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Reforesting the Atlantic Forest, through Forest Credits, PES or Carbon Credits

A systematic literature review of Payments for Environmental Services and carbon credits

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Contents

Abstract

The Atlantic Forest (AF) biome has been impacted by deforestation over the years. Only 2-5% of the original forest is still in its original condition. In order to mitigate the deforestation efforts, the Environmental Reserve Quota (CRA) trading mechanism was introduced. This mechanism allows for the trade of legal reserves (LR) between landowners, with as goal to increase the forest cover in the Atlantic Forest biome.

This study attempts to gain more insight into the CRA market and alternatives. A Scientific Literature Review (SLR) analyzed the financial mechanisms, carbon credits & Payments for Environmental Services (PES). These results were then compared to the outcomes of an Agent Based Modelling (ABM) model of the CRA market. Forest cover increases as a direct result of the CRA market. Reforestation to the 20% legal reserves threshold is observed. Carbon credits cannot exceed the opportunity costs of farms, under current regulations, and are unlikely to be eligible as additional financial incentive. The best results in terms of forest cover, revenue streams and land quality is likely to be observed under integration of PES schemes locally, with the CRA market nationally. More research should be performed in order to determine the integration possibilities of PES and CRA for future forest conservation policy.

Introduction

The Atlantic forest biome is a very important region in Brazil. More than 60% of the total inhabitants of Brazil live in this region and it is responsible for approximately 80% of the national GDP (Pinto et al. 2014). The biome houses a total of 389 endemic animals and over 50% of the tree species are thought to be endemic (FAO 2012). However, only 2-5% of the original Atlantic Forests is still in its original condition (FAO 2012).

In order to mitigate the deforestation efforts, the Forest Code was implemented in 1934 by the Brazilian government (Pinto et al. 2014). One of the main instruments was to oblige private land owners to establish Legal Reserves (LR). In the Atlantic Forest (AF) region this mechanism compels private land owners to retain at least 20% natural vegetation of their entire land (Bernasconi et al. 2016). The Forest code has been adjusted over the years but hasn't achieved its original goals (Tavares et al. 2019). In 2006, it was forecasted that another 140 Mha would be deforested due to agricultural expansion (Sparovek, Giaroli, and Pereira 2011). Additionally, the Forest Code limited agricultural development due to the perceived consequences, as full compliance enforcement would lead to a decrease of 85 Mha in agricultural lands (Sparovek, Giaroli, and Pereira 2011).The Forest Code was therefore replaced by the Native Vegetation protection law in 2012 (Pinto et al. 2014). The new law introduced the Environmental Reserve Quota (CRA) trading mechanisms . This trading mechanism allows landowners to trade their forest surplus or deficit. The private landowners control approximately 90% of the remaining Atlantic forest (Pinto et al. 2014). Thus, gaining insights in the operations of private landowners is crucial in order to adjust governance instruments and pivot where necessary.

Ascenzi who researched this topic has created an Agent Based Model (ABM) in order to determine which interactions among landowners result in higher forest cover and revenues for credit sellers (2021). ABM's are models that are capable of combining both: actors in the form of agents and a physical representation of the environment they act in. This enables interactions between agents and their environment. Consequently, even with incomplete information the agents and environment can be given characteristics on which simulations can be performed (Loomis, Bond, and Harpman 2008). This allows for simulating real world scenarios as well as validating whether the characteristics given to the model, result in the processes observed in economic theory, like rational choice and profit maximization. Ascenzi used three scenario's ranging from a regional market, restricting trade to the borders of a state, to a national market in which CRA trade is permitted across the whole country (2021). The main question being; which size CRA market would result in the most revenue for credit sellers and the most forest cover (Ascenzi 2021).

The main findings of her research were that forest cover increased intermittingly in all scenario's, but only reached a stable increase in the scenario in which there's a national market and trade across the AF biome and participation of illiterates. Moreover, a restricted CRA market at regional level correlated with more forest cover and a higher CRA price. However, the amount of characteristics appointed to the agents and environment were fairly limited. For example, the agents strategy solely depended on whether the agent belonged to nature conservationists, economic opportunists or illiterate. The deciding factor for buying forest credits was limited to whether agricultural crop yield exceeded the CRA price.

Furthermore, not all crops yield the same outcome. The two most produced crops in Brazil in terms of yield are respectively soy and sugar cane (IBGE 2017). The average yield and associated production costs observed, differs per region and per crop (IBGE 2017; CONAB 2017). Moreover, around 42% of agricultural land are related to livestock (IBGE 2017). These pastures must also comply to LR. Therefore, it is necessary to determine what the effects of land use can be on the CRA market. Furthermore, the deciding factor for buying or selling forest credits was whether agricultural yield exceeded CRA price. However economically, the option to invest should depend on the potential profit derived from buying or selling forest credits. This potential profit is dependent of the CRA price but also of the revenue minus costs that is associated with a piece of agricultural land. This is called opportunity costs and differs per land use as the yields and costs are not equal for soy, sugar cane and pasture. The opportunity costs are also dependent on the size of the farms. Of the 5.17 million farms, 68% are smaller than 20ha whilst more than half of the farmland belongs to the 2% farms with a size of more than 500 ha (Helfand, Rada, and Magalhães 2017). This discrepancy in farm size could influence the opportunity costs via the economy of scale principle. Just like most industries, larger corporations i.e. farms incur less costs per added production value (Duffy 2009).

These characteristics could add value to the ABM model as these will likely influence economic mechanisms driving the ABM, which in turn could generate new results. Though these results are only relevant when compared to other ways of environmental finance mechanisms. As the results of other financial mechanisms for the increase of forest, may or may not differ from the results found in the model. The possible discrepancy between the ABM model and the literature could contribute to possible leads and discussion points for future forest conservation policy. Therefore the research question is as follows:

What are the effects of differentiation in land use and farm size on the realization of legal reserves area and revenue streams, within a restricted CRA market in the Atlantic Forest biome and to what extent are there feasible alternatives to this CRA market?

This research question is answered through two methods; the ABM model and a systematic literature review. The results from the ABM model are used in order to formulate an answer for the following questions:

> *What are the effects of adding the three major types of agricultural land use to the model, on the realization of total legal reserves area and revenue streams?*
>
> *What are the effects of adding the economics of scale principle, on the realization of total legal reserves area and revenue streams?*

Subsequently, the systematic literature review will formulate an answer on the following question:

> *What are feasible alternatives to the CRA market and how could they be implemented?*

The hypotheses are as follows:

1. There will be a shift in legal reserves, such that smaller farms will obtain relatively more LR than larger farms, due to the economics of scale principle.
2. Land uses with higher profit margins per ha will outcompete the other type of land uses, resulting in a shift of LR from higher profit margin land uses to lower profit margin land uses.
3. Forest cover will increase but will not exceed the 20% LR threshold permanently.
4. Alternatives to the CRA market can only be a viable replacement, if the compensation for opportunity costs are exceeded.

Materials & Methods

Netlogo

Agent Based Modelling (ABM) has been used in a wide variety of scientific fields (Crooks and Heppenstall 2012). It is a versatile tool that has many uses of which one is informing land and agricultural policy (Hammond 2015). ABM is useful in this case because it enables the modeling of interactivity between agents and their environment. This spatial component allows the model to create an interactive world, which allows for the extrapolation of data that is informative for real world purposes. The agents in ABM can be personalized and have the following characteristics:

- **Heterogeneity**: Agents can be given traits that enable the development of autonomous individuals (Crooks and Heppenstall 2012). Due to these traits, a wide variety of interactive agents can be created.
- **Autonomous**: Agents are capable of processing information from their surroundings and are free to act upon this information (Crooks and Heppenstall 2012). Meaning, that there is no centralized control structure that determines what the agents will do in each situation. This enables agents to, according to a set of rules, interact freely with their environment and other agents (Crooks and Heppenstall 2012).
- **Active**: Agents are not dormant individuals that are affected by their environment but can be proactive in the world they act in. They have active features that include, but are not limited to: communication, rationale, perception, goals, mobility and adaptation (Crooks and Heppenstall 2012).

In this paper, the application Netlogo is used to perform the ABM. Netlogo has extensively been used in ABM and is very well suited for simulating complex systems that develop over time (Tisue and Wilensky 2004).

The model works in a sequence of events displayed in the flow chart in figure 1. First, the model is initiated through the setup module. This creates the landscape in which the simulation is ran and sets up the different farms, the intermediary party and the market. When this is completed the simulation i.e. cycle can be started. The farms can either buy or sell land and acquire or depose of LR based on their production value relative to the CRA price. Subsequently, the total amount of LR in the model is updated and the CRA price, which depends on the supply and demand of LR, is updated. This cycle repeats for a total of 50 timesteps. Every timestep represents the duration of contract length, in this case five years. A more extensive explanation of how the model works can be found in the ABM report (Chukundah 2021).

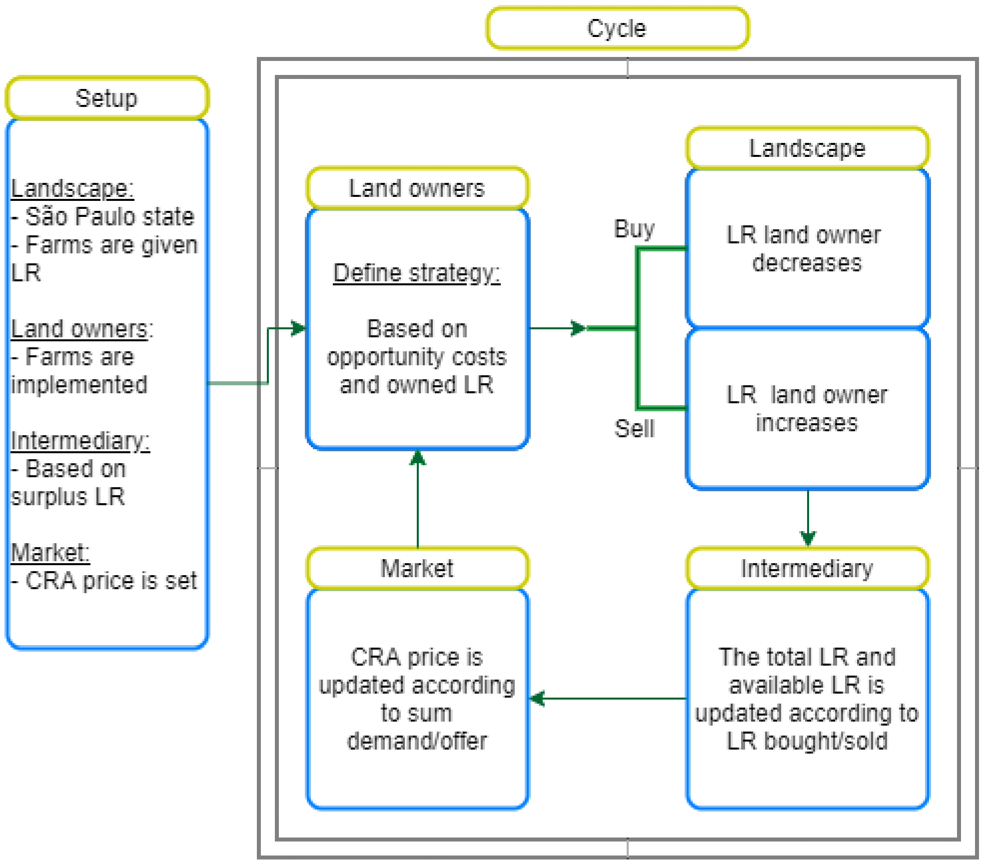

Figure 1. A flowchart of the ABM. The yellow compartments are titles. The green compartments showcase modules that execute commands in the model.

Scenarios

The simulations are divided into three separate scenarios. The scenarios are based on the concepts of efficiency and production value. The model distinguishes production value in terms of land use and efficiency in terms of farm size. The efficiency trait is linked to farm size. This is based on the principles of economics of scale. This principle describes how much production increases when an unit of input is added (Rasmussen 2013). The scenarios are given by table 1.

Table 1. Table displaying the different scenarios.

	Distinguishing factor	Based on	Calculation	Data
Scenario 1	Land use: Soy, Sugar Cane & Pasture	Land use specific production values	Production values were calculated by subtracting land use specific production costs from land use specific yields	IBGE & CONAB database. Appendix 6, 7 & 8.
Scenario 2	Farm size: <5 ha, 5-20 ha, 20-100 ha, 100-500 ha & 500 ha+	An amplifier of farm size dependent, total factor productivity on the production value of soy.	Amplifier is based on TFP. which is the ratio of total production divided by the total of weighted inputs. it displays how efficiently inputs are utilized (Comin 2010)	(Rada, Helfand, and Magalhães 2019)
Scenario 3	Land use & farm size	Combination of farm size dependent amplifiers and land use specific production values	For soy TFP was amplified with production value, as no specific data was available for production values of different soy farm sizes. For pasture and Sugar cane, specific farm size dependent production values were used.	Soy: (Rada, Helfand, and Magalhães 2019) & Appendix 7 Sugar Cane: (Santos et al., 2018). Pasture: IBGE, Appendix 6

Literature review

Literature reviews are an essential feature of academic research as it allows for the creation of knowledge based on prior studies (Xiao and Watson 2019). Several techniques were used for the gathering of literature used in the introduction, material & methods and chapter one. The background information was gathered by specific literature search keywords, this was mainly done in google scholar as this search engine allows for a quick and simple overview of relevant literature. The data used for the model was mostly extrapolated from Brazilian databases, more information for the specific tables can be found in the ABM report (Chukundah 2021). The CONAB and IBGE databases are often used as primary source material in scientific literature revolving around Brazilian agriculture and thus were explored for the finding of relevant input data. Other information used in the theoretical framework of the model was found by a combination of the use of relevant search terms in google scholar and the use of snowballing. The snowballing was performed by first extensively reading the relevant scientific literature and afterwards screening the text and reference page for relevant references. This was not done systematically, rather whenever necessary information was required, a search was performed.

Systematic literature review

For the gathering of literature for chapter two the systematic literature review technique is used. This technique adds value to the literature review as it allows for validity, reliability and foremost repeatability (Xiao and Watson 2019). These are necessary for well written scientific studies. In order to provide an adequate scope for the study the first steps of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) method were used. This is the most widely used method and is the scientific standard for systematic reviews (Moher et al. 2009).

The search is performed in Scopus and Web of Science (WoS). These are the most widely used search engines for SLR by academics (Vermunt, Verweij, and Verburg 2020; Steur et al. 2020). The results were reviewed through the steps used in a systematic literature review (SLR). This is displayed in figure 1. After the first step of identification a total of 54 records were extracted from Scopus and 26 Were extracted from WoS. This resulted in a total of 80 articles. However 35 results were either duplicates or unavailable. These were consequently removed. The 45 other articles were catalogued in excel which can be found in appendix 1. These articles were screened for relevance and topic. This resulted in 39 relevant articles and 6 irrelevant articles. Subsequently, the irrelevant articles were excluded. This resulted in a corpus of studies eligible for review. These studies were extensively read and analyzed, of which the results are compiled in chapter two. In chapter two there are four articles that were not part of the systemic literature review process. These articles were found in preliminary searches and were deemed very important for a complete review, thus were included. These articles can also be found in appendix 1, in order to adhere to reapeatability.

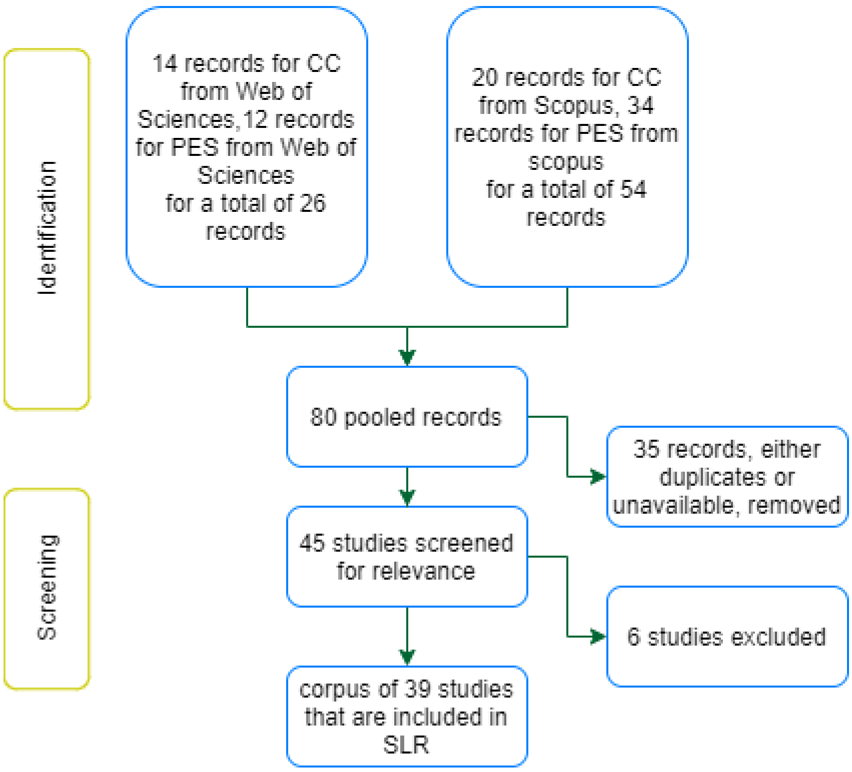

Figure 2: Information flow diagram of the systematic literature review (SLR), based on PRISMA method (Steur et al. 2020; Moher et al. 2009). *CC are carbon credits and PES are payments for environmental services.*

The search terms are defined narrowly in contrast to broadly. This is mainly done to limit the scope of the study. The search terms are based on the recurring themes of the preliminary literature review. These were not the only recurring themes. Financial instruments as incentives and subsidies were also encountered multiple times during the preliminary review. However, the framework of this article is limited to financial mechanisms. This is interpreted as instruments that involve some kind of market forces. Subsidies can influence the market, however, it is not a market of itself. Therefore subsidies and other incentive were excluded from the search. PES and carbon offsets are the most common financial mechanisms, influenced by market forces, that are reported on by scientific literature. Therefore PES and carbon offsets were the focus of interest in this study and separate search strings were used for PES and carbon offsets. PES has the variations “payments for ecosystem services” and “payments for environmental services”. Additionally, carbon offsets are often referred to as carbon credits. Multiple variations of search strings were attempted but the most relevant results within an adequate scope were found by the following search strings.

The search string for PES was as follows:

(TITLE ("payments for environmental services" AND (forest OR forests)) OR TITLE ((("payments for environmental services" OR "payments for ecosystem services") AND agriculture)))

The search string for carbon credits was as follows:

(TITLE-ABS-KEY ((redd OR redd+) AND ("carbon offset" OR "carbon credits") AND (agricultural OR agriculture)) OR TITLE-ABS-KEY (("forest carbon credits" OR "forest carbon offset") AND (agriculture OR agricultural)))

With limitations set to include only articles from the subject areas “Environmental Scienes”, “Social Sciences”, “Agricultural and Biological sciences” and “Economics, Econometrics and Finance”. The outcomes resulted in the pool of records that were used for further review.

Results

The results of the ABM and SLR are displayed in this section. First the ABM results of the ABM report are summarized after which, the results of the SLR are given. Afterwards, these results are discussed.

Ch1. CRA market

Opportunity costs

The ABM model assumes that all agents i.e. farmers, act in their own economic benefit. This means that decisions are based on whichever is the most profitable. In the model, decisions around buying or selling Legal Reserves (LR) are based on the concept of opportunity costs. This concept is derived from economics and is often used in substantiating investment options (Fernando 2020). It works by calculating the returns of the chosen option and the returns of the best foregone option. Afterwards, the returns of the best forgone option are subtracted from the returns on the chosen option (Fernando 2020). The remaining sum are the opportunity costs.

In the model the best foregone option is the agricultural production value per hectare, which is calculated by subtracting production cost per hectare from yield per hectare. The chosen option in this case is the acquisition of LR which is given by CRA price per hectare. If the opportunity costs are positive, the farm owner will want to retain farmland instead of LR as this provides the most value. If the opportunity costs are negative, the farm owner will want to do the opposite. This is visualized in equation 1.

$$Opportunity\ costs = \left(\frac{\text{yield} - \text{production cost}}{\text{ha}}\right) - \frac{\text{CRA price}}{\text{ha}} \quad (1)$$

Market

The CRA price tends to follow a certain set of rules and has a relation with the observed total legal reserves. At the start of the simulation the CRA price always increases as there is a demand for legal reserves, since at the start the LR are below 20%. This can be seen in the first 4 timesteps of figure 3 The trajectory of the legal reserves area is dependent on the opportunity costs therefore, production values of the LR holders. The LR decreased in the first timestep due to sugar cane holding 58% of the total agricultural area and having a production value that is higher than the CRA price. In the following timesteps the LR will gradually increase as the CRA price increases until it has topped the production value of the pasture farms. This is due to soy holding 13% of the total agricultural area, which is not enough to accommodate 20% legal reserves for the whole market. Therefore, the soy areal will consist completely of legal reserves and the CRA price will still increase until it has reached the next production value, which in this case is pastures. Once the CRA price has reached the production value of pastures, these farms will obtain legal reserves for their own until the total LR has reached 20%. After which, the CRA price will decrease until it is more profitable for soy farms to cultivate crops instead of having a surplus of LR. This decrease can be observed as the major dips in the CRA price and LR percentage of figure 3.

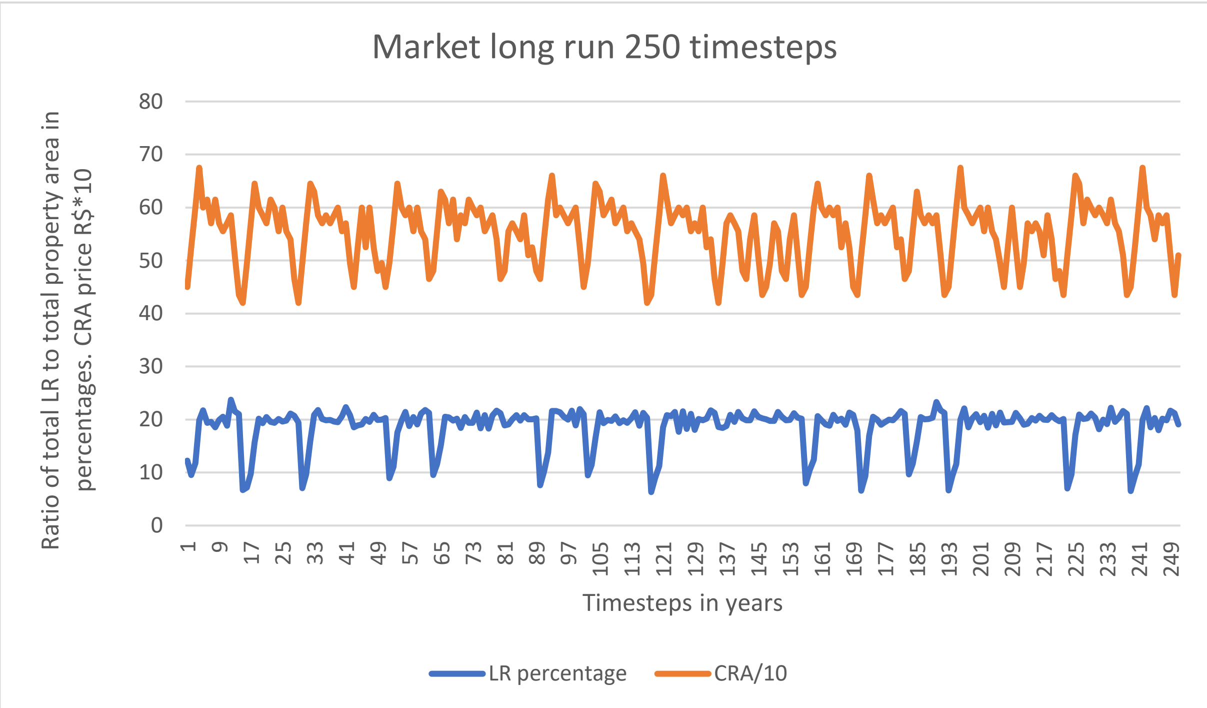

Figure 3. This figure shows the total LR percentage versus the CRA price divided by 10. Taken from long run scenario 1.

The trajectories mentioned above contribute to a clear cycle that the market resides in. This cycle shows a bimodality in both CRA price and total LR percentage. The cycle starts when CRA price is high and thus promoting the obtainment of a surplus of LR. Once the total LR has reached 20%, the CRA price will decrease, which promotes the cultivation of crops. This leads to a decrease in LR areal which, when under 20%, will increase the demand for LR and thus the CRA price. This cycle keeps repeating with a LR trend around 20% and a CRA price trend around the first production value that is encountered once the total LR area has reached 20%.

The model results give insights in the effects of land use and farm size for the amount of legal reserves per farm and the corresponding revenue streams. The simulations of the three separate scenario's each give a different insight into this matter. Therefore each scenario is discussed separately resulting in a short conclusion.

Land use

The first scenario gives insights in the effects of land use on the CRA market. The model has been ran for 20 simulations and makes a distinction between breeds via land use. The observed production values corresponding to the land uses are displayed in table 2 along with the start and end LR percentages.

The sugar cane farms have the highest production value and all have LR percentages lower than the 20% threshold, which means that they offset their LR requirement The production values determine the eventual LR percentages. However, due to fluctuations in production value between simulations, the LR percentages of soy are higher than the LR percentages of pasture, even though the average production value of pasture is lower than soy. The fluctuations in production value are a consequence of the high standard deviations of yield.

Table 2. The average production values and LR percentages of the different farm breeds in scenario 1.

Breeds	SOY1	SOY2	SOY3	SOY4	SOY5	SC1	Total (average)	SOY (average)
Production Value (R$ per ha)	660,67	660,67	660,67	660,67	660,67	1484,85	904,87	660,67
Start LR (% of farm area)	14,81	14,94	12,14	0,00	0,00	19,87	11,92	8,38
End LR (% of farm area)	48,99	48,85	45,73	47,93	46,50	11,98	19,53	47,60
Breeds	**SC2**	**SC3**	**SC4**	**SC5**	**COW1**	**COW2**	**SC (average)**	**COW (average)**
Production Value (R$ per ha)	1484,85	1484,85	1484,85	1484,85	569,10	569,10	1484,85	569,10
Start LR (% of farm area)	18,53	17,17	4,10	22,12	14,22	7,93	16,36	12,14
End LR (% of farm area)	11,33	6,80	5,03	3,51	35,67	29,60	7,73	32,63

Farm size

The second scenario makes a distinction between breeds via farm size. Every separate farm size has its own production value which is displayed in table 6. The relation between farm size and farmland percentage can be seen in figure 4.

Over 20 simulations the results show a clear distinction between 500+ ha farms and the other farm sizes. The 0-5 ha farms were also expected to outcompete the others but this was not the case due to fluctuations in the production value, as a result of the high standard deviation in yield. 500+ ha farms were the only breed to, on average, offset their LR requirements. All the other breeds have attained more legal reserves which has resulted in a LR surplus for these breeds. The 500+ ha farms hold more than 50% of the total agricultural area. therefore, the 500+ ha farm demand for LR, leads to a need for LR supply by almost all other farm sizes.

Table 3. The average production values and LR percentages of the different farm breeds in scenario 2

Breeds	SOY1	SOY2	SOY3	SOY4	SOY5	Total (average)
Farm sizes (ha)	**0-5**	**5-20**	**20-100**	**100-500**	**500+**	**n.a.**
Production Value (R$ per ha)	792,8267	658,3529	703,9338	775,8197	848,2653	755,8397
Start LR (% of farm area)	21,97802	19,32021	17,60204	7,614213	15,17011	14,39221
End LR (% of farm area)	29,47802198	50,61717	33,28444	27,08122	9,972114	19,96687

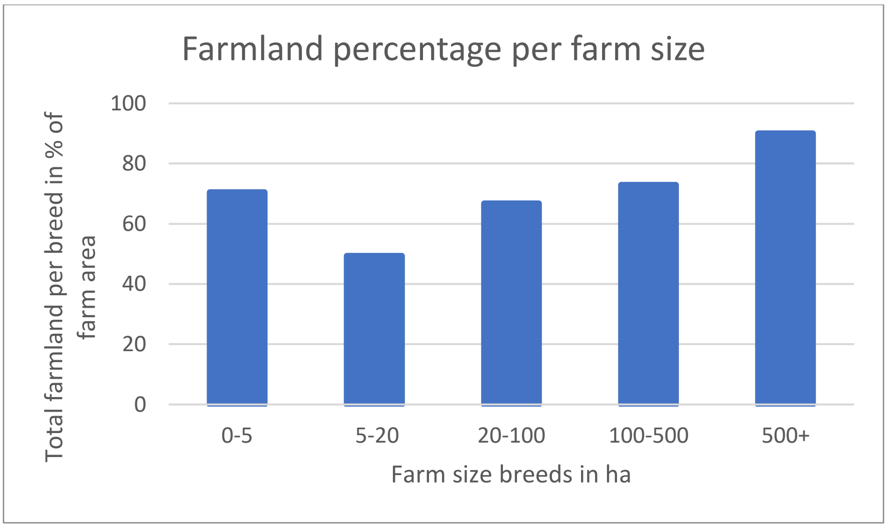

Figure 4. this graph depicts the percentage of farm land, to total farm area. On the x- axis, the different farm sizes are depicted.

Combined effects

The third scenario differentiates breeds via the combined effects of farm size and land use. The average production values are displayed in table 4. The production values for SOY2, SOY4 and SC4 as SOY2 and SC4 are significantly higher than expected and SOY4 is significantly lower than expected. This is due to the relatively high standard deviations in yield.

Over 20 simulations the results do show significant correlations as can be seen in table 7. Over all simulations, the farm with the highest average production value, SC4, also has lowest end lr at 5%. The three farms with the highest production values, all have on average a LR percentage lower than 20%, while all other farms exceed the LR threshold.

Table 4. The average production values and LR percentages of the different farm breeds in scenario 3.

Breeds	SOY1	SOY2	SOY3	SOY4	SOY5	Total (average)	SOY (average)
Production Value (R$ per ha)	679,67	940,50	526,57	372,99	977,54	782,76	699,45
Start LR (% of farm area)	15,38	15,38	12,24	0,00	0,00	11,88	8,60
End LR (% of farm area)	42,88	28,08	32,32	40,58	10,30	18,45	30,83
Breeds	**SC3**	**SC4**	**SC5**	**COW1**	**COW2**	**SC (average)**	**COW (average)**
Production Value (R$ per ha)	716,45	1501,44	989,35	547,92	575,19	1069,08	561,55
Start LR (% of farm area)	17,49	4,23	22,76	14,42	8,15	14,83	11,29
End LR (% of farm area)	37,64	5,14	14,28	35,19	20,38	19,02	27,78

Conclusive remarks

In all scenarios, forest cover increases and reaches the 20% LR threshold. Subsequently, when this threshold is met, the forest cover will fluctuate in a bimodality state around 20% LR. The forest cover will increase when under 20% LR and decrease when above 20% LR, as a result of the CRA price that does the direct opposite. The CRA price determines the decision of farms whether to acquire or offset LR. When CRA price is higher than the production value, farms will acquire LR and when the CRA price is lower, farms will offset LR.

Where LR is situated depends on the production values of all farms. Both land use and farm size influence the production values to the extent that LR composition depends on these factors. In scenario 1 sugar cane has the highest production value, which leads to the offset of LR to pastures and soy. In scenario 2, 500+ha farms have a high production value and 5-20ha farms a low production value, which results in LR offset from 500+ha farms to 5-20 ha farms. The combination of land use and farm size in scenario 3 has a weakening effect on some farms breeds and a strengthening effect on other farms breeds. Therefore, the LR composition is not solely dependent on one factor. Land use and farm size both influence the LR composition.

The forest cover also depends on yield fluctuations between simulations. The yield fluctuations cause production values to be erratic and therefore the LR composition are evened out over multiple simulations. Where in 1 simulation, some farms may have 100% LR or 0% LR, in multiple simulations these absolutes do not occur. The yield fluctuations can influence production values to the extent that in some simulations the land use and farm size effects are negated.

Ch2. Alternatives to the CRA market

There are multiple ways of promoting forest cover other than the CRA market. This chapter gives insights in two methods other than the CRA market that ensure financial compensation for additional forest cover. Here payments for environmental services (PES) and carbon offsets are dissected as these are financial mechanisms that have already been used and are promising instruments in achieving global and local environmental goals.

Payments for environmental services

PES is an instrument that translates societal benefits into payments for the providers of these benefits (Engel and Muller 2016). This is a voluntary transaction in which the providers of environmental services (ES) are rewarded by ES buyers (Wunder 2006). These PES schemes are not limited to agricultural landowners but this paper does make this restriction. In terms of agriculture these environmental services are extended from provisioning environmental services to regulating environmental services. These can include but are not limited to climate regulation, water purification and carbon sequestration (Indira Devi et al. 2017).

PES has been widely used in the last few decades and has also been used in the Atlantic forest biome. The most common goals of these PES schemes are biodiversity conservation, carbon sequestration and watershed services (Aza, Riccioli, and Di Iacovo 2021; Wunder 2006). PES schemes can either involve a payment from buyers that directly benefit from the environmental services, or it can be a (governmental) organization that rewards these environmental services (Engel and Muller 2016). In both scenarios there is a need for intermediary institutions that can regulate and monitor this market (Pereira 2010; Engel and Muller 2016).

Opportunities and limitations

The direct compensation of environmental services provides opportunities to reward quality of service. Not all farmers contribute equally to environmental services (Indira Devi et al. 2017). Consequently, the opportunity to distinguish which farms contribute to what extent can stimulate good behavior. In terms of LR this could for example create opportunities for farms that have property in the watershed (Pissarra, Sanches Fernandes, and Pacheco 2021). As area, surrounding waterways, legally has to be preserved as native vegetation. Native vegetation can provide environmental services like water purification and providing riparian habitat. Rewarding these ES could motivate farmers more to adhere to the regulations set by the forest code. However, to reward quality of service, intermediary institutions are required to regulate and monitor. If this is not done sufficiently, then there are less opportunities to provide the adequate rewards and there are risks for free riders and corruption (Newton et al. 2012)(Oliveira Fiorini, Swisher, and Putz 2020).

As PES schemes are mostly operated locally, there are opportunities for distributing wealth to communities or individuals in need. Multiple case studies have shown that the poverty status of smallholders can be improved through the use of PES (Clements and Milner-Gulland 2015; Engel and Muller 2016; Grieg-Gran, Porras, and Wunder 2005). This is possible because PES schemes can improve agricultural conditions and similarly to the CRA market provide additional revenue streams and a guaranteed income (Indira Devi et al. 2017)(Izquierdo-Tort, Ortiz-Rosas, and Vázquez-Cisneros 2019). Additionally, landowners often have property area that is either LR or not capable of producing agricultural value (Figueroa et al. 2016). PES provides opportunities for income for these areas.

However poverty alleviation is only as successful as the efficiency of the PES schemes. Smallholders have less property than larger landowners. Resulting in less potential rewards, as less services are provided by smallholders. However, the transaction costs do not necessarily differ significantly between large and small landowners (Oliveira Fiorini, Swisher, and Putz 2020). This in conjuncture with social factors can provide difficult circumstances for smallholders. For example, a considerable amount of smallholders are illiterate, raising transaction costs (Ascenzi 2021). This results in transaction that can amount to more than a third of the payment provided (Manasboonphempool, Milan, and Zeller 2015).

Implementation

Long term effectiveness requires permanence, a need to look beyond short-term incentives and long-term behavioral change stimulation (Izquierdo-Tort, Ortiz-Rosas, and Vázquez-Cisneros 2019; Engel and Muller 2016). Multiple case studies have shown that PES can be an effective mechanism for the increase of forest cover (Arriagada et al. 2012; Aza, Riccioli, and Di Iacovo 2021). However, for the question whether PES could be an alternative or addition to the CRA market, regulations and compensation must be considered. PES allows for the use of opportunity costs to determine the amount of payment. It is unclear whether the CRA market allows for PES compensation for the same property area. However, it is clear that integration of PES schemes is beneficial for the creation of new sustainable steady states (Bell et al. 2018). Through the integration of schemes, there is a higher chance of realizing a situation, in which farmers obtain enough monetary compensation to provide the corresponding environmental services (Aza, Riccioli, and Di Iacovo 2021). If this would be integrated in conjuncture with the existing CRA market then this could increase the chances for a more sustainable steady state of agriculture. In contrast, transaction costs increase when more schemes are applied. For smallholders this could offset the benefits, thus efficiency of the intermediary party is a prerequisite for achieving a sustainable steady state (Bell et al. 2018)(Engel and Muller 2016).

The primary drivers for successful implementation of PES schemes conventionally are monetary compensation and the existence of social structures (Gene 2007; Figueroa et al. 2016; Parlinah et al. 2018; Bell et al. 2018). However, in the AF biome, behavioral change is also driven by the perception of systemic corruption (Oliveira Fiorini, Swisher, and Putz 2020). The way compensation is calculated is important for the outcome. Previously, implementation in São Paulo used reference income of the most prominent crop sugar cane to determine the reward for land conversion (Pissarra, Sanches Fernandes, and Pacheco 2021). Compensation varied between 284.35–749.45 US$/ha/year (Pissarra, Sanches Fernandes, and Pacheco 2021). In this scenario land that has lower yields is more likely to be converted than land with higher yield. Consequently, area with lower soil quality or lower yield crops is more likely to be converted, influencing the local agricultural landscape.

Carbon credits

Carbon stocks i.e. carbon credits are certificates representing a measured amount of carbon dioxide emission reduction (Sapkota and White 2020). It is measured in ton carbon dioxide equivalent ($tCO2e$)(Sapkota and White 2020). As carbon sequestration is an environmental service, technically carbon credits could be labelled as a PES scheme. However, carbon credits tend to operate on a more market based mechanism and are used as a emission offset instead of an incentive to provide a service.

There are two ways of trading carbon credits namely, via a carbon tax where an emission price is directly set by the regulating authority or via an emission trading system (ETS) where the market defines the price for carbon credits (L. Santos et al. 2018). This ETS can be subdivided in the compliance market and the voluntary market (Sapkota and White 2020; Grabowski and Chazdon 2012). These markets allow for carbon offsetting by companies, individuals and organizations. The compliance market is centered around mandatory emission reductions set by regulations (Sapkota and White 2020). The largest of which is the EU ETS market. Whereas, the voluntary market consists of intermediary organizations that sell carbon credits to parties interested interesting in offsetting their emissions. One of the most promising voluntary markets is the reducing emissions from deforestation and forest degradation (REDD+) mechanism (Neudert et al. 2018). The credits offset emission for one party and reward the providing party for the amount of carbon sequestration they have delivered (Adams et al. 2011).

The main goal of these markets is to sequester carbon in order to mitigate climate change. Additionally, carbon credits could contribute to reducing deforestation and degradation, conservation and sustainable forest management and increase in carbon stocks (Edwards, Fisher, and Boyd 2010). In developing countries land based emissions are generally high (Swallow and Goddard 2013). This presents opportunities for carbon credits to finance land conversion and reduce the pressure that agriculture has on deforestation (Thangata and Hildebrand 2012; Motel, Pirard, and Combes 2009).

Opportunities and limitations

Providing financial compensation for carbon sequestration tends to increase forest cover (Ankersen et al. 2015). However the quality of this forest cover needs to be considered. There is no scientific consensus on whether carbon credits has a positive or a negative impact on other environmental services like biodiversity. Only if forest restoration mimics natural revegetation, a situation is created in which biodiversity can thrive (Grabowski and Chazdon 2012). However, projects that maximize carbon sequestration can reduce the biodiversity potential of the habitat (Grabowski and Chazdon 2012). This is mainly due to the use of fast growing vegetation or silviculture which can homogenize the remaining habitat (Edwards, Fisher, and Boyd 2010).

The financial compensation, can also alleviate poverty levels in developing countries. This is dependent on the height of the compensation and ease of access to these rewards. Smallholders can benefit from the steady income stream that carbon credits provide but they tend to have difficulties with accessing financing instruments (Thangata and Hildebrand 2012; Neudert et al. 2018). Additionally, transactions costs associated with carbon credits decrease relatively when the amount of carbon sequestration increases (Galik, Cooley, and Baker 2012). Thus, giving landholders with more property area, a competitive advantage. Consequently, poverty can only be alleviated when the institutions regulating carbon credits, can easily reach smallholders.

Implementation

Like the CRA market and PES, the relation between compensation and opportunity costs is the primary driver for behavioral change (Lu and Liu 2015). Therefore, carbon credits can stimulate farmers to convert agricultural land to forest cover, if the compensation exceeds the opportunity costs associated with agricultural production. It is questionable whether this is possible in Brazil. Brazil does currently not have a national ETS, thus carbon offsetting is completely dependent on international ETS schemes. However, currently forestry and agricultural carbon stocks are excluded from the compliance market, leaving only the voluntary market (Hyams and Fawcett 2013). The voluntary market has lower returns on investment than the compliance market (Adams et al. 2011; Hyams and Fawcett 2013). In fact, it is believed that converting agricultural land to forest may be possible with rewards from the compliance market but the compensation of the voluntary market is not enough to exceed opportunity costs (Butler, Koh, and Ghazoul 2009). Therefore it is unlikely that carbon credits could replace the CRA market with the contemporary regulations.

So an option could be to implement carbon credits in conjuncture with the CRA market. Legal reserves are per definition increases in natural vegetation and thus likely to sequester carbon. This could be measured and translated into carbon credits, providing farms with LR an additional income stream. However, one of the prerequisites for the implementation of carbon credits is additionality

(West et al. 2020)(Swallow and Goddard 2013). This concept defines the amount of sequestered carbon as the carbon that is sequestered, exceeding the business as usual scenario (Sapkota and White 2020)(Müller et al. 2014)(Adams et al. 2011). It is unclear whether LR are a business as usual scenario. If it is not, then this presents an opportunity to allow carbon credits in conjuncture with LR. However, it is unlikely that existing LR can be perceived as additional sequestered carbon for new carbon credits.

Other obstacles for successful implementation of carbon credits are leakage and permanence. Sequestered carbon can only reach its climate mitigation goals if it is stored long term. Carbon needs to be removed permanently. Consequently agricultural area that is conversed to forest cover is required to remain such, for decades. The farmer might not want to commit to a contract of this time length as potential benefits derived from other land uses can increase in the future (Latta et al. 2011). This would result in a loss of potential profits for the farmer. Additionally, with land use conversion the agricultural supply decreases but demand for agricultural product might not necessarily change (Borrego and Skutsch 2014). Therefore a decrease in production in one place can lead to an increase in production in some other place (Borrego and Skutsch 2014). This process is known as leakage and could lead to a scenario in which the net result sequestered carbon is nihil.

Discussion

The results stemming from the ABM model are compared to PES and carbon credits in this section.

Forest Cover

The results from the ABM show that no matter the scenario, forest cover will increase as a direct result from the CRA market. This is no surprise as the model assumes that all farms comply to the rules set by the CRA market, to reach the 20% LR threshold. However, not all farms acquire the same amount of LR. The results show that production values can have a significant effect on which farms acquire LR. Agriculture with lower production values acquire more LR. This could be an issue that needs addressing, as farms with lower yields are often situated in areas that have lower environmental quality. While areas with higher environmental quality are more interesting for conservation goals (Duke 2004). This could have a negative effect on the quality of native vegetation and therefore, on biodiversity, endemic species and other ecosystem services.

PES schemes could perhaps be of value in this case. PES schemes allow the targeting of local areas and therefore additional financial incentives can be supplied to farms that have areas of high environmental quality. Therefore the integration of PES schemes with the existing CRA market could be beneficial for the quality of the native vegetation. Carbon credits are unlikely to be of a beneficial additional effect in this, as carbon credits cannot be targeted locally. Furthermore carbon credits are unlikely to be of value due to the additionality principle that they must adhere to. If carbon credits would replace the CRA market than this could also increase LR. However, the effects are unlikely to be much more positive, because it would motivate farms to quickly sequester carbon, which leads to lower environmental quality as well.

Farm size consequences

The results from the ABM show that the medium sized farms tend to acquire the most LR. This is contradictory to the economics of scale principle. Under this principle the smallest farms would acquire the most LR and the largest farms would acquire the least, while the latter was certainly the case, under scenario 2, it is the medium-sized farms that acquire the most LR. This is somewhat of a u-shaped relation that is often encountered in the Brazilian agricultural sector (Rada, Helfand, and Magalhães 2019). The results show that the largest farms will offset most of their LR.

This could have implications for forest cover as this would mean that large areas of land will barely have any LR. This could create issues for the connectivity of forest cover, which in turn leads to habitat fragmentation and loss of biodiversity. In these regions of intensive agriculture protected areas could be beneficial for the forest connectivity (Rother et al. 2018). These protected areas could also be motivated through PES. Because PES schemes allow for the local addressing of issues it would be less likely that habitats would be fragmented. These PES schemes would need to provide additional income to these large farms, which will increase the connectivity of forest cover. However, it will also skew the market, as large farms already have the best market position this could be unfair to smallholders. Whether PES schemes adhere to the principle of additionality in this case, is questionable as the conservation of forest cover is the main goal of legal reserves.

Compliance

The increase in forest cover is only possible when there is enough compliance. The CRA price can only reach profitable levels for farms when there is enough demand for forest credits. The institutions that monitor and regulate the CRA market need to be strict in enforcement of the regulations. The earlier forest certificate trading market was not implemented due to lack of enforcement (Bernasconi et al. 2016). The CRA market can only drive the price for CRA to opportunity cost levels when there is enough risk involved with not adhering to the rules, set by the Brazilian government. Therefore the quality of institutions that enforce the CRA market is a key issue for the success rate of the CRA market. PES schemes and carbon credits on their own are unlikely to outperform the CRA market when it comes to compliance. This is due to the fact that the CRA market has consequences for not adhering to the LR threshold, while carbon credits and other PES schemes are voluntary. Replacement could only happen if carbon credits or PES schemes would generate more rewards than the opportunity costs, which under the current voluntary market will not happen for carbon credits. It is possible for PES schemes but this would probably me more complicated than the CRA market.

Revenue streams

With the increase in LR, there is an increase in revenue for the farms with LR. In fact, the CRA trade enables the agricultural market to flatten the profit discrepancies between different types of farms. This is mainly due to the concept of how the CRA price is developed. In the model the CRA price increases until the 20% LR threshold is met. This means that farms that have a production value, lower than the CRA price, will acquire more LR than other farms. Eventually the CRA price finds an equilibrium at the moment that the 20% LR threshold is met. The average observed CRA prices in the model are quite similar to the CRA prices observed in the real world, they range from a minimum of R$98 to a maximum of R$560 . César et al., found that the CRA price varied between R$61 to R$908 (2020).

As long as carbon credits are not allowed on the compliance markets there is no possibility for rewards higher than agricultural activities (Butler, Koh, and Ghazoul 2009). Therefore, under the current regulations, carbon credits cannot outperform the CRA market when it comes to rewards for increasing forest cover. PES schemes are completely dependent on specific situations and therefore could outperform the CRA market locally, in terms of monetary rewards, like in the watershed of São Paulo (Pissarra, Sanches Fernandes, and Pacheco 2021). Combining PES with CRA could be very beneficial locally, as this allows for specific goals to be met. Additionally, the compensation provided by PES would not have to be as high in conjuncture with CRA as without CRA.

Farms that can efficiently use the CRA market have lower restoration and transaction costs than less efficient farms. This can be a burden on the profits derived from trading LR. The transaction costs associated with these financial incentives are proportionally higher for smallholders (César, Barella, and Fonseca 2020) . This is an issue, with respect to poverty. Because, Small farms also have the highest poverty rates in Brazil (Helfand and Moreira 2015). These transaction costs will hinder the extra income they can obtain from LR. Carbon credits will have the same issues in terms of transaction and restoration costs. Therefore, it cannot replace the CRA market. PES schemes could be directed at smallholders in order to lower poverty rates.

Conclusion

Forest cover increases as a direct result of the CRA market. Reforestation to the 20% threshold is observed in all scenarios. Both land use and farms have a direct effect on the LR composition and corresponding revenue streams. Carbon credits cannot exceed the opportunity costs of farms, under current regulations. Therefore carbon credits cannot replace the CRA market as it will not have the desired effects on forest cover. PES schemes can provide additional forest cover through specific programs. However, these are mostly ran on a local scale and therefore will probably not have the desired effects on a national scale.

The first hypothesis stated that there will be a shift in legal reserves, such that smaller farms will obtain relatively more LR than larger farms. This statement was found to be untrue. The results from scenario 2 indicate that there is an U-shaped relation between farm size and production value, instead of a linear relation. The economics of scale principle therefore does not completely translate to farm sizes. Instead, small farms are more efficient when it comes to production value than medium sized farms. Nevertheless, small farms have higher poverty rates than medium sized farms.

The second hypothesis stated that land uses with higher profit margins per hectare will outcompete the other type of land uses, resulting in a shift of LR from higher profit margin land uses, to lower profit margin land uses. The results from scenario 1 agree with this statement. The results from the model show that on average sugar cane farms offsets their LR, because of the higher production value that sugar cane has. Subsequently, pastures and soy farms acquire more LR, as the CRA price is higher than their production values.

The third hypothesis stated that forest cover will increase, but not exceed the 20% LR threshold permanently. This statement was also found to be true. Legal reserves steadily increased in all scenarios until it reached the 20% LR threshold. Once this threshold was met, the CRA price and LR percentage entered a bimodality state. In this state, CRA price increased when LR was under 20%, resulting in more LR to be acquired. Once the LR was above 20%, CRA price decreased, resulting in LR to be offset.

The final hypothesis stated that alternatives to the CRA market can only be a viable replacement, if the compensation for opportunity costs are exceeded. This statement was found to be somewhat true, as the main motivation for farms is determined to be best foregone option, i.e. opportunity costs. Carbon credits does not exceed opportunity costs therefore is not a viable replacement. PES schemes can exceed opportunity costs locally and could therefore replace CRA locally, but probably not on a national scale.

The integration of carbon credits with the CRA market is not possible as this would counteract the additionality principle. The integration of PES schemes with the CRA market might be possible locally and could have specific benefits for forest cover and wealth distribution. Further research is required in order to determine the possibilities of integrating PES schemes with the CRA market. This is likely to grant the best results, in terms of forest cover, revenue streams and land quality. Therefore, future forest conservation policy could use the CRA market nationally with localized PES schemes in order to achieve national forest cover and specific local goals.

References

Adams, D M, R Alig, G Latta, and E M White. 2011. "Regional Impacts of a Program for Private Forest Carbon Offset Sales." *Journal of Forestry* 109 (8): 444–53. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84856682734&partnerID=40&md5=847520b8c95df3f430975d66c2249e96.

Ankersen, J, K Grogan, O Mertz, R Fensholt, J.-C. Castella, G Lestrelin, D T Nguyen, F Danielsen, S Brofeldt, and K Rasmussen. 2015. "Vietnam's Forest Transition in Retrospect: Demonstrating Weaknesses in Business-as-Usual Scenarios for REDD+." *Environmental Management* 55 (5): 1080–92. https://doi.org/10.1007/s00267-015-0443-y.

Arriagada, R A, P J Ferraro, E O Sills, S K Pattanayak, and S Cordero-Sancho. 2012. "Do Payments for Environmental Services Affect Forest Cover? A Farm-Level Evaluation from Costa Rica." *Land Economics* 88 (2): 382–99. https://doi.org/10.3368/le.88.2.382.

Ascenzi, Irene. 2021. "Forest Credits to Foster Reforestation in the Brazilian Atlantic Forest," 5–39.

Aza, A, F Riccioli, and F Di Iacovo. 2021. "Optimising Payment for Environmental Services Schemes by Integrating Strategies: The Case of the Atlantic Forest, Brazil." *Forest Policy and Economics* 125. https://doi.org/10.1016/j.forpol.2021.102410.

Bell, A R, T G Benton, K Droppelmann, L Mapemba, O Pierson, and P S Ward. 2018. "Transformative Change through Payments for Ecosystem Services (PES): A Conceptual Framework and Application to Conservation Agriculture in Malawi." *Global Sustainability* 1. https://doi.org/10.1017/sus.2018.4.

Bernasconi, Paula, Stefan Blumentrath, David N Barton, Graciela M Rusch, and Ademar R Romeiro. 2016. "Constraining Forest Certificate's Market to Improve Cost-Effectiveness of Biodiversity Conservation in São Paulo State, Brazil," 1–18. https://doi.org/10.1371/journal.pone.0164850.

Borrego, A, and M Skutsch. 2014. "Estimating the Opportunity Costs of Activities That Cause Degradation in Tropical Dry Forest: Implications for REDD." *ECOLOGICAL ECONOMICS* 101: 1–9. https://doi.org/10.1016/j.ecolecon.2014.02.005.

Butler, R A, L P Koh, and J Ghazoul. 2009. "REDD in the Red: Palm Oil Could Undermine Carbon Payment Schemes." *CONSERVATION LETTERS* 2 (2): 67–73. https://doi.org/10.1111/j.1755-263X.2009.00047.x.

César, Júlio, César Falcão Barella, and Alberto Fonseca. 2020. "Compensating Deforestation with Forest Surplus : Key Regulatory Issues within Brazil ' s Atlantic Forest." *Ecological Economics* 167 (September 2019): 106444. https://doi.org/10.1016/j.ecolecon.2019.106444.

Chukundah, Ruben Ekemeke. 2021. "Reforesting the Atlantic Forest through Forest Credits: An Agent Based Modelling Approach to the Effects of Land Use and Farm Size on Forest Cover." Utrecht University.

Clements, T, and E J Milner-Gulland. 2015. "Impact of Payments for Environmental Services and Protected Areas on Local Livelihoods and Forest Conservation in Northern Cambodia." *Conservation Biology* 29 (1): 78–87. https://doi.org/10.1111/cobi.12423.

Comin, Diego. 2010. "Total Factor Productivity." In *Economic Growth*, edited by S.N. Durlauf and L.E. Blume, 260–63. London: Palgrave Macmillan. https://doi.org/https://doi.org/10.1057/9780230280823_32.

CONAB. 2017. "Historical Yields." https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=30.

Crooks, Andrew T, and Alison J Heppenstall. 2012. “Introduction to Agent-Based Modelling.” In *Agent-Based Models of Geographical Systems*, edited by Alison J Heppenstall, Andrew T Crooks, Linda M See, and Michael Batty, 85–105. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-90-481-8927-4_5.

Duffy, Michael. 2009. “Economies of Size in Production Agriculture.” *Journal of Hunger & Environmental Nutrition* 4 (3–4): 375–92.

Duke, Joshua M. 2004. “Participation in Agricultural Land Preservation Programs: Parcel Quality and a Complex Policy Environment.” *Agricultural and Resource Economics Review* 33 (1): 34–49. https://doi.org/DOI: 10.1017/S1068280500005621.

Edwards, D P, B Fisher, and E Boyd. 2010. “Protecting Degraded Rainforests: Enhancement of Forest Carbon Stocks under REDD.” *CONSERVATION LETTERS* 3 (5): 313–16. https://doi.org/10.1111/j.1755-263X.2010.00143.x.

Engel, S, and A Muller. 2016. “Payments for Environmental Services to Promote ‘Climate-Smart Agriculture’? Potential and Challenges.” *Agricultural Economics (United Kingdom)* 47: 173–84. https://doi.org/10.1111/agec.12307.

FAO. 2012. “Brazil: The State of the World’s Forest Genetic Resources,” 7.

Fernando, James. 2020. “Opportunity Cost.” 2020. https://www.investopedia.com/terms/o/opportunitycost.asp.

Figueroa, F, Á Caro-Borrero, D Revollo-Fernández, L Merino, L Almeida-Leñero, L Paré, D Espinosa, and M Mazari-Hiriart. 2016. “‘I like to Conserve the Forest, but I Also like the Cash’: Socioeconomic Factors Influencing the Motivation to Be Engaged in the Mexican Payment for Environmental Services Programme.” *Journal of Forest Economics* 22: 36–51. https://doi.org/10.1016/j.jfe.2015.11.002.

Galik, C S, D M Cooley, and J S Baker. 2012. “Analysis of the Production and Transaction Costs of Forest Carbon Offset Projects in the USA.” *JOURNAL OF ENVIRONMENTAL MANAGEMENT* 112: 128–36. https://doi.org/10.1016/j.jenvman.2012.06.045.

Gene, E I. 2007. “The Profitability of Forest Protection versus Logging and the Role of Payments for Environmental Services (PES) in the Reserva Forestal Golfo Dulce, Costa Rica.” *FOREST POLICY AND ECONOMICS* 10 (1–2): 7–13. https://doi.org/10.1016/j.forpol.2007.01.001.

Grabowski, Z J, and R L Chazdon. 2012. “Beyond Carbon: Redefining Forests and People in the Global Ecosystem Services Market.” *Sapiens* 5 (1). https://www.scopus.com/inward/record.uri?eid=2-s2.0-84868308606&partnerID=40&md5=55c1cc294cf3397c3f15edcb4dc753c1.

Grieg-Gran, Maryanne, Ina Porras, and Sven Wunder. 2005. “How Can Market Mechanisms for Forest Environmental Services Help the Poor? Preliminary Lessons from Latin America.” *World Development* 33 (9): 1511–27. https://doi.org/https://doi.org/10.1016/j.worlddev.2005.05.002.

Hammond, R.A. 2015. “Considerations and Best Practices in Agent-Based Modeling to Inform Policy.” In *Assessing the Use of Agent-Based Models for Tobacco Regulation*, edited by R. Wallace, A Geller, and V.A. Ogawa. Washington: National Academies Press. https://www.ncbi.nlm.nih.gov/books/NBK305917/.

Helfand, Steven M, and Ajax R B Moreira. 2015. “Agricultural Productivity and Family Farms in Brazil : Creating Opportunities and Closing Gaps.”

Helfand, Steven M, Nicholas E Rada, and Marcelo M Magalhães. 2017. “Brazilian Agriculture: Is It All about the Large Farms?” *Agricultural Economics Society and European Association of*

Agricultural Economists 16 (1): 17–22. https://doi.org/10.1111/1746-692X.12145.

Hyams, Keith, and Tina Fawcett. 2013. “The Ethics of Carbon Offsetting.” *Wiley Interdisciplinary Reviews: Climate Change* 4 (2): 91–98. https://doi.org/10.1002/wcc.207.

IBGE. 2017. “Census of Agriculture.” https://www.ibge.gov.br/en/statistics/economic/agriculture-forestry-and-fishing/21929-2017-2017-censo-agropecuario-en.html?edicao=25839&t=resultados.

Indira Devi, P, L Kumar, D Suresh Kumar, M Manjula, P Mukhopadhyay, P Raghu, D Sharma, R Sridhar, and L Venkatachalam. 2017. “Payment for Ecosystem Services Guaranteed Farm Income and Sustainable Agriculture.” *Economic and Political Weekly* 52 (17): 12–14. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85018249690&partnerID=40&md5=c52ef8277ad6e2ada4f271a6f168f025.

Izquierdo-Tort, S, F Ortiz-Rosas, and P A Vázquez-Cisneros. 2019. “‘Partial’ Participation in Payments for Environmental Services (PES): Land Enrolment and Forest Loss in the Mexican Lacandona Rainforest.” *Land Use Policy* 87. https://doi.org/10.1016/j.landusepol.2019.04.011.

Latta, G, D M Adams, R J Alig, and E White. 2011. “Simulated Effects of Mandatory versus Voluntary Participation in Private Forest Carbon Offset Markets in the United States.” *Journal of Forest Economics* 17 (2): 127–41. https://doi.org/10.1016/j.jfe.2011.02.006.

Loomis, John, Craig Bond, and David Harpman. 2008. “The Potential of Agent-Based Modelling for Performing Economic Analysis of Adaptive Natural Resource Management The Potential of Agent-Based Modelling for Performing Economic Analysis of Adaptive Natural Resource Management.” *Journal of Natural Resources Policy Research* 1 (1): 35–48. https://doi.org/10.1080/19390450802509773.

Lu, H, and G Liu. 2015. “Opportunity Costs of Carbon Emissions Stemming from Changes in Land Use.” *Sustainability (Switzerland)* 7 (4): 3665–82. https://doi.org/10.3390/su7043665.

Manasboonphempool, A, F M Milan, and M Zeller. 2015. “Transaction Costs of Farmers’ Participation in Forest Management: Policy Implications of Payments for Environmental Services Schemes in Vietnam.” *Journal of Agriculture and Rural Development in the Tropics and Subtropics* 116 (2): 199–211. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84948776716&partnerID=40&md5=c7d67f90c74d93a587767d29424ff4f2.

Moher, David, Alessandro Liberati, Jennifer Tetzlaff, and Douglas G Altman. 2009. “Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement.” *BMJ* 339 (b2535). https://doi.org/10.1136/bmj.b2535.

Motel, P C, R Pirard, and J L Combes. 2009. “A Methodology to Estimate Impacts of Domestic Policies on Deforestation: Compensated Successful Efforts for ‘Avoided Deforestation’ (REDD).” *ECOLOGICAL ECONOMICS* 68 (3): 680–91. https://doi.org/10.1016/j.ecolecon.2008.06.001.

Müller, D, Z Sun, T Vongvisouk, D Pflugmacher, J Xu, and O Mertz. 2014. “Regime Shifts Limit the Predictability of Land-System Change.” *Global Environmental Change* 28 (1): 75–83. https://doi.org/10.1016/j.gloenvcha.2014.06.003.

Neudert, R, K Olschofsky, D Kubler, L Prill, M Kohl, and F Watzold. 2018. “Opportunity Costs of Conserving a Dry Tropical Forest under REDD plus : The Case of the Spiny Dry Forest in Southwestern Madagascar.” *FOREST POLICY AND ECONOMICS* 95: 102–14. https://doi.org/10.1016/j.forpol.2018.07.013.

Newton, P, E S Nichols, W Endo, and C A Peres. 2012. “Consequences of Actor Level Livelihood Heterogeneity for Additionality in a Tropical Forest Payment for Environmental Services

Programme with an Undifferentiated Reward Structure.” *Global Environmental Change* 22 (1): 127–36. https://doi.org/10.1016/j.gloenvcha.2011.10.006.

Oliveira Fiorini, Ana Carolina, Marilyn Swisher, and Francis E Putz. 2020. “Payment for Environment Services to Promote Compliance with Brazil’s Forest Code: The Case of ‘Produtores de Água e Floresta.’” *Sustainability* 12 (19). https://doi.org/10.3390/su12198138.

Parlinah, N, B Nugroho, M B Saleh, and Hendrayanto. 2018. “Possibility of Harnessing Social Capital to Support the Development of Payment for Environmental Services in Small-Scale Forests: A Case of Jatigede Catchment Area.” *Jurnal Manajemen Hutan Tropika* 24 (2): 70–80. https://doi.org/10.7226/jtfm.24.2.70.

Pereira, S N C. 2010. “Payment for Environmental Services in the Amazon Forest: How Can Conservation and Development Be Reconciled?” *JOURNAL OF ENVIRONMENT & DEVELOPMENT* 19 (2): 171–90. https://doi.org/10.1177/1070496510368047.

Pinto, Severino R, Felipe Melo, Marcelo Tabarelli, Aurélio Padovesi, Helena Carrascosa, Miguel Calmon, Ricardo Rodrigues, and Ricardo Gomes César. 2014. “Governing and Delivering a Biome-Wide Restoration Initiative: The Case of Atlantic Forest Restoration Pact in Brazil,” no. September: 2212–29. https://doi.org/10.3390/f5092212.

Pissarra, T C T, L F Sanches Fernandes, and F A L Pacheco. 2021. “Production of Clean Water in Agriculture Headwater Catchments: A Model Based on the Payment for Environmental Services.” *Science of the Total Environment* 785. https://doi.org/10.1016/j.scitotenv.2021.147331.

Rada, Nicholas, Steven Helfand, and Marcelo Magalhães. 2019. “Agricultural Productivity Growth in Brazil : Large and Small Farms Excel.” *Food Policy* 84 (April 2018): 176–85. https://doi.org/10.1016/j.foodpol.2018.03.014.

Rasmussen, S. 2013. “Economies of Scale and Size.” In *Production Economics*, 111–20. Berlin: Springer, Berlin, Heidelberg. https://doi.org/https://doi.org/10.1007/978-3-642-30200-8_11.

Rother, C, Cristina Y Vidal, Isabella C Fagundes, Metran Silva, Sergius Gandolfi, Ricardo R Rodrigues, G Nave, Ricardo Augusto G Viani, and Pedro H S Brancalion. 2018. “How Legal-Oriented Restoration Programs Enhance Landscape Connectivity ? Insights From the Brazilian Atlantic Forest.” https://doi.org/10.1177/1940082918785076.

Santos, David Ferreira Lopes, Camila Aparecida Fonseca Souza, Juliana Borba de Moraes Farinelli, Bruna Luísa da Silva, and Kandy Horita. 2018. “ANÁLISE ECONÔMICA DA PRODUÇÃO DE CANA-DE-AÇÚCAR EM DIFERENTES PACOTES TECNOLÓGICOS.” *Revista Estudo & Debate* 25 (2): 262–83. https://doi.org/http://dx.doi.org/10.22410/issn.1983-036X.v25i2a2018.1816.

Santos, Luan, Rafael Garaffa, André F.P. Lucena, and Alexandre Szklo. 2018. “Impacts of Carbon Pricing on Brazilian Industry: Domestic Vulnerability and International Trade Exposure.” *Sustainability (Switzerland)* 10 (7). https://doi.org/10.3390/su10072390.

Sapkota, Y, and J R White. 2020. “Carbon Offset Market Methodologies Applicable for Coastal Wetland Restoration and Conservation in the United States: A Review.” *Science of the Total Environment* 701. https://doi.org/10.1016/j.scitotenv.2019.134497.

Sparovek, Gerd, Alberto Giaroli, and De Oliveira Pereira. 2011. “The Revision of the Brazilian Forest Act : Increased Deforestation or a Historic Step towards Balancing Agricultural Development and Nature Conservation ?” *Environmental Science & Policy* 16 (February 2012): 65–72. https://doi.org/10.1016/j.envsci.2011.10.008.

Steur, Gijs, René W Verburg, Martin J Wassen, and Pita A Verweij. 2020. “Shedding Light on

Relationships between Plant Diversity and Tropical Forest Ecosystem Services across Spatial Scales and Plot Sizes." *Ecosystem Services* 43: 101107. https://doi.org/https://doi.org/10.1016/j.ecoser.2020.101107.

Swallow, B M, and T W Goddard. 2013. "Value Chains for Bio-Carbon Sequestration Services: Lessons from Contrasting Cases in Canada, Kenya and Mozambique." *Land Use Policy* 31: 81–89. https://doi.org/10.1016/j.landusepol.2012.02.002.

Tavares, Paulo A, Alice Dantas Brites, Gerd Sparovek, Vinicius Guidotti, Felipe Cerignoni, Daniel Aguiar, Jean Paul Metzger, et al. 2019. "Unfolding Additional Massive Cutback Effects of the Native Vegetation Protection Law on Legal Reserves , Brazil." *Biota Neotropica* 19 (4). https://doi.org/10.1590/1676-0611-bn-2018-0658.

Thangata, P H, and P E Hildebrand. 2012. "Carbon Stock and Sequestration Potential of Agroforestry Systems in Smallholder Agroecosystems of Sub-Saharan Africa: Mechanisms for 'reducing Emissions from Deforestation and Forest Degradation' (REDD+)." *Agriculture, Ecosystems and Environment* 158: 172–83. https://doi.org/10.1016/j.agee.2012.06.007.

Tisue, Seth, and Uri Wilensky. 2004. "NetLogo : A Simple Environment for Modeling Complexity," 1–10.

Vermunt, Dorith A., Pita A. Verweij, and René W. Verburg. 2020. "What Hampers Implementation of Integrated Landscape Approaches in Rural Landscapes?" *Current Landscape Ecology Reports* 5 (4): 99–115. https://doi.org/10.1007/s40823-020-00057-6.

West, T A P, J J Monge, L J Dowling, S J Wakelin, and H K Gibbs. 2020. "Promotion of Afforestation in New Zealand's Marginal Agricultural Lands through Payments for Environmental Services." *Ecosystem Services* 46. https://doi.org/10.1016/j.ecoser.2020.101212.

Wunder, S. 2006. "Are Direct Payments for Environmental Services Spelling Doom for Sustainable Forest Management in the Tropics?" *Ecology and Society* 11 (2). https://doi.org/10.5751/ES-01831-110223.

Xiao, Yu, and Maria Watson. 2019. "Guidance on Conducting a Systematic Literature Review." *Journal of Planning Education and Research* 39 (1): 93–112. https://doi.org/10.1177/0739456X17723971.

Appendix 1

Due to the length of the table, the SLR catalogue is available at supervisors.