated earnings and therefore higher prices. Furthermore, the issue of costs is the primary challenge for smaller-scale projects. Smaller projects can however use adjusted CSs and furthermore apply for project aggregation. Advancements in efficiency and emerging technologies further hold the potential to mitigate associated costs. The social and stakeholder part furthermore highlighted the challenge of adequately or sufficiently involving stakeholders and therefore the importance of effective stakeholder inclusion.

Chapter 4.1, showed that many market-related challenges preexist. This is in line with the market-related challenges that hinder the development of blue carbon projects. Therefore, it is likely that many of the challenges found are too significant of a hurdle for projects to develop. While the methodologies of the CSs have improved over time, regarding addressing the aforementioned challenges, it is crucial to maintain a critical perspective on the VCM for its continued positive development. The interviewees unanimously emphasized the inherent distinction between AR credits and avoided deforestation credits, as the former extract CO_2 from the atmosphere and the latter conserves existing carbon stocks. Their collective viewpoint highlights the potential benefits and importance of upscaling AR initiatives and furthermore the downsides of both types of credits existing in the same market.

5.1.2 II - Relevant stakeholders for carbon offsetting through mangrove restoration projects

The results of this chapter show the complex system of carbon offsetting for MRPs. From the chapter it can be highlighted that local stakeholder inclusion is crucial for effective project development. As they possess knowledge of the area, own land rights, and have to rely on alternative income generated from carbon credits. Hence, when undertaking the development of an MRP, it is crucial to allocate significant attention and consideration to stakeholder management and quality stakeholder inclusion, as discussed in 4.1.3.

Chapter 4.2, further showed the different stakeholders producing certified carbon credits, namely CSs, VVBs, and ICROA. It is however also possible to generate, purchase, and trade carbon credits that have not undergone certification by the three discussed CSs. The advantage of this is that bypassing certification, and thus validation and verification, reduces the costs significantly. These credits can come from standards not approved by ICROA, or from projects that do not acquire certification. An example of this is compensating emissions from office buildings from involved stakeholders, like Witteveen + Bos Singapore (Witteveen + Bos, 2021). Daan van de Kamp (personal communication, 2023) furthermore describes another option, as some companies seek a ‘cuddle project’ to achieve their corporate social responsibility. These projects generate emission reductions for the company but primarily focus on the co-benefits that such a project generates. Additionally, in the future, there could be a niche market that generates credits to achieve a host country’s NDC (Kreibich & Hermwille, 2021). Buyers aiming to produce carbon neutral products would however be more reluctant to this approach (Kreibich & Hermwille, 2021).

The interviewees however all disapprove of uncertified credits and Daan van de Kamp (personal communication, 2023), argues that refraining from certifying a project poses significant risks to the integrity of the VCM and also exposes credit buyers to potential liabilities if any issues arise. These credits could be of lower quality, as for example non-additional credits, can potentially harm the environment and furthermore damage the offset buyers' reputation (Chen et al., 2022). Furthermore, Daniel Balutowski (personal communication, 2023) states that carbon offsets should be as unbiased as possible, which is difficult to achieve for uncertified credits, whereas

Gregory Williams (personal communication, 2023) states that certification de-risks a project and that certifying is in everyone's best interest.

5.1.3 III - Comparison certification standards for mangrove restoration projects

Chapter 4.3 aimed to further analyse the insufficiently researched mangrove CS methodologies. Regarding this, the three different CSs suited for MRPs were examined. The analysis reveals that the variations among these standards primarily lie in their objectives rather than the quality they represent. The core principles of the CSs differ, leading to distinct objectives and aims for each standard. Therefore, when a project seeks certification, it should consider the different goals, services provided and approaches of the CSs.

Regarding mangrove-specific details of the CSs, both PV and Verra have implemented multiple projects. Furthermore, projects tend to exclude harvested wood, non-tree biomass, and dying dead wood from their calculations. Verra, in contrast, incorporates all of these biomass types, highlighting the divergent objectives between the standards. This suggests that Verra places greater emphasis on carbon benefits and larger-scale projects that possess the necessary resources and manpower to accurately quantify these biomass types, distinguishing the CS from other standards.

5.1.4 IV - Cost-effectiveness of certification standards for mangrove restoration projects

First of all, the feasibility frontiers reveal that Verra exhibits higher costs compared to GS and PV, both of which exhibit similar pricing patterns. Furthermore, the feasibility frontier of the 25-year scenario found relatively low break-even prices when compared to the above-mentioned carbon prices, indicating that with average values most MRP are cost-effective. The discrepancy between interest and development is therefore not caused by the profitability of such projects over 25 years. Other issues exist, such as higher carbon prices that are required for the 5-year period frontier to break-even. The required prices are above the minimum MRP carbon price in the carbon market. Therefore, the inclusion of co-benefits is required to increase carbon prices for global average projects to break-even in a 5-year period. Additionally, the high transaction costs associated with initial development, CSs, validation, and verification processes present significant challenges for projects.

It should be noted that not all the costs of the development of MRP could be included. For example, the implementation challenge of a 3-5 years' time delay is not included in the development costs from Jakovac et al. (2020) and in the feasibility frontier in general. Therefore, it should be considered that the break-even price should be higher than calculated in this study. Furthermore, it is important to note that unforeseen costs are not accounted for in the break-even prices. Therefore, the feasibility frontier represents the point at which a project breaks-even, but not necessarily when it becomes profitable for a company or organizations to use a standard for certification.

Therefore, this chapter aimed to further close the knowledge gap of the financial barriers hindering mangrove projects to develop. This chapter is in line with the market-related challenges and found that financial barriers are a major barrier to project development. Carbon prices are however likely to increase in the near future, possibly increasing the feasibility of projects to use a CS.

5.1.5 V - Case-study

The case-study or a similar project, cannot be fully financed through the carbon market, because of the cost-ineffectiveness found in the feasibility frontier. This has two reasons. Firstly, the returns from carbon financing are not high enough to compensate for the high development costs of the case-study. These high costs are primarily driven by large associated costs for staff and socio-economic measures. Many costs can be associated with the explorative nature of the BwN project and could potentially be lowered for future projects. Secondly, the permeable dams were constructed over multiple years, instead of being constructed simultaneously. Therefore, the carbon earnings could be increased significantly if the biomass and SOC had a longer time to accumulate. Therefore, an improvement of the project could have been to build all the dams at the same time, and therefore increase the carbon benefits after the initial 5 years. The two reasons for the aforementioned cost-ineffectiveness are closely linked to the most sensitive variables identified in the SeA from chapter 4.4.4, which further underscores the significance of these variables. Carbon financing could however pay a part of the financing such as projects analyzed by Friess et al. (2022).

Besides insufficient cost-effectiveness, the case-study does not pass permanence requirements and its additionality is questionable. The permanence of the project is uncertain, due to severe land subsidence. Additionally, the ability of the BwN project to address groundwater extraction from Semarang city is unlikely (Tonneijck et al., 2022). Furthermore, in order to be additional, a project should have to rely on carbon financing, which is not the case in the BwN project. Besides, new Indonesian regulations make the country currently unattractive for project development. This could however change in the near future, as there is the intention from the Indonesian government the open up for foreign carbon investments (Christi & Mecca, 2023).

5.2 Main limitations and future research

Due to the inherent complexity of carbon offsetting and the intricate nature of carbon sequestration in mangrove ecosystems, it is important to acknowledge the presence of limitations. Therefore, this paragraph will further discuss the limitations of this study, whilst also providing recommendations for future research.

Firstly, this study primarily concentrates on assessing the carbon benefits associated with MRPs. It is important to note that other benefits are addressed to a lesser extent in this study. The valuation of these co-benefits is less advanced than those of carbon benefits but should not be neglected when developing an MRP (Jakovac et al., 2020). In addition, as identified in chapter 4.2, effective management of local stakeholders and their meaningful inclusion were recognized as crucial for enhancing the value of an MRP through carbon credits. This study, however, did not examine the specific strategies for achieving effective stakeholder management. Consequently, future research could focus on exploring these strategies and investigating the associated complexities involved in stakeholder engagement for an MRP using carbon financing.

Furthermore, as aforementioned a limitation exists in that not all costs from an MRP could be included, because of the lack of information thereof. In addition, for the feasibility frontier average development costs from Jakovac et al. (2020) and the validation and verification costs were chosen to stay constant per hectare, regardless of the project size. The development, verification, and validation costs per hectare are likely more expensive for smaller projects. Although the VVB, Mutu International (personal communication, 2023), set a single price regardless of project size. Moreover, a review of mangrove restoration costs by Bayraktarov et al. (2015) found no relationship between development cost and project size. Further research could clarify the relationship between cost per hectare and project size.

Another limitation exists in the fact that no field data has been retrieved for the case-study. Therefore, the study's from Bijsterveldt et al. (2022) and Ardhani et al. (2020) had to be combined, leading to increased uncertainties in the calculations. Furthermore, for the estimation of carbon storage within 25 years, the average SOC carbon storage of Indonesia had to be utilized, as no nearby case-study data exists on corresponding 2-meter depth SOC measurements from Ardhani et al. (2020). As, most nearby studies have examined SOC for 1-meter depth and could therefore not be compared to measurements from Ardhani et al. (2020) of SOC stocks (Jakovac et al., 2020). This is especially important as it is clear that carbon-rich soils exist to a depth of 3 meters and SOC is the largest carbon stock (Murdiyarso et al., 2015). Thus, constraining estimates to a 1-meter depth underestimate the carbon storage of mangrove ecosystems (Atwood et al., 2017). It is furthermore unclear to which depths SOC is measured from the VCS (2021) methodology, whilst the often-used methodology from Kauffman & Donato (2012) by PV projects, advice measuring until a depth of 3 meters. Therefore, there is a need to gain a clearer understanding of the influence of SOC on total carbon storage, and how this is incorporated within CSs methodologies.

5.3 Recommendations

To address the issue of overestimating carbon storage in carbon offset projects, which arises from challenges in accurately accounting for additionality, permanence, and leakage, a potential solution would be for project developers and CSs to integrate the risks more comprehensively into the buffer pool calculations (Haya et al., 2023). Furthermore, accounting for leakage, especially indirect leakage could be countered with more conservative baselines and further research on the required leakage rates (Haya et al., 2023). Efficiently addressing these challenges has the potential to deliver higher-quality offsets and restore confidence in the market, which has been considerably damaged due to recent criticism surrounding REDD+ credits. These solutions would however lower the total carbon storage for projects, and therefore lower cost-effectivity. Furthermore, the standards must be cautious of the trade-off between quality and escalating costs and time, as found in chapter 4.1.4.

This research has shown that, in the case of an average 5-year period project, the break-even carbon prices exceed the lowest mangrove restoration credits prices in the market, indicating the need for co-benefit inclusion. For the case-study higher prices are required, because of high development costs. In addition to these costs, the challenges from chapter 4.1 bring additional risks and complications, such as the time-delay between investment and returns. Therefore, such a project cannot be fully financed through the carbon market. This is an issue, as it can be argued that MRPs like the case-study have an overall positive cost-benefit assessment when also considering other benefits, such as coastal protection benefits and social benefits (Hakim, 2018; Witteveen + Bos, 2022). Therefore, other solutions for financing should be sought to enable the development of similar projects.

Generating carbon credits without certification would cut costs, but with the available knowledge from chapter 5.1.2, this would be inadvisable. Valuing the other benefits could however be a solution, but valuing these benefits is less advanced than carbon benefits (Jakovac et al., 2020). Yet, there is an expanding body of literature describing the benefits of nature, referred to as ‘ecosystem services’ (Lester, 2023). Payments for ecosystem services (PES) could therefore provide additional capital to the case-study or a similar project. Regarding this, mangroves are strong candidates for PES projects, because of their wide range of ecosystem services beyond carbon storage (Locatelli et al., 2014). Project contexts in which carbon benefits are not enough to compensate for investment costs, such as the case-study, could therefore utilize additional funding from other mechanisms, such as PES (Jakovac et al., 2020).

Through this study, the three most crucial factors to consider for the development of a carbon offset MRP can be identified. Firstly, the StA analysis found that ensuring effective stakeholder management is of high importance for achieving successful project development. This finding is reinforced by a study conducted by Triyanti et al. (2017) within the case-study area. The study argues that the success of the BwN project relies on inclusive civil society participation. Furthermore, project development costs and carbon storage capacity are crucial factors for the development of a carbon offset MRP, as the SeA found that these variables exert the most significant impacts.

6 Conclusion

This research has investigated how carbon credits can add monetary value to mangrove restoration projects. The study aimed to address the existing knowledge gaps in the field of carbon offsetting for mangrove restoration, by researching the not yet extensively researched CSs regarding mangrove ecosystems. Additionally, it aims to identify and analyse the market-related challenges that hinder the development of MRPs, with a particular focus on the less understood financial barriers.

The results of this thesis can act as a guide on how an MRP could add monetary value to a project through carbon offsetting. As, foremost, the challenges for the development of carbon offset MRPs were examined. Methodological challenges exist in the overestimation of carbon storage in projects, as it is difficult to accurately account for additionality, permanence, and leakage. Furthermore, implementation challenges are primarily focused on the issue of costs, especially the high initial costs. In addition, the presence of low carbon prices in the highly volatile market poses challenges to project development. In addition, challenges exist in the social and stakeholder field, as stakeholders, especially local stakeholders, are sometimes inadequately or insufficiently involved.

The latter challenges were also compared to, the often smaller-scaled, mangrove restoration projects, such as the case-study. Major challenges exist in the costs, especially the high transaction costs for smaller projects. A further bottleneck was found to be the time delay between returns and investment, supplemented by the high minimum transaction costs found for the different CSs. Possible solutions were also identified, such as project accreditation and the use of adjusted CSs programs.

The different CSs were furthermore examined and how they differ in their goals and approaches. It was found that Verra is aimed at larger scale projects with environmental criteria insight, for which CCB and SD VISta may be added with a higher focus on co-benefits and the SDG's respectively. PV is aimed at local communities and alleviating poverty, accordingly, the standard enables projects reducing less than 10,000 tCO_2 per year, to use the adjusted standard without the expensive verification and validation requirements. GS also allows micro projects, and is a standard aimed at delivering the highest level of environmental integrity. All standards furthermore have different approaches for assessing additionality, permanence and leakage. Notably, Verra methodologies encompass all forms of biomass to calculate carbon storage for mangroves, while a significant number of projects from both Verra and PV often exclude various biomass forms, primarily to add to the conservativeness of the calculations.

In addition, the stakeholder ecosystem map underscores which stakeholders are relevant. The chapter particularly highlights the importance of effective local stakeholder inclusion for successful mangrove restoration implementation. Furthermore, a feasibility frontier was developed, which shows that with current mangrove carbon prices, average MRPs are cost-effective over a 25-year lifetime. Over a 25-year period, carbon prices of around $5 per credit are required to break-even. When considering a 5-year lifetime higher prices above $20 per credit are required to break-even, indicating the need for co-benefit inclusions to increase carbon prices.

The gained knowledge was then applied to a case-study in Indonesia, which found a total carbon storage potential of 111,211.6 tCO_{2e} and a carbon accumulation of 26.1 Mg/ha/year between 2013 and 2018. The feasibility frontier showed that this project cannot be fully financed through carbon credits, as the development costs are too high. Mangrove restoration is however desirable for the co-benefits it generates. Therefore, to fully finance a similar future project, other financing mechanisms like PES, could bridge this financing gap. It is important to note that the case-study cannot guarantee permanence, and its additionality is questionable. Furthermore, the current state of the Indonesian carbon market is unattractive for carbon investments.

Generating carbon offset credits through mangrove restoration holds significant potential in contributing to negative emissions required to achieve net-zero emission goals. However, major challenges need to be addressed in order to harness this potential. Moreover, generating finance through the VCM may not be suitable for every MRP.

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8 Appendices

Appendix A - semi-structured interview

Introduction

-Thank you for his/her time
-Permission to record conversation
-Explanation research
-Objective: Using carbon credits to add value to mangrove restoration projects

Part 1

1. What is your view on the voluntary carbon market?

   Are you aware of the latest developments at the VCM and what do you think of this?
   What do you see as challenges for the VCM?
2. Are there carbon certification standards suitable for smaller carbon offset projects?
   Do you know what the costs are of certification, verification & verification and how much time does it take?
   Do you know the price of carbon credits for mangrove restoration projects?

3. Do you think that is it possible to trade carbon offsets without a Carbon Certification Standard or a third party verifier?

   If yes: What alternatives are there for carbon offset projects to trade carbon?

Part 2

1. What is your role and what is the role of your company within the VCM?
   Do you have your own projects? If so, how far are you with them?

2. Which stakeholders are you involved with within the VCM? What are their interests and what is their influence?

3. Are you aware of using carbon credits for mangrove restoration projects?
4. Which other stakeholders are involved in mangrove restoration projects?

Final questions
Where do you see the voluntary carbon market in the future?
Do you have any further questions or comments?

Appendix B – Example of consent form

INFORMED CONSENT FORM (INTERVIEW)

In this study I want to learn about using carbon credits to add value to mangrove restoration projects. Participation in this interview is voluntary and you can quit the interview at any time without giving a reason and without penalty. Your answers to the questions will be shared with the research team. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Please respond to the questions honestly and feel free to say or write anything you like.

I confirm that:
- I am satisfied with the received information about the research;
- I have no further questions about the research at this moment;
- I had the opportunity to think carefully about participating in the study;
- I will give an honest answer to the questions asked.

I agree that:
- the data to be collected will be obtained and stored for scientific purposes;
- the collected, completely anonymous, research data can be shared and re-used by scientists to answer other research questions;

I understand that:
- I have the right to see the research report afterwards.

Do you agree to participate? ○ Yes ○ No

INFORMATION SHEET **(INTERVIEW)**

INTRODUCTION

You are invited to take part in this study with the purpose of learning about the voluntary carbon market with a focus on using carbon credits for mangrove restoration projects. The study is conducted by Mats Houben who is a student in the Msc program Sustainable Development at the Department of Sustainable Development, Utrecht University. The study is supervised by Anna Duden.

PARTICIPATION

Your participation in this interview is completely voluntary. You can quit at any time without providing any reason and without any penalty. Your contribution to the study is very valuable to us and we greatly appreciate your time taken to complete this interview. We estimate that it will take approximately 45 minutes to complete the interview. The questions will be read out to you by the interviewer. Some of the questions require little time to complete, while other questions might need more careful consideration. Please feel free to skip questions you do not feel comfortable answering. You can also ask the interviewer to clarify or explain questions you find unclear before providing an answer. Your answers will be noted by the interviewer in an answer template. The data you provide will be used for writing a Master thesis report and may be used for other scientific purposes such as a publication in a scientific journal or presentation at academic conferences. Only patterns in the data will be reported through these outlets. Your individual responses will not be presented or published.

DATA PROTECTION

The interview is also audio taped for transcription purposes. The audio recordings will be available to the Master student and academic supervisors. We will process your data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act).

Audio recordings will be deleted when data collection is finalized and all interviews have been transcribed

Name of participant : _________________________________ Signature:
___________________________________ Date, place: ___ / ___ / ____, ___________

Appendix C – Feasibility frontier

1. Fees carbon certification standards

- **Plan Vivo**

Table 19: Plan Vivo standard costs. Retreived from Plan Vivo (n.d)

Description costs	Micro	Macro	Type
	<10.000t/year	>10.000t/year	
Project Idea Note (PIN) review	1000	1000	/ project
Project Design Document review (including one Technical Specification)	3000	1500	/ project
Additional Tech Spec Review	500	500	/ project
PDD / Tech Spec Updates	6000	6000	/ project
Validation and Verification Coordination (desk research)	2000	1000	/ project
Issuance Fees	0.4	0.35	/ PVC
Conversion (of credits)	0.05	0.05	/ PVC
Methodology Concept Note Review	350	350	/ project
Methodology Assessment	Unknown	Unknown	

- **Verra**

- **VCS**

Table 20: VCS standard costs. Retreived from Verra (2023b).

	Description	VCS	Type
Fee	Opening account	500	Once
	1: Registration fee	0.1 per annual credit capped at 10,000	/ VCU
Issuance	Issuance Levy 1-10000	0.05	$/ VCU
	Issuance Levy 10001-1000000	0.14	$/ VCU
	Issuance Levy 1,000,001-2,000,000	0.12	$/ VCU
	Issuance Levy 2,000,001-4,000,000	0.105	$/ VCU
	Issuance Levy 4,000,001-6,000,000	0.085	$/ VCU
	Issuance Levy 6,000,001-8,000,000	0.06	$/ VCU
	Issuance Levy 8,000,001-10,000,000	0.04	$/ VCU
	Issuance Levy 10,000,001-60,000,000	0.025	$/ VCU
	Retroactive label fee	1500	/ Project
Methodology	Minor methodology, module or tool revisions	6000	Not relevant
Methodology review fees	1-1,000,000 VCU	0.02	/ VCU
	1,000,001-2,000,000VCU	0.018	/ VCU
	2,000,001-4,000,000 VCU	0.016	/ VCU
	4,000,001-6,000,000 VCU	0.012	/ VCU
	6,000,001-8,000,000 VCU	0.008	/ VCU
	8,000,001-10,000,000 VCU	0.004	/ VCU
	10,000,001-60,000,000 VCU	0.002	/ VCU
Validation/verification body annual fee		2500	/ Year
Gap analysis fee		Unknown	Unknown
Validation/verification		VVB	VVB

- **CCB**

Table 21: VCS CCB standard costs. Retreived from Verra (2023c).

Description	CCB	Type
CCB validation	2500	/ project
CCB verification	5000	/ project
1-1,000,000 VCU	0.05	/VCU
1,000,001-2,000,000VCU	0.045	/VCU

2,000,001-4,000,000 VCU	0.04	/VCU
4,000,001-6,000,000 VCU	0.03	/VCU
6,000,001-8,000,000 VCU	0.02	/VCU
8,000,001-10,000,000 VCU	0.01	/VCU

- **SD VISta**

Table 22: VCS SD VISta standard costs. Retreived from Verra (2023d).

Description	SD VISta	Type
Project listing fee	2500	/ project
Design evaluation fee	1500	/ project
Project ex-post assessment fee	5000	/ project
1-1,000,000 VCU	0.05	/VCU
1,000,001-2,000,000VCU	0.045	/VCU
2,000,001-4,000,000 VCU	0.04	/VCU
4,000,001-6,000,000 VCU	0.03	/VCU
6,000,001-8,000,000 VCU	0.02	/VCU
8,000,001-10,000,000 VCU	0.01	/VCU

- **Gold Standard**

Table 23: Gold Standard costs. Retreived from Gold Standard (n.d.).

Description	Micro	Macro	Type
Annual Registry account fee	1000	1000	/ year
Preliminary Review	500	3500	/ project
Project Design Review	0.15	0.15	/ VER
Project Design review	1500	1500	/ project
Performance Review	650	1500	/ project
Issuance fee	0.3	0.3	/ VER
Validation fee	5000		/ project
Annual verification fee	2500		/ year
Additional rounds of review	50	50	/ hour
Soil Review Fee	500	500	/ Project

2. Validation and verification mangrove

Table 24: Costs of validation and verification.

Description	Price	Source	Location and size
Validation and verification	$30K - $70K	SCS global services, third party validation and verification	Not defined
Validation and verification	€70K-€110K	Daan van de Kamp, Climate Neutral Group	Not defined
Verification	~$10K	Mutu International, GHG verification institute	Indonesia, regardless of size
Validation	~$10K		
Support validation and verification	€5K-€10K	IUCN (2021)	Europe
Support monitoring	€5-20K		
Verification	€10K-30K		
Total	€20K-50K		
Feasibility study	10s of thousands	Gregory Williams, vanOord	Not defined
Project design document	100s of thousands		Not defined
Monitoring	10s of thousands		Not defined

3. Variables

Table 25: Input variables used for the feasibility frontier and the sources used.

	Amount:	Unit:	Source or note:
Average restoration development cost mangroves	4368	$/ hectare	Jakovac et al. (2020)
Validation	30000	$	See Table 24
Verification	40000	$	See Table 24
Verification time per period	5	Years	Common for carbon offset projects
Discount rate (d)	10%	-	Advised by Witteveen + Bos
Average carbon storage mangrove	738.9	MgC/ha	Alongi (2020)
Growth rate mangroves median	37.78	MgC/ha/yr	Alongi (2020)
Conversion carbon to CO_2	3.66	-	General conversion factor

Verification period	5 or 25	Years	5 years for transaction costs before second verification. 25yr common lifetime and full growth mangroves (Kandasamy et al., 2021)

4. Assumptions

Table 26: Assumptions made for feasibility frontier.

	Topic	Description	Amount ($)
General assumptions	Costs CS	Simplest method of certification used. e.g. No project accreditation, no fines or conversion of carbon credit types	
	Verification	Assumed that costs stay the same in the next 25 years	
	Validation/verification micro scale	Assumed that micro projects do not use a VVB for validation or verification, but independent experts.	
Plan Vivo assumptions	PDD / Tech Spec Updates	Not specified for PVC issuing projects, therefore same used as for non-issuing project	6000
	Methodology assessment	Not specified	
	Independent expert	Independent expert required for microscale projects not known, therefore not included in price	
Verra assumptions	Registration fee	Assumed that number of credits are the same yearly and do not increase over time.	
	Gap analysis fee	Not specified	
Gold Standard assumptions	Cash fee or SOP	Cash fee used instead of carbon credit payment to GS	
	Additional rounds of review	Assumed that it would take 50 hours to conduct additional rounds of review	$50 / hour. 100 hours
	LUF carbon	Assumed that one soil review fee and new area certification is necessary	$500 and $1500 respectively
	Issuance fee	Set on 0.3 / credit	
	Standalone verification	Standalone verification used, instead of programme verification	

5. Formulas

Project lifetime 25 years scenario

Plan Vivo

Micro:

$$PV\ Costs = Development + 1000 + 3000 + 500 + 6000 + 2000 + 0{,}4X + 0.05X + 350 + 500$$

Macro:

$$PV\ Costs = \ Development + Validation - PV(d; years; verification; 0; 0) + 1000 + 1500 + 500 + 6000 + 2000 + 0{,}35X + 0.05X + 350 + 500$$

Verra

VCS:

$$PV\ Costs = \ Development + Validation - PV(d; years; verification; 0; 0) + 500 + (X/Lifetime) + MIN(10000; 0.1 * (X/Creditperiod) + X * IFS(X = 0; "n.a."; X < 10000;\ 0{,}05;\ X < 1000000;\ 0{,}14;\ X < 2000000;\ X;\ X < 4000000;\ 0{,}105;\ X < 6000000;\ 0{,}085;\ X < 8000000;\ 0{,}06;\ X < 10000000;\ 0{,}04;\ X > 10000000; 0{,}025) + X * IFS(C20 = 0; "n.a.";\ X < 1000000;\ 0{,}02;\ X < 2000000;\ 0{,}018;\ X < 4000000;\ 0{,}016;\ X < 6000000;\ 0{,}012;\ X < 8000000;\ 0{,}008;\ X < 10000000;\ 0{,}004;\ X > 10000000; 0{,}002) + 1500 + 6000 - PV(d; years; 2500; 0; 0)$$

VCS + CCB:

$$PV\ Costs = \ Development + Validation - PV(d; years; verification; 0; 0) + 500 + MIN(10000; 0.1 * (X/Creditperiod) + X * IFS(X = 0; \text{n.a.}; X < 10000;\ 0{,}05;\ X < 1000000;\ 0{,}14;\ X < 2000000;\ X;\ X < 4000000;\ 0{,}105;\ X < 6000000;\ 0{,}085;\ X < 8000000;\ 0{,}06;\ X < 10000000;\ 0{,}04;\ X > 10000000; 0{,}025) + X * IFS(C20 = 0; \text{n.a.};\ X < 1000000;\ 0{,}02;\ X < 2000000;\ 0{,}018;\ X < 4000000;\ 0{,}016;\ X < 6000000;\ 0{,}012;\ X < 8000000;\ 0{,}008;\ X < 10000000;\ 0{,}004;\ X > 10000000; 0{,}002) + 1500 + 6000 - PV(d; years; 2500; 0; 0) + 2500 + 5000 + X * IFS(X = 0; "n.a.";\ X < 1000000;\ 0{,}05;\ X < 2000000;\ 0{,}045;\ X < 4000000;\ 0{,}04;\ X < 6000000;\ 0{,}03;\ X < 8000000;\ 0{,}02;\ X < 10000000;\ 0{,}01;\ X > 10000000; 0{,}005)$$

VCS + SD VISta:

$$PV\ Costs = \ Development + Validation - PV(d; years; verification; 0; 0) + 500 + MIN(10000; 0.1 * \left(\frac{X}{Creditperiod}\right) + X * IFS(X = 0; "n.a."; X < 10000;\ 0{,}05;\ X < 1000000;\ 0{,}14;\ X < 2000000;\ X;\ X < 4000000;\ 0{,}105;\ X < 6000000;\ 0{,}085;\ X < 8000000;\ 0{,}06;\ X < 10000000;\ 0{,}04;\ X > 10000000; 0{,}025) + X * IFS(C20 = 0; "n.a.";\ X < 1000000;\ 0{,}02;\ X < 2000000;\ 0{,}018;\ X < 4000000;\ 0{,}016;\ X < 6000000;\ 0{,}012;\ X < 8000000;\ 0{,}008;\ X < 10000000;\ 0{,}004;\ X > 10000000; 0{,}002) + 1500 + 6000 - PV(d; years; 2500; 0; 0) + 2500 + 1500 + 5000 + X * IFS(X = 0; "n.a."; X < 1000000;\ 0.05;\ X < 2000000;\ 0.04;\ X < 4000000;\ 0.03;\ X < 6000000;\ 0.02;\ X < 8000000;\ 0.02;\ X < 10000000;\ 0.01;\ X > 10000000; 0.005)$$

VCS + CCB + SD VISta:

$$PV\ Costs = Development + Validation - PV(d; years; verification; 0; 0) + 500 + MIN(10000; 0.1 * (X/Creditperiod) + X * IFS(X = 0; "n.a."; X < 10000;\ 0,05;\ X < 1000000;\ 0,14;\ X < 2000000;\ X;\ X < 4000000;\ 0,105;\ X < 6000000;\ 0,085;\ X < 8000000;\ 0,06;\ X < 10000000;\ 0,04;\ X > 10000000; 0,025) + X * IFS(C20 = 0; "n.a.";\ X < 1000000;\ 0,02;\ X < 2000000;\ 0,018;\ X < 4000000;\ 0,016;\ X < 6000000;\ 0,012;\ X < 8000000;\ 0,008;\ X < 10000000;\ 0,004;\ X > 10000000; 0,002) + 1500 + 6000 - PV(d; years; 2500; 0; 0) + 2500 + 5000 + X * IFS(C20 = 0; "n.a.";\ X < 1000000;\ 0,05;\ X < 2000000;\ 0,045;\ X < 4000000;\ 0,04;\ X < 6000000;\ 0,03;\ X < 8000000;\ 0,02;\ X < 10000000;\ 0,01;\ X > 10000000; 0,005 + 2500 + 1500 + 5000 + X * IFS(X = 0; "n.a."; X < 1000000;\ 0.05;\ X < 2000000;\ 0.04;\ X < 4000000;\ 0.03;\ X < 6000000;\ 0.02;\ X < 8000000;\ 0.02;\ X < 10000000;\ 0.01;\ X > 10000000; 0.005)$$

Gold Standard

Micro:

$$PV\ Costs = Development + 1000 + 0.15X + 1500 + 0.3X + 5000 - PV(d; years; 2500; 0; 0) + 50h + 500 + 1500$$

Macro:

$$PV\ Costs = Development + Validation - PV(d; years; verification; 0; 0) + 1000 + 0.3X + 50h + 500 + 1500$$

Project lifetime 5 years scenario

Plan Vivo

Micro:

$$PV\ Costs = Development + 1000 + 3000 + 500 + 6000 + 2000 + 0,4X + 0.05X + 350 + 500$$

Macro:

$$PV\ Costs = Development + Validation + Verification + 1000 + 1500 + 500 + 6000 + 2000 + 0,35X + 0.05X + 350 + 500$$

Verra

VCS:

$$PV\ Costs = Development + Validation + Verification + MIN(10000; 0.1 * (X/Creditperiod) + X * IFS(X = 0; "n.a."; X < 10000;\ 0,05;\ X < 1000000;\ 0,14;\ X < 2000000;\ X;\ X < 4000000;\ 0,105;\ X < 6000000;\ 0,085;\ X < 8000000;\ 0,06;\ X < 10000000;\ 0,04;\ X > 10000000; 0,025) + X * IFS(C20 = 0; "n.a.";\ X < 1000000;\ 0,02;\ X < 2000000;\ 0,018;\ X < 4000000;\ 0,016;\ X < 6000000;\ 0,012;\ X < 8000000;\ 0,008;\ X < 10000000;\ 0,004;\ X > 10000000; 0,002) + 1500 + 6000 - PV(d; years; 2500; 0; 0)$$

VCS + CCB:

$$Development + Validation + Verification + 500 + MIN(10000; 0.1 * (X/Creditperiod) + X * IFS(X = 0; "n.a."; X < 10000;\ 0,05;\ X < 1000000;\ 0,14;\ X < 2000000;\ X;\ X < 4000000;\ 0,105;\ X < 6000000;\ 0,085;\ X < 8000000;\ 0,06;\ X < 10000000;\ 0,04;\ X > 10000000; 0,025) + X * IFS(C20 = 0; "n.a.";\ X < 1000000;\ 0,02;\ X < 2000000;\ 0,018;\ X < 4000000;\ 0,016;\ X < 6000000;\ 0,012;\ X < 8000000;\ 0,008;\ X < 10000000;\ 0,004;\ X > 10000000; 0,002) + 1500 + 6000 - PV(d; years; 2500; 0; 0) + 2500 + 5000 + X * IFS(X =$$

$$0; \text{"}n.a.\text{"};\ X < 1000000;\ 0{,}05;\ X < 2000000;\ 0{,}045;\ X < 4000000;\ 0{,}04;\ X < 6000000;\ 0{,}03;\ X < 8000000;\ 0{,}02;\ X < 10000000;\ 0{,}01;\ X > 10000000; 0{,}005)$$

VCS + SD VISta:

$$PV\ Costs = Development + Validation + 500 + MIN(10000; 0.1 \ast (X/Creditperiod) + X \ast IFS(X = 0; \text{"}n.a.\text{"}; X < 10000;\ 0{,}05;\ X < 1000000;\ 0{,}14;\ X < 2000000;\ X;\ X < 4000000;\ 0{,}105;\ X < 6000000;\ 0{,}085;\ X < 8000000;\ 0{,}06;\ X < 10000000;\ 0{,}04;\ X > 10000000; 0{,}025) + X \ast IFS(C20 = 0; \text{"}n.a.\text{"};\ X < 1000000;\ 0{,}02;\ X < 2000000;\ 0{,}018;\ X < 4000000;\ 0{,}016;\ X < 6000000;\ 0{,}012;\ X < 8000000;\ 0{,}008;\ X < 10000000;\ 0{,}004;\ X > 10000000; 0{,}002) + 1500 + 6000 - PV(d; years; 2500; 0; 0) + 2500 + 1500 + 5000 + X \ast IFS(X = 0; \text{"}n.a.\text{"}; X < 1000000;\ 0.05;\ X < 2000000;\ 0.04;\ X < 4000000;\ 0.03;\ X < 6000000;\ 0.02;\ X < 8000000;\ 0.02;\ X < 10000000;\ 0.01;\ X > 10000000; 0.005)$$

VCS + CCB + SD VISta

$$PV\ Costs = Development + Validation + Verification + 500 + MIN(10000; 0.1 \ast \left(\frac{X}{Creditperiod}\right) + X \ast IFS(X = 0; \text{n.a.}; X < 10000;\ 0{,}05;\ X < 1000000;\ 0{,}14;\ X < 2000000;\ X;\ X < 4000000;\ 0{,}105;\ X < 6000000;\ 0{,}085;\ X < 8000000;\ 0{,}06;\ X < 10000000;\ 0{,}04;\ X > 10000000; 0{,}025) + X \ast IFS(C20 = 0; \text{n.a.};\ X < 1000000;\ 0{,}02;\ X < 2000000;\ 0{,}018;\ X < 4000000;\ 0{,}016;\ X < 6000000;\ 0{,}012;\ X < 8000000;\ 0{,}008;\ X < 10000000;\ 0{,}004;\ X > 10000000; 0{,}002) + 1500 + 6000 - PV(d; period; 2500; 0; 0) + 2500 + 5000 + X \ast IFS(C20 = 0; \text{"}n.a.\text{"};\ X < 1000000;\ 0{,}05;\ X < 2000000;\ 0{,}045;\ X < 4000000;\ 0{,}04;\ X < 6000000;\ 0{,}03;\ X < 8000000;\ 0{,}02;\ X < 10000000;\ 0{,}01;\ X > 10000000; 0{,}005 + 2500 + 1500 + 5000 + X \ast IFS(X = 0; \text{"}n.a.\text{"}; X < 1000000;\ 0.05;\ X < 2000000;\ 0.04;\ X < 4000000;\ 0.03;\ X < 6000000;\ 0.02;\ X < 8000000;\ 0.02;\ X < 10000000;\ 0.01;\ X > 10000000; 0.005)$$

Gold Standard

Micro:

$$Development + 1000 + 0.15X + 1500 + 0.3X + 5000 + -PV(d; period; 2500; 0; 0) + 50h + 500 + 1500$$

Macro:

$$Development + validation + verification + 1000 + 0.3X + 50h + 500 + 1500$$

6. Sensitivity analysis carbon certification standards

Table 27: 5-year sensitivity analysis for all certification standards.

Variable	5-year period							
	PV micro	PV macro	VCS	VCS+ CCB	VCS+ SD VISta	VCS+ CCB + SD VISta	GS micro	GS macro
Development costs	+++	+++	+++	+++	+++	+++	+++	+++
Validation	NP	+	+	+	+	+	NP	+
Verification	NP	+	+	+	+	+	NP	+
Discount rate	+/-	+/-	+/-	+/-	+/-	+/-	+/-	+/-
Growth rate	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -	- - - -

Table 28: 25-year sensitivity analysis for all certification standards.

Variable	25-year period							
	PV micro	PV macro	VCS	VCS+ CCB	VCS+ SD VISta	VCS+ CCB + SD VISta	GS micro	GS macro
Development costs	+++	+++	+++	+++	+++	+++	+++	+++
Validation	NP	+/-	+/-	+/-	+/-	+/-	NP	+/-

Appendix D – Information required to calculate carbon storage

Table 29: Information required to calculate carbon storage in mangrove forests summarized, derived from Howard et al. (2014) and Kauffman & Donato et al. (2012).

Carbon pool	Type	Information required
Soil carbon		Soil depth
		Subsample depth an interval
		Dry bulk density
		Soil organic carbon content (%C)
Aboveground living biomass	Live trees	Species
		Main stem diameter at breast height (dbh)
		Tree height if feasible
		Location and ID
		Wood density
		Biomass to carbon conversion factor
	Shrub trees	Lengths canopy
		Crown volume
		Main stem diameter at 30cm
	Lianas	Main stem diameter at breast height (dbh)

Aboveground dead biomass	Standing dead trees	Decay status tree
		Main stem diameter at breast height (dbh)
		Diameter at base
	Litter	Biomass litter from 0.5x0.5m site
	Dead and drowned wood	Diameter of wood in chosen plot
		Number of pieces sampled
Belowground living biomass		Main stem diameter at breast height (dbh)
		Wood density