Can We Reverse the Atmospheric CO_2 Concentration Trend Using Cooperation?: Model-based Management for Effective Cooperation.

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Abstract

The reversibility of the effects of Green-house gases is highly discussed by scholars nowadays. We tested whether cooperation mechanisms are efficient at overturning the current CO_2 concentration trend in the atmosphere. We approach the problem as a large-scale social dilemma. We developed a system dynamics model to find the conditions required to achieve effective cooperation that may contribute to reverse the current CO_2 concentration trend. Simulation experiments show that initial conditions of trust and information delays are determinant to attain cooperation in the direction of reducing the CO_2 concentration trend.

Key words: CO_2 Crisis, Green House Gases Crisis, Cooperation, Social Dilemmas, Mechanism, Large-Scale Situations, Dependence to Initial Conditions, Dynamic Complexity.

1 Introduction

Social dilemmas are conflicts between collective best interests and individual rationality (Kollock, 1998). Such conflicts may affect the performance of groups to manage shared resources (Ostrom, 2000) and the capability of humanity to keep a sustainable use of large-scale resources like the atmosphere (Buck, 1998). A short-term individualistic rationality could produce over-exploitation, pollution and reduce the availability of common resources. However, people can mitigate and avoid this situation. The availability of common resources depends on the way that people resolve such dilemmas.

Human groups face the problem of common-resource conservation. The conservation of common resources offers situations of social dilemma (Hardin, 2009, 1243) that sometimes lead to over-exploitation and pollution (Ostrom, 1990, 27). There are three possible ways to solve social dilemmas: cooperation (Ostrom, 1990), private rights (Smith, 1981), markets (Voogt et al., 2000; Morthorst, 2000), and the enforcement by an external agent (the state) (Hardin, 2009, 1243). Private rights and markets have shown problems when they are used in situations of large-scale dilemmas (Ostrom, 1990, 33). Because these alternatives are not always feasible options in large-scale social dilemmas, we are going to focus our work on cooperation. Over-pollution, as a consequence of a social dilemma, can be avoided if individuals cooperate to reduce their pollution (Ostrom et al., 2002, 3). However, individuals could decide not cooperate and reduce polluting at the level required to sustain the common resources. If individuals follow their own interest in this situation, they will drive the situation collectively,and they will deplete common resources (Schlager, 2002, 801).

1.1 Cooperation as an alternative to solve large-social dilemmas

Cooperation is then an alternative feasible solution to confront small-scale social dilemmas (Ostrom and Walker, 2005; Ostrom et al., 2002; Ostrom, 2000). In both laboratory (Ostrom et al., 1994) and field (Cardenas and Ostrom, 2004) settings, cooperation is promoted and sustained using a mechanism based on trust (Ostrom, 2000). Contemporary theories of collective action consider that cooperation is possible because of the possibility of communication. Individuals develop a reputation of cooperation from past encounters that enable new cooperation (Ostrom, 2000, 12). In the principles of rational decision making for collective action on commons resources, Elinor Ostrom offers a frame to explain cooperation based on trust. This frame of reputation, reciprocity, and trust is built around causal relationships which define the core of cooperation. This core drives the change of cooperation according to initial conditions defined by situational variables (Ostrom, 2000, 13).

Contemporary cooperation theories suggest auto-regulation as a way to deal with social dilemmas. Ostrom (2000, 11) developed her theory of cooperation for small-scale resource social dilemmas to specific conditions:

- There is face to face communication.
- Agreements are possible and enforceable.

- Groups have few members.
- Members have similar characteristics.
- There is perfect information about the state of the resource and the results of others' actions.

These conditions are met by small-scale social dilemmas, but are not met by large-scale ones.

People confront large-scale resource problems that could be considered social dilemmas. The gains of the selfish are higher than those of the non-selfish. However, everybody is worse off if the majority acts selfishly. Traffic jams, electricity crises, Internet congestion, climate change, and many others can be explained as social dilemmas (Buck, 1998, 8).

Large-scale resource social dilemmas have special conditions. We can offer some characteristics based on Markóczy (2007, 1931):

- There is no face to face communication, but there is some kind of information about the state of the resource and others' actions.
- Agreements are possible and enforceable.
- Groups have a lot of members.
- Members do not have similar characteristics.
- There is not perfect information about the state of the resource and the results of others' actions.
- There is dynamic complexity.

1.2 CO_2 crisis

Most documented explanations about Climate Change claim that the Green-house effect strongly influences temperature (Intergovernmental Panel on Climate Change-IPCC, 2007, 93). Greenhouse gases (GHGs) like CO_2 have been increased mainly because of industrial activity. This causes the atmosphere to retain heat (Intergovernmental Panel on Climate Change-IPCC, 2007, 95). As a globally shared resource, the climate is vulnerable to social dilemmas. Although people can immediately benefit from increasing CO_2 gas emissions, the delayed effects will be more damaging (Ostrom et al., 2002; Buck, 1998). To reduce the concentration of greenhouse gases, emissions must fall below the rate at which GHGs are removed from the atmosphere. However, people do not understand the dynamics of the climate change (Sterman and Sweeney, 2002, 207). Figure 1 shows data for CO_2 measured at Manua Loa, Hawaii (Tans, 2010). This behavior is explained as a consequence of the accumulation of CO_2 in the atmosphere, which occurs because emissions are higher than the system's ability to capture CO_2.

1.3 Reversibility of the Atmospheric CO_2 Concentration Trend.

Current scholarly debate about the reversibility of climate change has many uncertainties (Stern et al., 2006). Solomon et al. (2009) show that the climate change due to

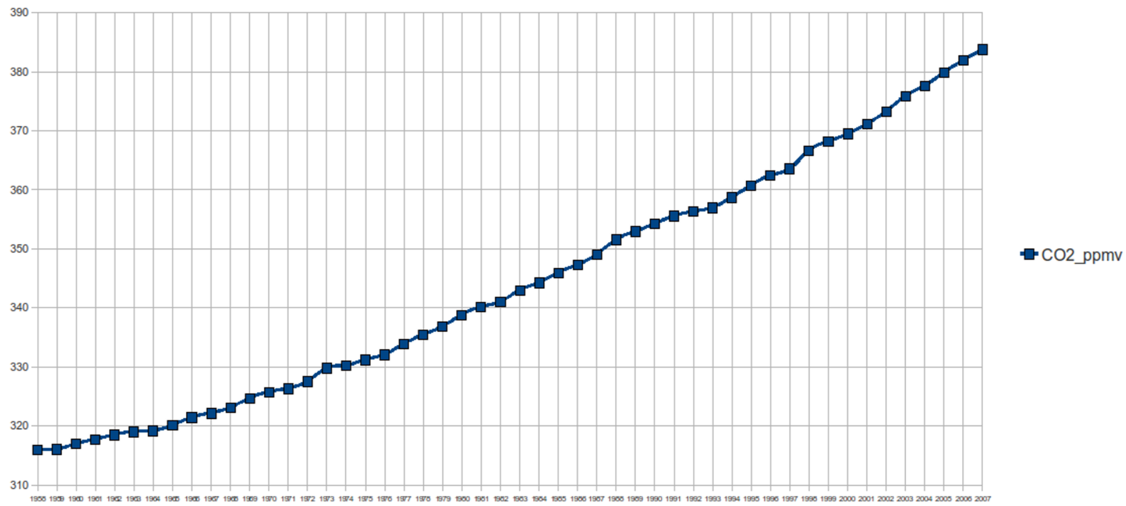

Figure 1: CO_2 Data measured at Manua Loa, Hawaii (Tans, 2010)

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increases in carbon dioxide concentration will be irreversible for 1,000 years after emissions stop. They also suggest that atmospheric temperatures will not drop significantly for at least 1,000 years (Solomon et al., 2009). Some other common irreversible effects will be dry-season rainfall reductions in several regions and sea level elevation (Solomon et al., 2009). Some other impacts will be the melting of permafrost, which could release huge quantities of methane and promote feedback that could lead to a global warming much greater than current projections (Stern et al., 2006). However, we did not find any research exploring the capacity of cooperation to reverse the carbon dioxide concentration. Literature suggests 350 ppmv is the highest level to preserve the planetary conditions necessary to support life, but they do not suggest how to stabilize this level (Hansen et al., 2008).

1.4 Preliminary Obstacles to Cooperation for Reversing the CO_2 Crisis

We found two problems that a manager should solve to reverse the CO_2 crisis using cooperation:

- The initial trust will be insufficient to promote and sustain cooperation (Castillo and Saysel, 2005).
- The delayed effect of past cooperative actions will discourage future cooperation (Sterman, 2000).

The insufficient initial trust to promote and sustain cooperation is a problem because of the kind of feedback loop that defines the core relationship of the mechanism based on cooperation and trust. A dynamic version of the mechanism based on trust is presented in Figure 2. Trust promotes reciprocity. Later, reputation is affected by

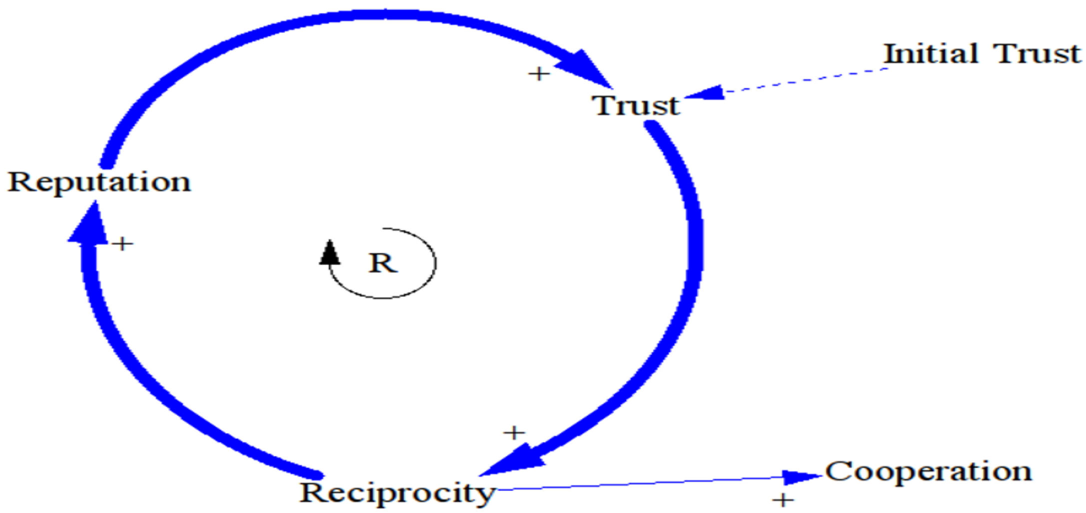

Figure 2: Dynamic mechanism of cooperation based on trust. This is our interpretation based in Ostrom (2000) and Castillo and Saysel (2005).

reciprocity. More reciprocity strengthens reputation and increases cooperation. Finally, reputation improves trust. In terms of dynamics, the initial conditions for trust affect the performance of cooperation as explained by these core variables (trust, reputation, and cooperation). These variables are joined in a feedback loop that reinforces any initial condition (Sterman, 2000). This is the case with the mechanism of cooperation based on trust which exhibits dependence on initial conditions (Castillo and Saysel, 2005).

Figure 3 presents how initial conditions drive trust. We performed a sensitivity analysis for initial conditions of trust. This analysis consisted of 200 simulations using initial values of trust between 0 and 10 based on the uniform probability distribution. Figure 3 shows how initial conditions of trust affect the resulting performance of trust because this mechanism is constituted of a reinforced feedback loop. To be effective, cooperation requires a minimum value of initial trust.

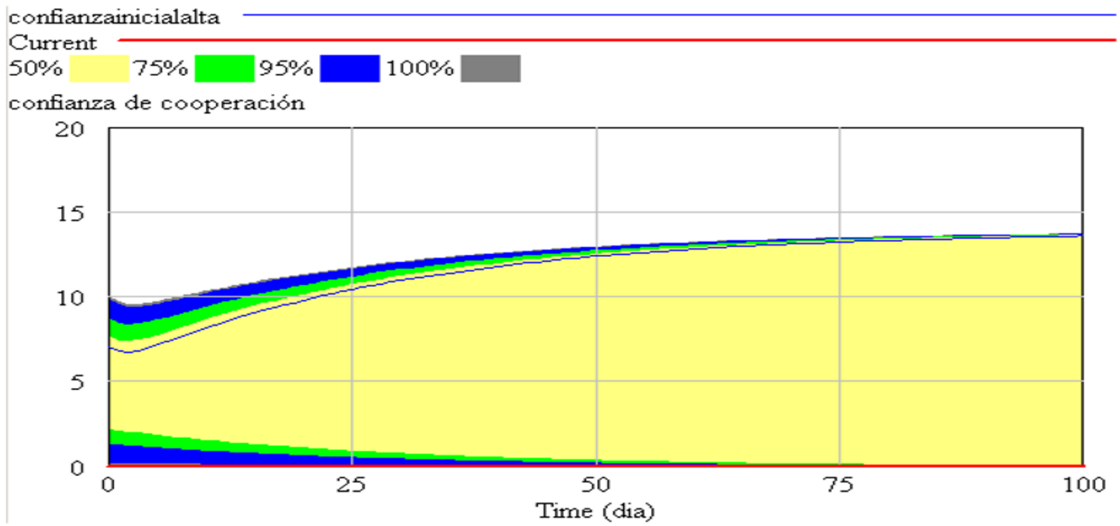

Figure 3: Dependence on initial conditions of trust. This sensitivity analysis presents confidence spaces for the mechanism of cooperation based on trust in a model for cooperation in energy provision for households.

Dependence on initial conditions of trust is a problem for managers because they do not know if the initial trust is enough to promote cooperation. Then they are not able to assure the effectiveness of cooperating to reverse the CO_2 crisis. Therefore, the mechanism of trust is insufficient to promote, assure, and sustain cooperation for all possible initial conditions. Additionally, there is disagreement about whether managers can apply cooperation based on trust to large-scale social situations (McGinnis and Ostrom, 2008) or not (Biel et al., 1999). The mechanism of cooperation based on trust was developed to meet the conditions of small-scale social dilemmas[1].

The core relationship of the mechanism based on trust supposes another problem for reversing the CO_2 crisis: the delayed effect of past cooperative actions will discourage future cooperation. According this mechanism, people require information about past cooperation effects to decide whether to make new cooperative actions. Because of the long life-time of CO_2 in the atmosphere, we will not see the results of cooperation in the short term. There is a debate about the residence time of CO_2 in the atmosphere with possible implications in policy design. The debate is defined by whether the residence time is above or below 10 years (Essenhigh, 2009). A larger residence time supposes more difficulties to enhance and sustain cooperation for reversing the CO_2 crisis.

In this paper, we test the effectiveness of cooperation to reverse the CO_2 crisis in a large-scale social dilemma using additional mechanisms combined with cooperation based on trust. To test this claim, firstly we developed a simulation model of the CO_2 crisis. Secondly, we designed and tested a construct to assure effective cooperation for reversing that CO_2 crisis. Finally, we developed a simulation model that integrates a

[1]We assume a small-scale social dilemma is a conflict between individual and collective rationality which is faced by no more than 10 people. This definition is compatible with the definitions proposed by Kollock (1998) and Ostrom (2000).

representation of accumulation of CO_2 in the atmosphere. The model explains how the construct could reduce the accumulation of CO_2. We are going to explain how our mechanism is able to deal with both initial dependence on trust and the delayed results of cooperation to assure the possibility for reversing the increasing trend of the CO_2.

2 Method

The steps we followed to develop the construct and model the case were:

- To develop a dynamic hypothesis that explains how mechanisms can promote and sustain cooperation.
- To model the CO_2 crisis as a large-scale social dilemma.
- To simulate experiments to test the reversibility of the concentration of GHGs through cooperation.

We use system dynamics guidelines (Sterman, 2000; Forrester, 1961) to develop our construct as a dynamic hypothesis and to apply it for modeling the concentration of CO_2 in the atmosphere and the effect of the mechanisms for promoting cooperation. We developed the model using Vensim 5.7 for Windows.

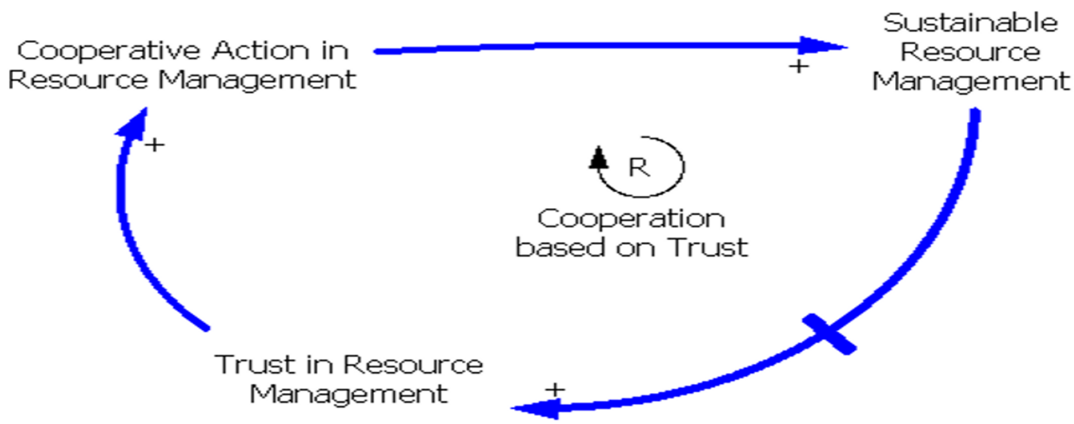

Figure 4: Mechanism of cooperation based on trust as a component of the proposed construct.

3 Results

Firstly, we present the construct that defines our claim about how cooperation mechanisms can reverse the CO_2 crisis. Then, we explain a model that represents the CO_2 crisis. Finally, we present simulation experiments that support our dynamic hypothesis.

3.1 The Construct

We define a construct as a structure that combined mechanisms to promote a social objective (Elster, 1989; Maskin, 2008). Our construct integrates three mechanisms: cooperation based on trust, cooperation as a norm, and cooperation as perception of damage. Figure 4 presents the mechanism of cooperation based on trust. This mechanism is defined by a reinforced feedback loop as explained before. This means that every change in a variable present in this kind of feedback loop is also reinforced. This feedback loop presents dependence on initial conditions. An increase of trust in resource management promotes cooperation in resource management, therefore achieving a sustainable use of the resource. This feedback loop is based on Ostrom (2000).

Figure 5 presents the mechanism of cooperation based on trust integrated with the mechanism of cooperation as a norm. This part of the construct suggests that people can learn to cooperate in the long term because they learn to cooperate in the short term. An increase in cooperative actions promotes learning about resource management that improves the resource's sustainability. This learning allows us to assume cooperation as a norm. This mechanism is inspired by Biel et al. (1999).

Figure 6 presents the mechanism of cooperation as a perception of damage incorporated into the construct. A perception of a lack of sustainable resource management leads to an expectancy of scarcity. This expectancy creates an improvement in the sustainability of resource management. This mechanism consists of a balance feedback loop. This means that a change in one variable in the feedback loop is compensated by an opposite

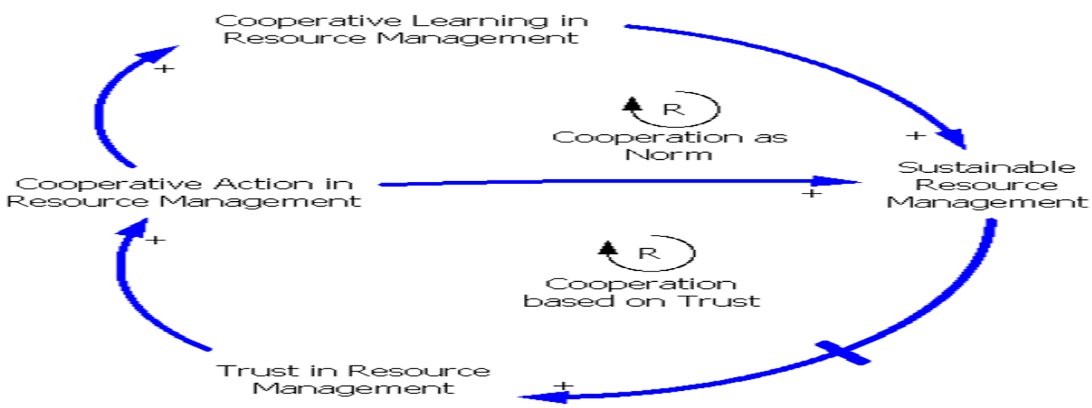

Figure 5: Mechanism of cooperation as a norm with cooperation based on trust.

change in the other variable. This mechanism is inspired by Schelling (1958).

Figure 7 presents the construct as a united configuration of mechanisms which promote and sustain cooperation in large-scale social dilemmas. This construct is based on a general structure proposed by Parra (2010). All mechanisms allow community members to confront the temptation to free ride. Free riding is represented by a feedback loop of balance. An increase in the availability of the resource produces free riding which feeds back to decrease the sustainable resource management. Our construct suggests a configuration of mechanisms which are able to face social dilemmas with effective cooperation. Finally, we present the model which was developed to test the ability of these mechanisms to promote cooperation in the CO_2 crisis.

We proposed our dynamic hypothesis as an expression of the mechanism for cooperation for large-scale resource social dilemmas. In Figure 8 we claim that people will only recognize a threat of damage about climate and the emission of GHG if they find a strong relationship between the emission of GHG and the extreme effects of global warming. Only this recognition will produce enough pressure to reduce emissions in the short term.

3.2 The Simulation Model

We developed a simulation model to test the proposed mechanisms. The model is a system of differential equations. The general structure of the model is presented in Figure 9. This structure is formed by the mechanisms presented previously.

We present a separate configuration for each mechanism. Figure 10 presents the differential equation for recognition of danger which is accumulated by the awareness of an increase in the concentration of CO_2. This recognition suffers depreciation because of its defined lifetime. The longer the lifetime, the better we are able to sustain cooperation with this mechanism.

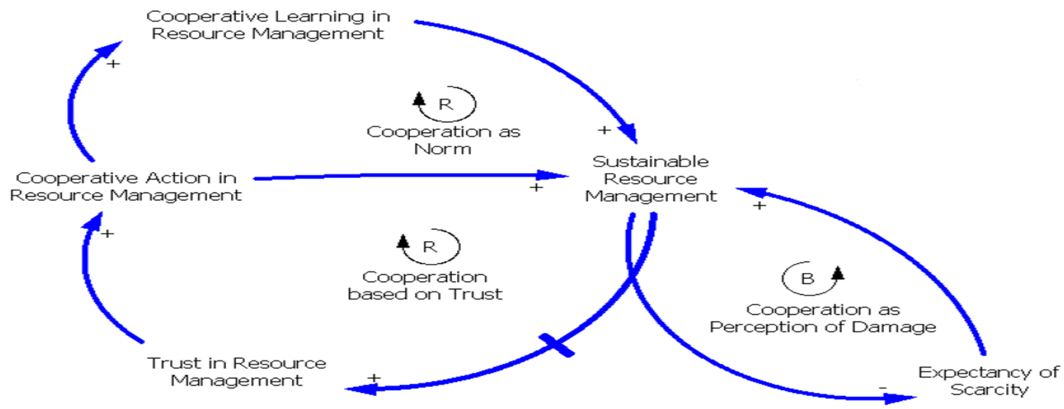

Figure 6: Mechanism of cooperation based on a perception of damage.

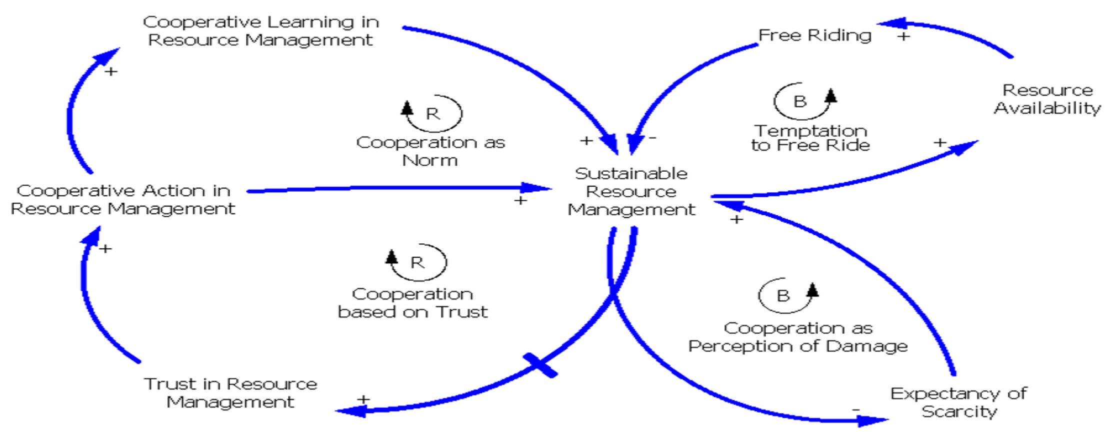

Figure 7: Free riding and mechanisms of cooperation.

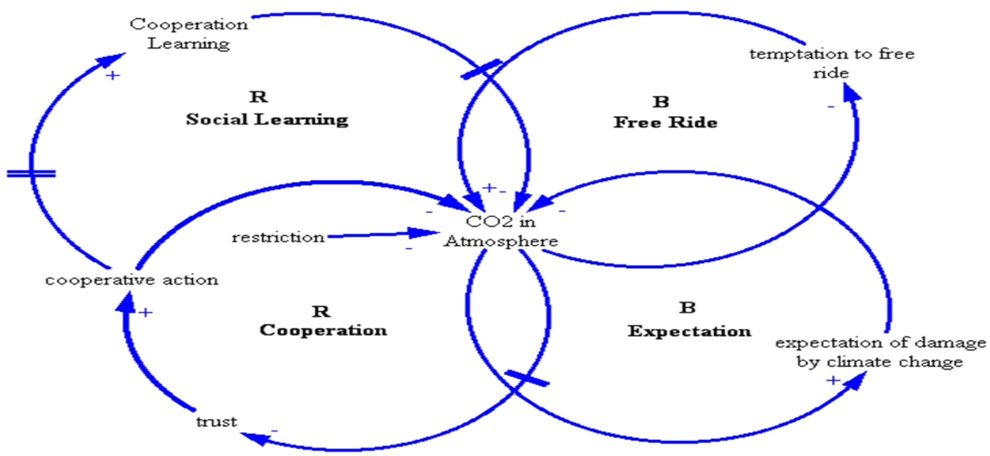

Figure 8: Dynamic hypothesis about how cooperation could contribute to reduce CO_2 concentration in the atmosphere.

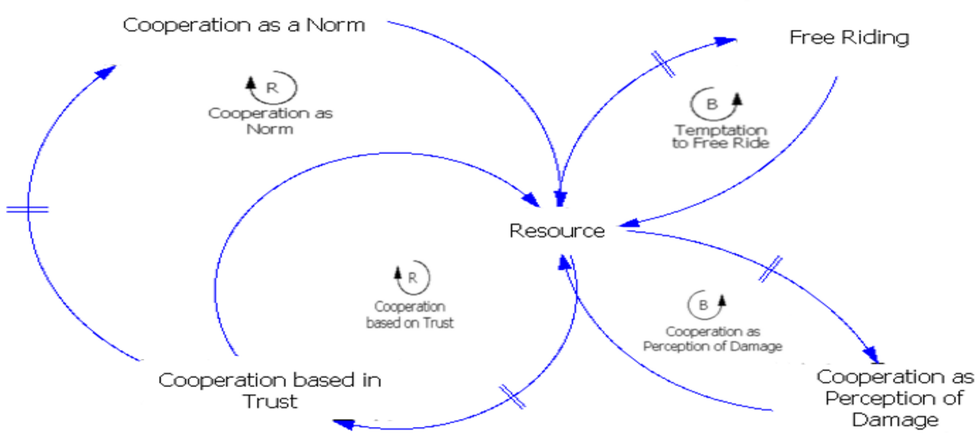

Figure 9: General structure for the model.

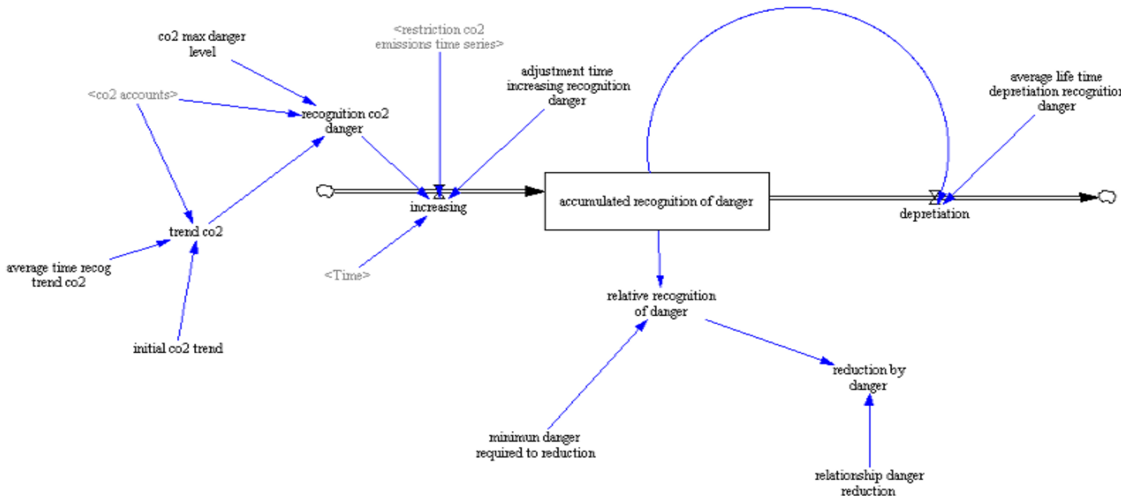

Figure 10: Structure for perception of danger.

Figure 11 presents the structure for the temptation to free ride. If the concentration of CO_2 is reduced, then the temptation to free ride is increased. The level of temptation to free ride depends on lifetime.

Figure 12 presents the structure for trust. Cooperation is measured by the improvements made to reduce the CO_2 concentration. The perception of this reduction is accumulated in the differential equation as trust. This trust is depleted according to a lifetime. The larger lifetime, the longer trust is sustained.

Figure 13 presents the structure for the CO_2 concentration. We suppose emissions are accumulated in the atmosphere. Due to nature's process, the C in CO_2 is captured according to its lifetime in the atmosphere. The larger the lifetime, the greater the climate change effects.

3.3 Simulation Experiments

Figure 14 presents the results for a simulation experiment. We defined the value for the social objective in 315 ppmv for CO_2 in the atmosphere. Then, we assumed the concentration of CO_2 for 2010 as an initial value for the simulation. Later, we tested if the mechanisms inside the construct were able to promote and sustain cooperation in order to achieve the social objective proposed below. The simulated results support our dynamic hypothesis.

Each mechanism has predominance in a specific period of time. Figure 15 shows the predominance of cooperation as perception of damage. In this simulation, the perception of damage solves the exponential growth of CO_2, because this mechanism allows us to promote cooperation even if the initial condition for trust is zero. This assures enough initial trust to develop cooperation based on trust.

Figure 16 presents the zone of predominance for cooperation based on trust. This kind of cooperation, which will be learned as a norm, will allow us to achieve the goal

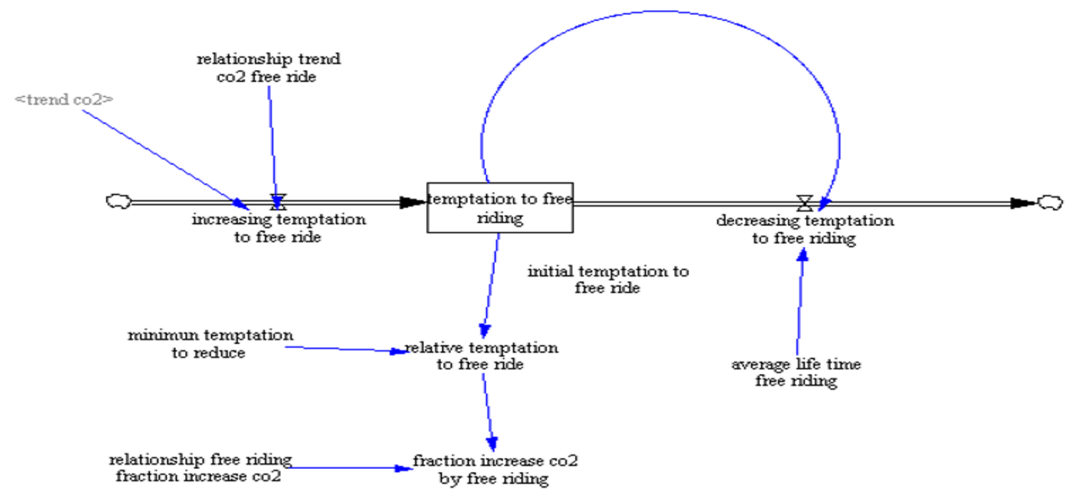

Figure 11: Structure for temptation to free ride.

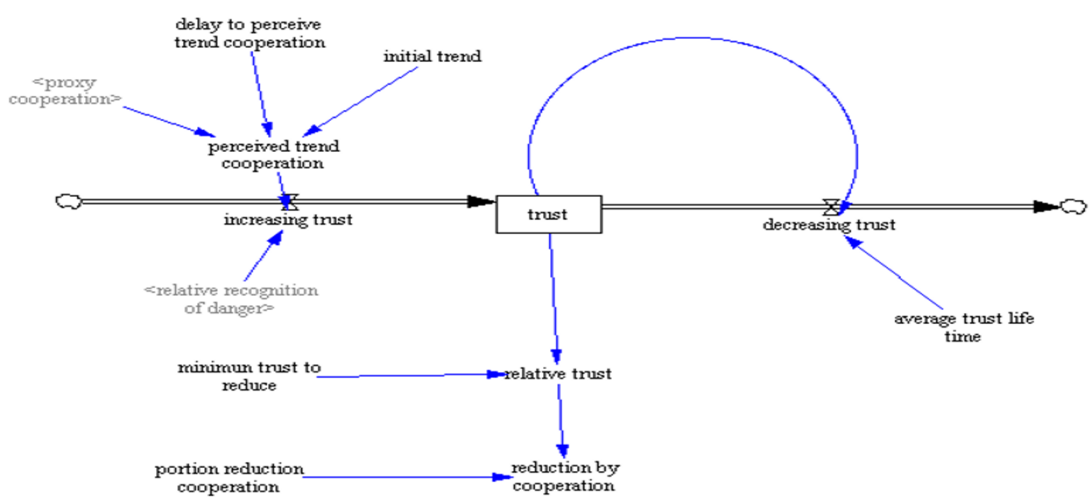

Figure 12: Structure for trust.

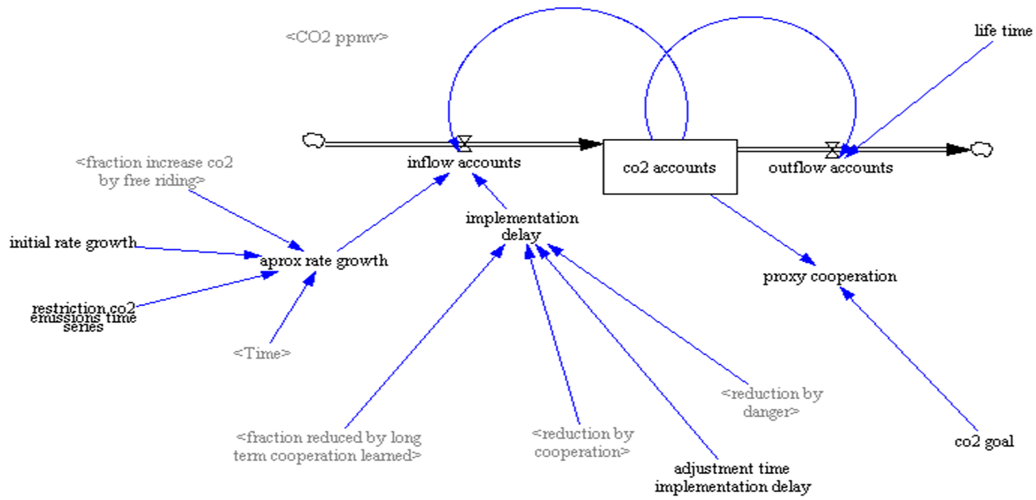

Figure 13: Structure for the CO_2 basic dynamics.

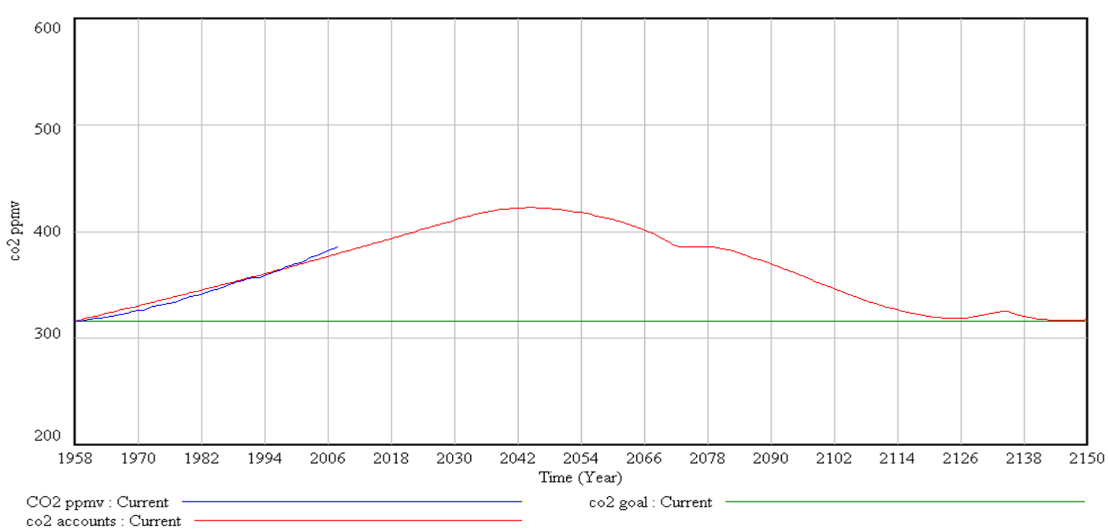

Figure 14: Simulated behavior for CO_2 under a treatment based on mechanisms for promoting cooperation in red. CO_2 data by Tans (2010) is presented in blue.

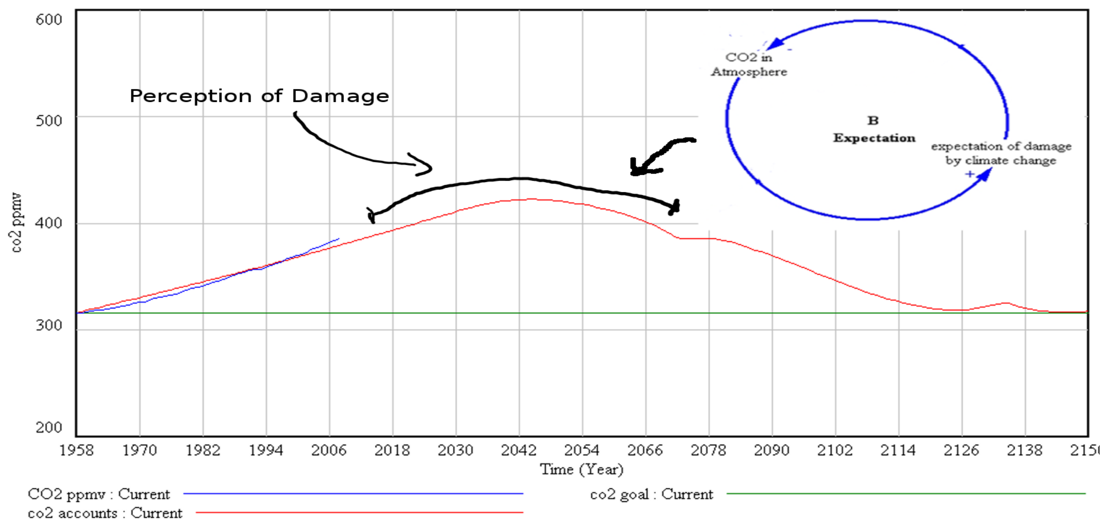

Figure 15: Simulated behavior for CO_2 under a treatment based on mechanisms for promoting cooperation. The predominance for cooperation as perception of damage is presented in red. CO_2 data by Tans (2010) is in blue.

of 315 ppmv for CO_2 in the atmosphere.

Figure 17 presents how cooperation as a norm controls CO_2 in the long term.

3.4 Sensitivity Analysis

We performed a sensitivity analysis to test if small changes in the average lifetime for cooperation as perception of damage could produce more than proportional changes in cooperation. We made 200 simulations defining lifetime values from 5 to 33 years. Figure 18 presents the dynamic confidence bounds for the sensitivity analysis for CO_2. The longer the lifetime in cooperation as perception of damage, the more CO_2 is reduced.

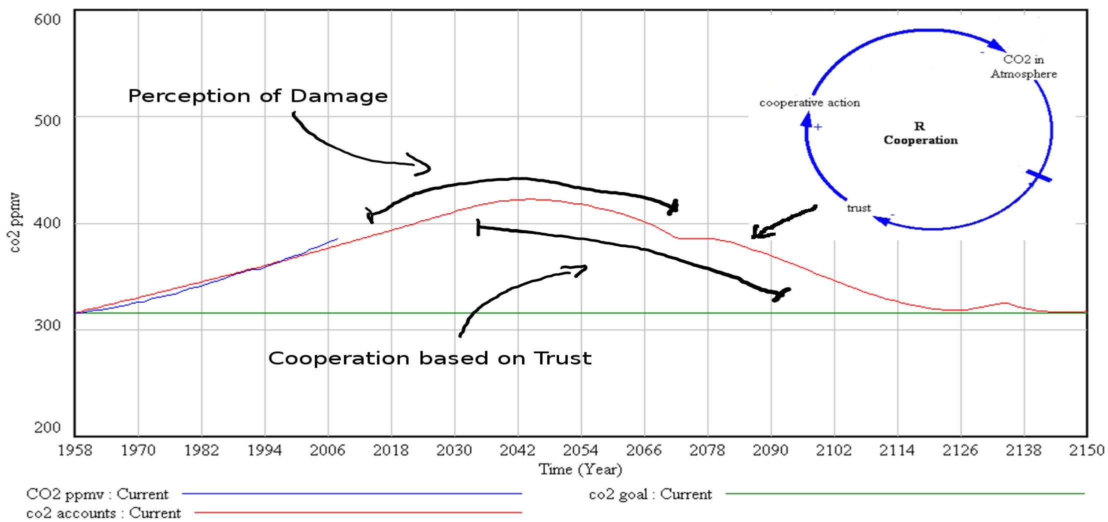

Figure 16: Simulated behavior for CO_2 under a treatment based on mechanisms for promoting cooperation. The predominance for cooperation based on trust is presented in red. CO_2 data by Tans (2010) is in blue.

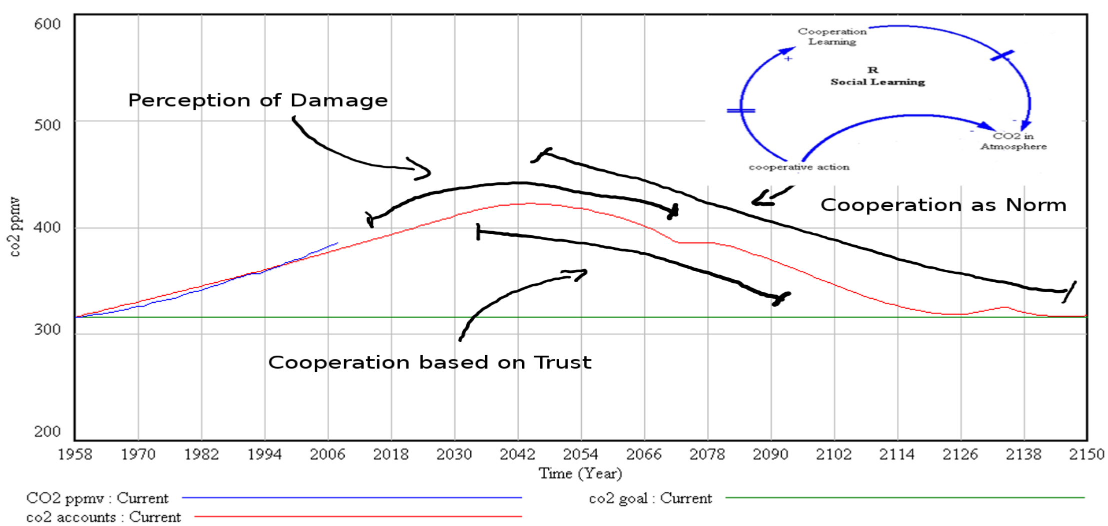

Figure 17: Simulated behavior for CO_2 under a treatment based of mechanisms for promoting cooperation. The predominance for cooperation as norm is presented in red. CO_2 data by Tans (2010) is in blue.

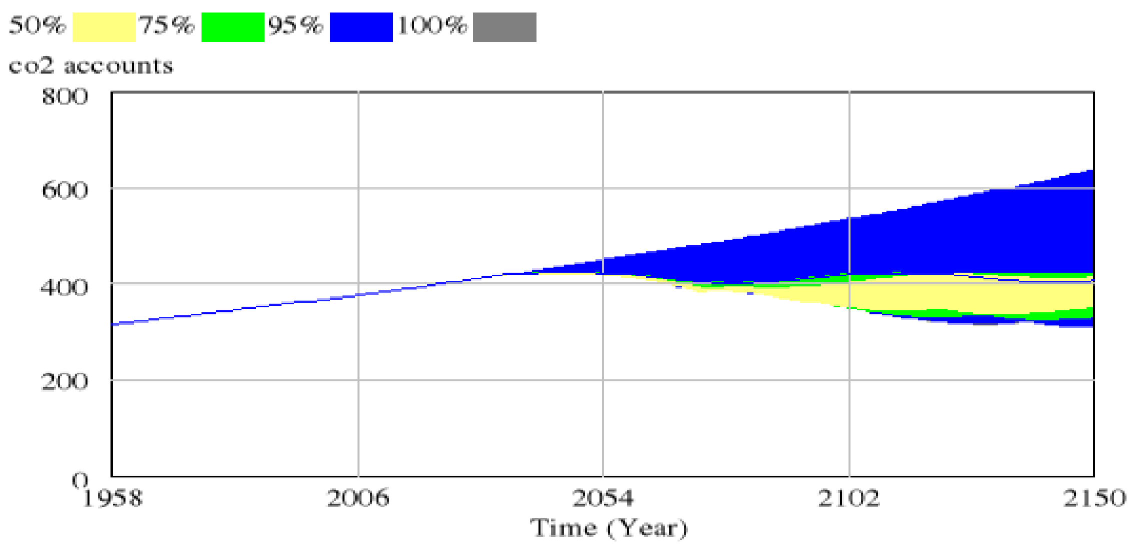

Figure 18: Sensitivity analysis for cooperation as perception of damage.

4 Discussion

We presented a construct as a dynamic hypothesis which explains how mechanisms could be combined to reverse the CO_2 crisis through cooperation. We explained how the dependence of initial conditions of trust in the Mechanism of Cooperation Based on Trust is controlled with our construct using complementary mechanisms such as perception of damage and cooperation as a norm. We applied system dynamics guidelines to develop the model and test the construct (Parra, 2010).

Our work suggests how cooperation can be effective to reverse the CO_2 crisis, and supposes a new alternative to solve this crisis. This alternative solution could be combined with other institutional designs to solve the CO_2 crisis such as green certificates (Morthorst, 2000) and emissions permits (Jensen and Rasmussen, 2000). Cooperation is a possible option to reverse the CO_2 crisis and other crises and its undesired effects.

The construct has limitations which need to be considered. For example, dynamic complexity, understood as the effect of delays regarding information about the state of the shared resource and the effect of the cooperation of others, is critical if we want to succeed using cooperation. This problem could be linked with previous work about the difficulties of people to make high quality decisions in situations characterized by high inertia and delays (Sterman and Sweeney, 2007; Diehl and Sterman, 1995; Sterman, 1989). Our results suggest a new application of dynamic complexity studies for solving large-scale social dilemmas such as the CO_2 crisis.

5 Conclusion

This paper presented a system dynamics model to gain insights about the conditions required to achieve effective cooperation which allows us to reverse the current CO_2 concentration trend in the atmosphere. Simulation experiments show that initial conditions of trust and information delays about the results of cooperation are necessary key elements to ensure the capability of cooperation to reverse the CO_2 crisis.

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