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# Aggregation Technology of Common Goods and its Strategic Consequences.

## Global Warming, Biodiversity, and Siting Conflicts.

von
Katharina Holzinger

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# Aggregation Technology of Common Goods and its Strategic Consequences.

## Global Warming, Biodiversity, and Siting Conflicts.[1]

### Abstract.

The analysis of common goods needs to look very carefully at the characteristics of the goods and of the social situations of their provision. Different characteristics lead to different strategic constellations and therefore to different opportunities for institutional solutions to the problems of provision. Basic differences in strategic constellations can be shown clearly by employing matrix games. In this paper a particular attribute of common goods, their aggregation technology, is systematically analyzed. Variations in this dimension are exemplified by three cases from environmental policy: global warming, biodiversity, and siting conflicts. It becomes clear that the analysis of one specific attribute of a good will seldom suffice to predict empirical behavior. Nevertheless, rigorous game theoretic analysis provides valuable insights into the links between the characteristics of common goods and the need for institutions.

## 1 Introduction

Traditionally, two properties of goods are considered as determining their publicness: non-rivalry of consumption, and non-excludability from consumption. The necessity for collective provision is based on these two properties, as non-rivalry is the cause of undersupply in the case of public goods, and non-excludability the cause of overuse in the case of commons. They create an incentive structure for rational individuals which prevents the efficient private provision of the respective goods.

However, a social situation where a common good is to be provided is characterized by many more properties than the two just mentioned. Therefore, the analysis of common goods needs to look very carefully at the properties of the respective goods and of the social situations of their provision, and to analyze the consequences which these properties have for costs and benefits for the actors. Different cost and benefit structures lead to different strategic constellations, and these, in turn, lead to different opportunities for institutional solutions to the problems of common goods provision.

What I propose here is a systematic theoretical treatment of how such attributes influence the strategic constellation. For this purpose matrix games are a useful analytical tool. Basic types of strategic constellations can be captured by two-by-two matrix games, although this is a great simplification. In an actual common goods problem the number of actors will usually be (much)

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[1] I gratefully acknowledge the suggestions and comments on earlier versions of this paper I have received from Todd Sandler, Iowa State University; Elinor Ostrom, University of Indiana; Fritz W. Scharpf, Max Planck Institute for the Study of Societies, Cologne, Germany; Frank Maier-Rigaud, Christoph Knill, Adrienne Héritier, and Christoph Engel, Max Planck Project Group, Bonn, Germany.

greater than two. The same is true for the number of strategies available; in general, actors will be confronted with some degree of uncertainty; measurement of benefits and costs will not be easy. However, the two-by-two games have the merit of demonstrating a given strategic structure very clearly and accessibly. From these clear structures implications for possible institutional solutions to the dilemmas can easily be derived.

I will exemplify this approach by varying the conditions of a particular dimension which determines the strategic constellation, namely the production function or aggregation technology of a common good. Hirshleifer (1983) has shown how aggregation technology, i.e. the way individual contributions add up to the socially available quantity of the good, affects the structure of the games and thus the equilibrium solutions. As aggregation technologies may vary greatly, it is useful to concentrate on three extreme cases. It can be shown that the three different conditions of the production technology variable lead to different social dilemmas.

Section 2 starts with an overview of properties of situations in which common goods are provided which might have an effect on the strategic constellation of actors. Section 3 introduces the concept of aggregation technology. In sections 4 to 6 the variations in this dimension will be illustrated by three cases from the field of environmental policy: global warming, biodiversity preservation, and siting conflicts. In section 7 conclusions will be drawn about the requirements for institutional solutions to the dilemmas. In the concluding section some reflections will be added about what can be achieved by using such an approach and what cannot be achieved.

## 2 Characteristics of Common Goods Provision

Public goods are usually defined by two characteristics: there is non-rivalry of consumption and nobody can be excluded from consumption. Both attributes lead to the existence of positive or negative externalities, which is a general characteristic of common goods.[2] As a consequence of the externalities common goods will not be provided in sufficient quantities if their provision is left to the market. Provision by the state is traditionally legitimized by this market failure. Game theoretic analysis of common goods leads to a similar result. The provision of common goods is mostly considered to be a strategic interaction of individuals within a certain strategic constellation, the prisoner's dilemma. Given this incentive structure, rational individuals choose the collectively and individually suboptimal action, i.e. not to contribute to the provision of the common good. In game theoretic terms, this problem can only be solved by an external power, for example the state.

These two properties, however, are not the only attributes to play a part in the provision of common goods. The need for common goods arises in a given social environment and they have to be provided within a certain social setting. The social situations in which common goods are provided have many more attributes than the basic defining properties mentioned above. In many cases these attributes influence the strategic constellation of actors. Some of these attributes have already been theoretically or empirically analyzed, in some instances, such as group size, even

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[2] The term common goods is used here as a collective term for goods which are not purely private goods, for example public goods, common pool resources, club goods or network goods.

extensively. Often the research question has been, how these properties influence the degree of actual cooperation in dilemmas. The strategic constellation may, and will, influence the degree of actual cooperation, but it is not equivalent to it. Situations of common good provision vary in many dimensions. The resulting strategic constellations may therefore be very different and may in some cases have cooperation as part of a rational strategy. We already know that the strategic constellation associated with common goods provision is not necessarily a prisoner's dilemma. For example, Godwin and Shepard (1979) have shown that common property resources have many different characteristics and that the prisoner's dilemma is not a proper representation for all of them. Also, public goods, CPRs and other collective action problems have been analyzed as assurance games (e.g. Runge 1984) or, more generally, as coordination games (e.g. Sandler and Sargent 1995), as well as volunteer's dilemmas (e.g. Rapoport 1988, Diekmann 1992).

However, Aggarwal and Dupont's observation that ”the links between the characteristics of goods, the nature of strategic interaction between actors, and the effectiveness or need for international institutions have not been systematically treated” (1999: 393) is still correct, at least as far as political science research is concerned. In economics some work of this kind has been done in recent years, for example by Sandler (e.g. 1998, 1997), Barrett (e.g. 1998a, 1998b, 1999), or Mäler and De Zeeuw (e.g. 1998). Nevertheless, the statement of Aggarwal and Dupont has to be accepted, as it implies that much more work is needed in this direction (see also Sandler 1998: 223).

Before presenting Hirshleifer's concept of aggregation technology and its applications, I shall give a short overview of possible properties of situations in which common goods are provided. It is intended neither as a comprehensive list of attributes, nor as a literature review. Only a few examples are mentioned for both properties of common good situations and related research. Broadly, three categories of attributes which influence strategic constellations can be distinguished: properties of the institutional setting, properties of the actors involved, and properties of the good itself.[3]

1) The institutional setting includes rights, rules, and conventions which apply in the respective situation. An important example are property rights in cases of unidirectional externalities. Another example might be trade rules if the common good is an environmental regulation in the case of transboundary pollution. So far, not much research has been done with respect to the effects of rules on the incentive structure for common goods. An exception is Ostrom, Gardner, and Walker (1994). However, experimental public goods research has, for example, analyzed the effects of communication (Ledyard 1995) and of sanctions (e.g. Ostrom, Gardner, and Walker 1992).

2) The attributes of actors involved in a common goods problem are manifold. For example, many studies are devoted to the question of whether the usual assumption of individual rationality of

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[3] A similar grouping is made by Ostrom 1999, who distinguishes additionally between “types of actors” and “attributes of the group involved”. “Types of actors” refers mostly to their rationality as assumed in rational choice models, or to their apparent empirical willingness to cooperate, although the theory predicts non-cooperation, respectively.

actors is empirically valid or not.[4] For the analysis I am proposing this question is not relevant, since the idea of a game theoretic representation of incentive structures presupposes that the assumption of individual rationality be made. Another important strand of research, spawned by Olson (1965), deals with the effects of group size or anonymity of actors (e.g. Isaac, Walker, and Williams 1991; Güth and Kliemt 1995). Homogeneity or heterogeneity of actors is another important aspect. Heterogeneity may stem from different benefits from the good, different costs of contributing, different strategies open to actors, and so on. It has been claimed that it is easier for heterogeneous actors to find a solution to the dilemma (Martin 1995). While this may be valid in certain situations, it is by no means a general result, as has been shown for example by Hausken and Plümper (1999).

3) Many attributes of the goods themselves have a clear impact on the strategic constellation. First of all, this is true for the ”defining properties” of common goods (Samuelson 1954; Musgrave and Musgrave 1976): Non-rivalry and non-excludability are the properties which enable actors to free ride, and which provide the incentive not to contribute. These attributes of goods are the factors which lead to a social dilemma, i.e. a situation where individual rationality does not lead to a collective optimum. There are other demand-side properties of common goods which may influence the incentive structure, for example non-rejectability of a good. The importance of supply-side properties for the incentive structure in situations of common goods provision was first shown by Hirshleifer (1983 and 1985), the term *technology of public supply aggregation* was coined by Cornes and Sandler (1996). Whether the contributions of the individual actors to a common good are additive or not, and whether they can be substituted for each another, is of crucial importance for the strategic constellation. These conditions of aggregation technology will be analyzed and applied to environmental goods in the remainder of the article.

## 3 Strategic Constellations as a Result of Aggregation Technologies

Traditionally it has been assumed in public good models that the total amount X of a public good available to the collective is the sum of the individual contributions $x_i$. Hirshleifer (1983 and 1985) points out that this ”summation technology” ($X = \sum_i x_i$) is not the only possibility of an aggregation technology. He treats two cases of other production technologies where the good can only be provided as a fixed total amount whose level is determined by a single contribution. For ”weakest-link technology” goods the total quantity is determined by the smallest contribution ($X = \min_i (x_i)$), for ”best-shot technology” goods by the largest contribution ($X = \max_i (x_i)$). The two aggregation functions are extreme cases, other functions in between are also possible (cf. Cornes and Sandler 1996: 186f.).

Hirshleifer provides two intuitive examples for weakest-link and best-shot technologies. His example of a weakest-link common good is about protection against flood on a circular island. Each citizen owns a wedge-shaped slice of the island and each builds a dike along the coastal line of the slice. As we are in a state of anarchy, the height of the dike is decided solely by the individuals. Protection against flood is here only as good as the lowest dike – the sea will penetrate at the slice

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[4] An overview of this line of research is given by Ostrom 1998 and 1999.

with the lowest dike and flood the whole island. The dike can be seen as a chain (cf. Engel 1998: 549): each link is necessary for achieving the common good and the weakest link determines which level (quality or quantity) of the good can be achieved. The contributions are not additive and they cannot –physically- be substituted for each other. A piece of dike higher than the average cannot compensate for a piece which is lower.

Hirshleifer’s cover story for a best-shot aggregation function is as follows: A city is protected against nuclear attack by a number of anti-missile batteries. All of them are supposed to fire at a single incoming nuclear-armed missile, which will devastate the whole city if not destroyed by the anti-missile devices. In this situation the best defensive shot is sufficient to provide the good for the city. Again, the contributions are not additive, a single shot is enough. In Hirshleifer’s example the contributions cannot be substituted for each other, as ”the best shot” is required. This is not true for all aggregation technologies equivalent to ”best-shot”. One can easily imagine situations where each individual is capable of providing the single necessary contribution. In a similar example, the city has to be protected against a dragon attack. If there are several equally experienced dragon-slayers, any of them can go and kill the dragon. Then, the question is: Who will do it? In sociology and social psychology best-shot situations are known as volunteer's dilemmas or as missing hero dilemmas (e.g. Schelling 1978; Diekmann 1992; Weesie and Franzen 1998).

Different aggregation technologies result in different strategic constellations. In terms of matrix games, summation technology leads to a prisoner's dilemma, weakest-link technology to an assurance game, and best-shot technology to a chicken game (cf. Sandler 1997: 46-59). Aggregation technology and the possibility of substitution are independent dimensions. Aggregation technologies may vary when the individual physical contributions are perfect substitutes, or, as economists say, are anonymous. But they may also be combined with physical contributions which are not interchangeable. However, the empirical difference between those situations where substitution is possible and those where it is not, does not always affect the strategic situation. Predominantly, the strategic situation is determined by the aggregation technologies. The possibility of substitution may still make a strategic difference. This will depend on the specific circumstances, for example the number of actors.

Capturing strategic constellations by two-by-two matrices implies reduction and simplification in comparison to the modeling technique Hirshleifer has used. In particular, the strategy set is continuous in Hirshleifer’s model as the individuals can choose their contribution quantities as they like. In a two strategy matrix players can only choose to contribute or not to contribute, or between high and low levels of contribution, respectively. In a two player game two contributions is the maximum, we thus talk only about zero, one, or two contributions to the common good. In symmetric games it is also generally assumed that the contributions are equal (the players contribute ”one unit”), while the contributions in Hirshleifer’s model differ quantitatively in the mathematical formulation (*largest* contribution) and qualitatively in the examples used (*best* shot). It is the qualitative difference which prevents physical contributions from being substituted for each other.

In an environment of two players, two strategies, and of equal contributions the equivalent to a weakest link technology is the requirement that *both* players must contribute in order to provide the common good. In an environment with more than two players the equivalent is that *all* or *at least n* players contribute. The equivalent to a best shot technology is that the contribution of *one* player is sufficient to provide the good. If there are more than two players, the equivalent is that *n* players' contributions *are sufficient* for provision. In the case of a summation technology the contributions are restricted to a maximum of two in a two-by-two game, and to a maximum of n in the n-by-two game. If contributions are allowed to be non-substitutive, this does not lead to a difference for summation technology goods – as long as the good can be provided in "degrees". For best-shot technology goods there is a difference between both players being capable of providing the good interchangeably and only one of the two players being capable of provision. There is no strategic interaction in the latter case: The player capable of provision just decides if she will or will not provide on the basis of her personal cost-benefit analysis. In the case of a two player game with weakest-link technology there is no difference whether physical contributions are substitutive or not. The weakest-link character of the good requires both contributions anyway. However, if there are more than two, for example m, players, and at least n contributions are necessary, there is a difference. In the case of substitutive contributions m!/(m-n)!n! coalitions of n players are able to provide the good, while in the case of perfectly non-substitutive contributions only one such coalition is possible. These are different strategic situations. In order to illustrate some of these contingencies I will go through a number of politically relevant applications from three fields: global warming, biodiversity, and siting conflicts.

## 4 Global Warming

The basis for a distinction between different aggregation technologies is the definition of the common good. In the case of global warming the good is a certain composition of the atmosphere. This composition keeps the climate and, as a consequence, the biosphere on earth within the parameters which we are used and have adapted to, and to which we have accommodated our lives, culture, economic activities, and so on. The composition of atmospheric gases and its effect on biosphere and humans is a public good, as enjoying the effects is non-rival and nobody can be excluded from it. In principle, all species on earth are concerned, although only humans can contribute to the preservation of the atmosphere.

The public good is destroyed by the emission of six different gases which change the composition of the atmosphere to produce the greenhouse effect.[5] The greenhouse effect leads to global warming, and this in turn is expected to have serious consequences, for example the flooding of low lands, an increase in heavy storms, and negative impacts on world food supply (cf. Loske 1996; Sandler 1997: 99ff; Sandler and Sargent 1995; Tietenberg 1997, part II). The effects are unevenly distributed over the world, some states will suffer first and severely, while in other states only marginal effects will be felt. The same is true for the contributions to the destruction of the atmosphere: Some states emit much more of the greenhouse gases than others. Also, global warming must be viewed as a unidirectional, intergenerational externality (Tietenberg 1997, part IV). I will not take into account these distributional aspects (heterogeneity of pay-offs) here. It should be kept in mind, however, that this aspect may have greater effects on the strategic constellation than the aggregation technology (Barrett 1999b).

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[5] The atmosphere could also be viewed as a common pool resource. It is used as a reservoir for dumping emissions, and with respect to this, there is rivalry.

The contributions to the preservation or restoration of a composition of the atmosphere such that there are no negative climate effects, are reductions in climate gas emissions. The reductions not only produce benefits for the global climate, but also costs where the emissions are cut. The emissions which can be reduced result mainly from human production or consumption activities. A decrease in emissions also means a decrease in benefits from these activities. The contributions to the greenhouse effect are *additive*: The higher the level of greenhouse gas emissions, the greater the damage caused. The more the emissions decrease, the more of the common good will be preserved (see also Sandler 1998: 225). This is not completely true, however, as the atmosphere tolerates a certain amount of manmade greenhouse gases above the natural level. This can be overlooked, however, since most scientists now agree that we are above this threshold. The necessity for emission reduction is generally accepted. The contributions are also *substitutive*: It does not matter where and by whom the greenhouse gases are emitted or reduced, respectively. The level of common good achieved is determined solely by the total amount of emissions, or by the sum of the contributions in terms of emission reduction, respectively. Not only are quantities of each greenhouse gas substitutive, but the six gases can also be substituted for each other. The effects of each gas in the atmosphere are different, of course, but their effects on the climate can be compared. They are usually expressed as GWP: their ”greenhouse warming potential” relative to $CO_2$ (Loske 1996: 46ff.).

The following matrix game models the strategic situation of two states 1 and 2 which have the options to contribute one unit (CU) of emission reduction or not to contribute (NC). As the contributions are additive and substitutive the aggregation technology follows the summation rule (see table 2). The actors are homogenous, the game is a symmetric one. One unit of emission reduction causes a benefit of b and a cost of c, with c>b, to each player. The cost and benefits of each strategy combination for state 1 (and *vice versa* for state 2) are:

**Table 1 Summation Technology**

| | *Strategy combination* | *benefit* | *cost* | *player 1's pay-off* |
|---|---|---|---|---|
| *State 1* | 1: CU, 2: CU | 2b | c | 2b-c |
| | 1: CU, 2: NC | b | c | b-c |
| | 1: NC, 2: CU | b | 0 | b |
| | 1: NC, 2: NC | 0 | 0 | 0 |

State 2

| | | contribute one unit | not contribute |
|---|---|---|---|
| State 1 | contribute one unit | 2b-c, 2b-c | b-c, b |
| | not contribute | b, b-c | *<br>0, 0 |

$0<b<c<2b$

This game is a prisoner's dilemma. Both states have a dominant strategy not to contribute. This is a result of the assumptions of additivity and of the individual benefit of one unit being smaller than the individual costs. If the individual benefit is greater than the costs, the game changes into a harmony game, where both states have a dominant strategy to contribute. If c were greater than 2b, the game would also change to a harmony game. However, as in the prisoner's dilemma both states would have a dominant strategy not to contribute. Unlike in the prisoner's dilemma, the (NC, NC) outcome would be socially optimal, as this would be a case of a common bad. Therefore, the interpretation of protection against global warming as a prisoner's dilemma is only valid if the cost-benefit relation is as specified in the game above –and if we do not take into account heterogeneity and intergenerational effects. The strategic situation between the states could also be modeled differently for other reasons. For example, Sandler and Sargent (1995) focussed on the aspect of international treaty formation where a minimum number of signatories is required. Under these conditions the strategic situation is similar to that of a weakest-link technology, as at least n contributions are required.

## 5 Biodiversity

Biological diversity is a very complex good. It is a good for several reasons. First, it facilitates ecosystem functions, which are of crucial importance for the continued habitability of the earth, for example carbon exchange, regulation of surface temperature and local climate, or protection of soils. Second, it is and will continue to be the source of many products, like food, fibres, and chemicals, and will serve as an input for biotechnology. Third, biodiversity is the basis for the development of new crop and livestock varieties and the improvement of existing ones. Fourth, it provides aesthetic, scientific, and cultural values and serves recreational purposes (cf. OECD 1996: 19ff.).[6] Although some of these goods are private in character, others, like the ecosystem functions mentioned above, are public goods. Therefore biodiversity as such may be treated as a common good. Biodiversity is in danger, as human activities can destroy ecosystems, exterminate species and threaten genetic variability. Protection of biodiversity means that we restrict our productive, consumptive and recreational activities. This causes costs.

Biodiversity is difficult to define and to measure, however. The definition of biodiversity in article 2 of the Convention on Biological Diversity emphasizes *diversity* or *variability*, it is not about the protection of single entities: Biological diversity is ”the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems”. Thus, the goal of biodiversity is pursued at three levels – genes, species, and ecosystems. The following illustrations and examples are mainly taken from species diversity. At each level the diversity goal consists of two components: ”One is a measure of how many different living things there are, the other is a measure of how different they are” (OECD 1996:19).

If biodiversity were to be measured only by counting the number of species, it could be achieved in degrees. The preservation of existing species or the creation of new ones would count as a contribution to biodiversity. The more species that were preserved, the more of the biodiversity goal we would have achieved. The contributions to biodiversity would be both additive and substitutive and, thus, the strategic situation would be a prisoner's dilemma as in the global warming case – provided the individual costs of preserving one species were higher than its individual benefit but lower than the collective benefit. Intuitively, however, the species are not substitutes for each other, at least not in general. The breeding of a new funghi species may be viewed as a sufficient substitute for a similar funghi species which is extinct. The extinction of a bird, however would not be sufficiently compensated for by the cultivation of a new bacteria species. Also, to stay not only

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[6] This is not the place to discuss the goal of biodiversity as such. Two caveats shall be made, however. First, it is human valuation that makes biodiversity a good. That we want to keep biodiversity is a result of the valuations mentioned above, as well as of ideas and theories about the relationship between a diverse biosphere and the goods we want to make use of – theories which are not uncontested. There is no naturally given ”good” biodiversity, and more specifically, nature itself does not tell us how diverse the biosphere should be and does not even demand that the biosphere be diverse. Second, loss and change of genetic variability, the extinction of species and the change of ecosystems are natural processes. The causes for such changes are partly the consequences of other natural processes, partly of human activities. One might say it would be wise to restrict human biodiversity regulation to the correction of humanly caused effects on biodiversity. This is difficult, however, as the causal relationships are often not well understood. It should be kept in mind, however, that biodiversity preservation activities are just another human intrusion into nature.

within the same order but even within the same family, the extermination of the elephant will not be judged as offset by the preservation of the manatee (the seacow), the next and only remaining relative of the elephant.

Here the second element of species biodiversity invariably plays a part, i.e. how different the species are. The examples given above are examples of the so-called *taxonomic diversity*: ten species in the same genus are valued as less diverse than ten species, each in a different genus. There is, however, no generally accepted way of balancing *species richness* (the mere number of species) against taxonomic diversity. Another important factor for substitutability of species is their ubiquity or their *endemism*, respectively. Biodiversity has a geographical dimension: It is measured with respect to a certain area, an ecosystem, a continent, the planet. A species endemic to a certain area is clearly more worthy of preservation in this area than an ubiquitous species. Nevertheless, it may even be desirable for an ubiquitous species to be preserved within a certain area, as its extinction could cause the destruction of an ecosystem. This possibility hints at a third factor of different importance of species, and thus, of different degrees of substitutability. The extinction of a *dominant species* within an ecosystem may lead to the break-down or significant change of the whole system – it may often be impossible to replace it by another species, even if closely related, without grave repercussions (Woodward 1994; OECD 1996: 20ff.). As a consequence of all this, one could argue that biodiversity has to be viewed as a chain where the preservation of each and every species is required in order to achieve the goal. Each species counts, as each has its unique function within the global ecosystem. The contributions to the global common good of biodiversity are not substitutive. However, at the global scale this interpretation of the goal is not convincing either, as a certain degree of substitution of species, as well as a certain reduction of species richness seems possible without the complete loss of the good.

The idea of a chain is more plausible for small ecosystems or biotopes. For modeling purposes one could think of a biotope where two dominant (or two crucial) species live. They interact in way such that the system breaks down if one of the two species vanishes.[7] There are two actors who are each capable of protecting one of the species. Both species have to be preserved, as the loss of each one leads to the extinction of the complementary one. This is not an unrealistic scenario, although in most cases the interaction of more than two species is necessary to preserve an ecosystem, or sometimes only one dominant species may cause the break-down of the biotope. An example of a two species case was Lake Nakuru in Kenya. The lake was inhabited by a very dense and dominant population of a specific blue alga which served as food for a certain species of dwarf flamingo, which also had a large population and was a dominant one within this ecosystem. As a result of an unknown event the alga suddenly vanished within one year. The dwarf flamingos followed. In the event a green alga species population grew. It serves as food for a plankton, which in turn now feeds the flamingo ruber (Remmert 1992: 309ff.).

The assumptions for the model are the same as above: There are two actors who can each preserve (PS) or not preserve (NP) one species and pay-offs are symmetric. The contributions are non-additive and non-substitutive, the aggregation technology is of the weakest-link type. The individual

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[7] In general the system will not completely break down but change to another system which is often more unstable than its predecessor.

benefit of achieving the goal (preservation of both species and the biotope) is $b$ for each player. The costs of each contribution are $c$ with $b>c$. The cost and benefits of each strategy combination for actor 1 (and *vice versa* for actor 2) are:

**Table 2 Weakest-link Technology**

| | *Strategy combination* | *benefit* | *cost* | *player 1's pay-off* |
|---|---|---|---|---|
| *Actor 1* | 1: PS, 2: PS | b | c | b-c |
| | 1: PS, 2: NP | 0 | c | -c |
| | 1: NP, 2: PS | 0 | 0 | 0 |
| | 1: NP, 2: NP | 0 | 0 | 0 |

| | | Actor 2 | |
|---|---|---|---|
| | | preserve species | not preserve species |
| Actor 1 | preserve species | * b-c, b-c | -c, 0 |
| | not preserve species | 0, -c | * 0, 0 |

$0<c<b$

This game is an assurance game. There are two Nash equilibria in pure strategies, one at a low and one at a high level of preservation (actually: preservation and non-preservation).[8] Only the preservation equilibrium is pareto-optimal. None of the actors has a dominant strategy, their best strategy depends on the strategy of the other. Preservation of one's own species only makes sense if the other player preserves as well. The real problem here is of coordinating the strategies such that both choose the same strategy, or better, that both choose preservation. If the individual benefit from the biotope is less valued than the individual cost of preservation ($b<c$) the game is a harmony game again. Both players have a dominant strategy not to preserve their species. As the biotope - under this cost-benefit assumption - is a common bad, their behavior is socially optimal. If we observe that biotope or species preservation does not take place in reality this may simply be due to the fact that the actors value the biotope less compared to the preservation costs. However, it may also be due to heterogeneity or unidirectionality.

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[8] There is a third equilbrium in mixed strategies, which is pareto-inferior. I will neglect randomization here.

The biotope example, however, is still not completely plausible, there is a problem with respect to the actors. One could imagine a scenario where, for example, one of the actors is a farmer and the other a tourist. Both are capable of preserving one species and both suffer from the break-down of the biotope. In general, the actors capable of preservation are political actors who can decide on the necessary regulations. If two species in a small biotope are to be preserved there will only be one territorial jurisdiction, for example the government of Kenya.

One can, however, think of examples from species protection where two territorial jurisdictions are involved. Brown bears, for example, can be found in Europe and North America. Both Europe and North America can preserve their brown bear populations. If the goal were just to preserve the species the bear populations could be considered to be substitutes, although the aggregation function is not additive. It would be sufficient then, if the bears were protected in only one of the two areas. In the two player case this aggregation technology is equivalent to the best-shot technology. There are two varieties of bears, however: the European brown bear in Europe and the grizzly bear in Canada, Alaska and the United States. Let us assume that biodiversity with respect to bears is considered to be achieved only if both varieties are preserved. The bear populations are then no longer substitutive. The contributions of both continents are required to achieve the goal and we are again in a weaker-link technology game. In Europe there are brown bear populations in Southern Europe, Eastern Europe and Scandinavia. The goal to preserve the European brown bear is not additive and the populations are substitutive. Let us assume, however, that political regulation prescribes that the brown bear be preserved in at least five populations in five different states. Then we have a scenario where non-additive, but substitutive contributions lead to a weakest-link technology game (at least n), not to a best shot technology (one is sufficient). As there are bear populations in more than five states, several different coalitions of five states could be formed to contribute to preservation.[9]

## 6 Siting Conflicts

Siting conflicts are a very plausible example of a best-shot or a single-contribution aggregation technology. Siting conflicts arise from so-called LULUs, ”locally unwanted land uses” (e.g. Mazmanian/Stanley-Jones 1995). The main characteristic of the goods associated with siting decisions is that the scopes of their benefits and their costs differ. The projects have a spatial dimension. While only the neighbors of a specific project suffer from negative external effects, the benefits generally accrue to a larger group of persons. Locally unwanted land-uses are often public projects, but private projects may have the same consequences. Examples are the building of roads and motorways, or airports; the construction of waste management facilities, like waste disposal or incineration plants; nuclear power plants and disposal facilities; industrial facilities in general; prisons or psychiatric clinics; or the zoning of protected areas, which restrict economic activities. As the examples show, in many cases the goods provided by the project are public goods or club goods, in other cases, like industrial facilities, the main benefits of the good are purely private. The common good character shared by all siting projects arises from their negative external effects on

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[9] Actually, the goal of brown bear preservation in Europe is to protect each population that has survived hitherto.

the neighbors. As a side effect the goods provided produce a non-rejectable public bad. Typical externalities are health or environmental risks caused by the emission of chemical substances, annoyances by noise or unusual people, monetary losses because of a decrease in real estate values or because of restriction of economic activities.

As this article is about the provision of common goods, the siting conflict modeled here should be about a public project providing a good which has the characteristic of a public good or a club good. One may think of a waste management facility or a nature reserve. The benefits of the project accrue to all citizens of the state or county or to all club members. The contributions to the provision of the good consist of taxes for all citizens and/or fees for the users. The neighbors of the site, however, have additional costs to bear as they suffer from the negative externalities. Thus, the neighbors, for example the inhabitants of communities which can offer a site, pay an additional, site-specific contribution. In some cases there are also site-specific benefits, for example, additional jobs for the community. They work as selective incentives. I will neglect this aspect here and only consider the site-specific costs.

If a jurisdiction, the county for example, wants to provide such a locally unwanted land use good, a hero community is needed which offers the site. The physical contributions are not additive: A single site suffices to provide the good for all county citizens. Depending on the type of project, the contributions may or may not be substitutive. In the case of a nuclear waste facility it is possible that only one specific site is suitable. The nature reserve, as well, has to be a specific area. In the case of waste management facilities or prisons probably several communities in the county could offer a suitable site. If in fact only one site is suitable, no strategic game between potential site contributors will be played. The site will be offered voluntarily, if the benefits for the community are higher than the costs; otherwise the respective community can only be forced by state authority for the sake of the common good and/or it can be compensated for suffering the negative externalities. Thus it only makes sense to talk about a game between site contributors[10], if at least two sites are substitutes for each other.

Again, the general assumptions for the model are the same as above. There are two communities with potential sites which have symmetric pay-offs. The benefit from the project is b for each community. The costs of the externalities are c, with b>c. The physical contributions are non-additive, but substitutive. The two strategies are to offer the site (OS) or not to offer the site (NO). The cost and benefits of each strategy combination for community 1 are:

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[10] The single site contributor and the users of the project may play a game, however, if there is no hierachical decision.

**Table 3 Best-shot Technology**

| *Strategy combination* | | *benefit* | *cost* | *player 1’s pay-off* |
|---|---|---|---|---|
| *Community 1* | 1: OS, 2: OS | b | c | b-c |
| | 1: OS, 2: NO | b | c | b-c |
| | 1: NO, 2: OS | b | 0 | b |
| | 1: NO, 2: NO | 0 | 0 | 0 |

| | | Community 2 | |
|---|---|---|---|
| | | offer site | not offer site |
| Community 1 | offer site | b-c, b-c | * b-c, b |
| | not offer site | * b, b-c | 0, 0 |

0<c<b

The resulting game is a game of chicken. It has two Nash equilibria in pure strategies, where the pay-offs to the players are different for each outcome.[11] There is thus not only a coordination problem but also a problem of reaching agreement. As both players strive for a different equilibrium there is a risk that they end up without a site for the project, which is the individually and collectively least desirable solution. Discoordination of the players at the solution whereby both offer the site is less likely, but possible. The pure coordination problem could be solved by communication. Simple arrangement (coordination by communication) is not enough however, as both players aim at the solution whereby the other one offers the site. A bargaining process is necessary to find an agreement as to which of the two pareto-optimal equilibrium solutions will be chosen. The game presupposes that the project is both individually and collectively beneficial. In the case of c>b, we are in a weak harmony game: there is a unique equilibrium in dominant strategies where no site is offered. This is a pareto-optimal solution, while the outcome of both players offering the site is inferior. The solutions of only one player contributing are also pareto-optimal, but no equilibria.

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[11] Again, there is a third, pareto-inferior, equilibrium in mixed strategies.

# 7 Institutional Solutions

The three different aggregation technologies produce different matrix game structures: prisoner's dilemma, assurance game, chicken game, and harmony games. Basically harmony games result if costs of provision are higher than benefits on the aggregate level and if benefits are greater than costs on the individual level. As harmony games pose no dilemma between individual and collective rationality, there is no collective action problem to solve. They can thus be neglected in the following. The other three strategic constellations are different social dilemmas, which require different solutions. The three game structures are of a universal nature. They do not necessarily arise only as a result of aggregation technologies, they may also be the result of completely different attributes of situations of common goods provision. On the other hand, situations where a specific aggregation technology applies will have other attributes which change the game structure.

The prisoner's dilemma is dominated by a problem of defection. Communication between the players is not sufficient to achieve the socially optimal outcome whereby both players contribute to the common good. Even if they negotiate and come to the conclusion that it would individually and collectively be best to contribute, the incentive to free ride remains. In theory a binding contract and an external actor who is capable of securing compliance is required to solve a single shot prisoner's dilemma. In an infinitely repeated prisoner's dilemma cooperation is possible without sanctions or external actors. In practice this implies a solution by the state or a self governance solution in the shadow of hierarchy. Experimental and case study evidence has shown, however, that players are able to solve the dilemma without the power of an external actor (Ostrom 1990, Ledyard 1995). In the case of global warming the conclusions about institutional solutions are plausible. There is still no agreement as to how the burden of emission reduction will be distributed. The incentive to free ride seems to even prevent a contract. However, the asymmetry in costs and benefits plays a major part in the difficulties of finding an agreement. So far, we do not know about defection after the treaty has been ratified by the major contributors to the problem.

The assurance game poses a pure problem of coordination. Communication should be sufficient to ensure that both coordinate at the high level equilibrium. As this is not only collectively, but also individually the best solution, there is no incentive to defect after an arrangement has been made. For the same reason it should not be difficult to achieve the arrangement. Only consultation is needed. A coordination committee may be a sufficient institution. If one looks at the empirical problems of biodiversity preservation, representation as a pure coordination game does not seem very plausible. The Convention on Biological Diversity includes possibilities for the international community to intervene in domestic matters and for strict sanctions, which are unusual at the international level (Wolfrum 1997). If biodiversity preservation were a mere coordination game, as the theory predicts, no such institution would be needed. The reason is probably that the benefits and costs of the good biodiversity are valued very differently by the states concerned. Given these valuations the actors are extremely heterogeneous. Under conditions of asymmetry, with one of the players experiencing higher costs or lower benefits from the good, coordination at the high level equilibrium is less likely to be achieved. Redistribution may help to find a solution more easily.

The chicken game poses both a coordination problem and a problem of finding an agreement. The coordination problem could be resolved by communication and the solution whereby no one makes the contribution can thus be avoided. However, as both players prefer a different solution, a bargaining process is necessary for finding an agreement. In theory there is no internal solution to this problem, as long as we talk about a single-shot game with two discrete equilibrium outcomes. In practice, there are several (external) ways of solving a bargaining problem. First, a compromise solution in between the two outcomes may be found. Second, one player makes the contribution, but gets a compensation for the additional provision costs. Third, a package deal involving the same players may be found. Fourth, if the game is played repeatedly, turn-taking is a possible solution. Also, in the case of heterogeneity of actors it may be easier to find a solution. If one of the players benefits much more from the good it is likely that this player will provide it. Experience with siting decisions shows that there are often negotiated solutions which rely on package deals, turn-taking, and compromises. In general, compensation is the least accepted solution (cf. Bingham 1986; Holzinger 1997; Raiffa 1985). But there are also many cases where no hero can be found. Locally unwanted land-uses often meet with stiff resistance. Sometimes the projects fail after many years of litigation.

## 8 Conclusion

The basic idea behind this paper is the assumption that it would be helpful for the analysis of common goods to look much more closely at the properties of the goods and of the social situations of their provision and to analyze the consequences of these properties on costs and benefits for the actors. Different cost and benefit structures lead to different strategic constellations, and these, in turn, lead to different opportunities for institutional solutions to the common good provision problem. It became clear, however, that the analysis of one specific attribute of a good or one property of the social situation will not suffice to capture the strategic constellation in a way such that it predicts empirical behavior. Therefore I will conclude with some reflections on what can be gained by such an approach and what cannot be expected.

The game theoretic analysis can clarify how certain attributes of the common goods itself and certain properties of the social situations embedding the provision of the goods affect the strategic constellation for the actors. It allows systematic variation of the properties or their different conditions, respectively. Using the same framework allows a comparison between properties as different as the aggregation technology of the good, heterogeneity of actors, or institutional provisions, like trade rules. Given a specific strategic constellation, conclusions can be drawn about the possibilities of institutional solutions, or other forms of solution to a social dilemma - provided that the strategic structure poses a dilemma. All this is pure analytical reasoning, however. What we can learn from it, is that it is necessary to analyze a common goods provision situation very carefully, before drawing any conclusions about the mode of provision.

It is difficult, however, to use this type of analysis for the prediction of real world phenomena. The examples which were used here for illustrative purposes show that modeling only one property does not necessarily produce results which are empirically plausible. However, as the goods and the social situations embedding their provision are determined by so many factors, the result of an analysis of all properties which are empirically relevant, might become inconclusive. Considering property after property and cumulating them in order to match the empirical situation would constantly change the game. In the process of following this route the strategic constellations may loose their clear attributes and thus their analytical value diminishes. Also, matrix games are probably too simple a technique to be able to capture a real situation adequately. As a consequence it is also difficult to recommend specific institutional solutions. Nevertheless, it might be promising to compare real world solutions with the solution one could recommend after the analysis of a property considered dominant or crucial for this common good provision problem.

However, the analytical value of an examination of the effects of single properties on the strategic structure, keeping other factors constant, should not be underestimated. The typical way of testing the hypotheses derived from such an analysis is the experiment. Experiments allow the reconstruction of the properties to be analyzed in simple situations like the ones represented by two-by-two matrices. This would allow scrutiny of the analytical correlations derived from a certain property of a common good, its effect on the strategic structure, and the solutions found, to see if they hold true empirically.

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