Large reservoirs and greenhouse gas emissions – A network thinking analysis

Staudämme und Treibhausgase – Ein netzwerkbasierter Lösungsansatz

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Abstract

In recent times large reservoirs in tropical regions have become a subject of controversial discussion concerning sustainability and Green House Gas emissions (GHG). The complexity of this problem is highlighted and assessed by applying a network thinking approach. The main factors are identified and the influence of different measures is discussed.

Zusammenfassung

Wasserkraft gilt seit langem als eine emissionsarme Form der Energiegewinnung hinsichtlich der Vermeidung von Treibhausgasen. Wegen des Abbaus organischer Biomasse, vornehmlich in tropischen Gegenden, wird die Errichtung neuer Staudämme allerdings kontrovers diskutiert.

Der hohe Komplexitätsgrad dieser Problematik bedingt einen integrierten Lösungsansatz. In diesem Zusammenhang stellt sich die Methode nach Gomez und Probst als geeignet heraus.

Es zeigt sich, dass neben der präventiven Beseitigung bestehender Biomasse die Einbeziehung lokaler naturschutzorientierter Nicht-Regierungsorganisationen (NGOs) einen wesentlichen Einfluss auf die Reduzierung treibhausrelevanter Gase haben kann.

1 Introduction

Hydropower has been long time seen as a non-pollutant and sustainable alternative to the use of fossil combustion to produce energy. Avoiding the emission of GHG is considered as a main advantage concerning environmental impacts such as global warming.

Despite these conveniences large reservoirs especially in tropical areas have become a subject of controversial discussion in recent times. Besides several positive impacts of reservoirs such as energy production, irrigation flood protection and tourism among others, decaying biomass from flooded land may also cause severe environmental damage. Thus, the problem is characterized by a high degree of complexity requiring the application of integrated approaches and the consideration of the interactions and inter-reactions between all elements influencing the problem.

The study shows that on the one hand cutting trees appears to be a reasonable measure to reduce GHG emissions from a planed reservoir, since there is a significant contribution of pre-existing biomass to produce CH_4 and CO_2. However, this choice must be analyzed from the economical point of view.

On the other hand the participation of ecological NGOs in the reservoir planning process might result in a reduction of GHG emissions. This happens rather indirectly, since usually a resizing of the project (reducing dam height and reservoir surface) is brought about.

2 Review on large reservoirs and GHG emissions

A huge and controversial debate concerning greenhouse gas emissions from large hydro reservoirs in tropical areas has taken place and is still going on. The following paragraph summarizes some opinions and points currently discussed.

In tropical reservoirs, the average amount of biomass (per hectare) can be five times greater than the biomass in a northern climate. Nevertheless, GHG emission from decaying biomass from flooded land is considered as a substantial problem of hydropower. The emissions mainly depend on the size, shape and depth of the reservoir and the flooded ecosystem. This source of emission still needs a more detailed discussion and research is urgently required in this area [1].

In 2002, Gagnon [2] stated that research on GHG emissions of hydro reservoirs has advanced significantly, mainly due to more extensive measurement programs on a wider variety of eco-systems. Emissions recorded over reservoirs appear to be significantly higher in the first years after impoundment compared with those in the following years. Numerous research programs have confirmed the fact that significant GHG emissions at the surface of all water bodies, e.g. reservoirs, natural lakes and rivers, take place. According to these studies, the main source of organic carbon that is flushed in reservoirs results from surrounding ecosystems.

Opponents of hydropower have highlighted concerns about GHG emissions from hydro reservoirs. The International Rivers Network (IRN) [3] pointed out that emissions from tropical reservoirs are typically between five and 20 times higher per unit of area flooded than those from reservoirs in boreal regions. Furthermore, the IRN stated that tropical reservoirs might contribute many times more to global warming than coal plants generating the same amount of power. This short review on large reservoirs and GHG emissions gives an impression of the controversial debate, which is currently under discussion. Especially the uncertainty concerning methane (CH_4) emissions from tropical reservoirs is confirmed in the IPCC report [4].

3 Assessment of the complex problem of reservoirs and GHG

The underlying problem is characterized by a high degree of complexity including several factors possessing strong interaction and dynamics. The aim of this study is therefore to highlight and analyze this situation and to propose possible solutions.

3.1 The complex system of a large reservoir in tropical regions

A complex problem has a high number of factors with strong interaction and high dynamic relations between each other. Therefore such problem has to be evaluated, studied and solved using a systematic approach. The network thinking approach of Gomez and Probst [5] is thus applied for the complex problem of GHG emissions in large reservoirs.

In a first step the network is built in order to find an acceptable solution minimizing the green house effect and satisfying most of the people involved in the project. To achieve these goals, all players and their interests in the project have to be identified. This complex problem of GHG emissions in large reservoir can be treated and studied by a global and integrated approach. By the help of network thinking a five-step methodology is applied.

1. Discovering problem: involved factors, players with their interest in the project.
2. Understanding the problem situation.
3. Considering possible measures in order to influence and control the elements of the problem and identification of controllable elements.
4. Analysis of possible solutions for problems.
5. Realisations and implementation of solutions for the problem.

The list is not exhaustive but the following players are found to be interested in a dam construction project:

– Local population and communities: Expectation of jobs, more fishing, less risk of flood, safety of land, water quality, irrigation, immigration, and exodus
– Agricultural organisations: Safety of land, infrastructures and roads in order to sell products
– Ecological part of the government: Preservation of flora and fauna, interest in sustainable development
– Energy department of the government: Best energy production, with less investment, and less importation of fuel
– Promoters of the project: More benefits, best reputation to get the money to invest
– Ecological NGO: No exodus of people, less impact on fauna and flora
– Economical NGO: Promotion of hydropower and dams
– Employees and industries: Furnishing equipment and more jobs
– Financial institute: Expectation of having worthy project to invest, good reputation (economically and environmentally) and achievement of more benefits

These parameters are classified in four groups that are environmental, technical, social, and economical (**Table 1**). Some of these parameters can be found in more than one group.

Table 1: Related parameters

Technical:	**Social:**	**Economical:**	**Environmental:**
Surface of the reservoir	Water quality	Tourism	Fishing
Volume of the reservoir	Exodus	Investment	Protection of fauna & flora
Water depth	Leisure	Equipment	Agricultural land use
Height of the dam	Taxes (represent people)	Interest of economical NGOs	Interest of ecological NGOs
Depth variation	Satisfaction of the project	Interest of investor of the project	Inflow to reservoir (hydrology)
Dam operation	Infrastructure	Benefit	Use of fossil energy
Life duration of the dam	Jobs	Hydroelectric energy production	Use of “clean“ energy
(= volume of the reservoir /	Immigration	Peak energy	Density and type of submerged vegetation
inflow	Water disease		Submerged organic soil
	Other water sources		Submerged bushes & grass
	Flood risk		Submerged trees
			Temperature of water
			Impact on landscape
			Nutrification

3.2 Parameters involved and their interaction

From each point of view, a lot of elements can influence the network system. Deep discussions have to be conducted in order to understand the preoccupation and interest of everyone. All parameters that are considered to affect GHG emissions in large reservoirs and the relation between them are shown in **Figure 1.a** (white boxes with black text). Parameters having effect on other parameters are represented by dashed lines, while those affected by other parameters are shown by solid lines.

3.3 Key factors influencing the complex system

In order to really understand and to build an overview of the problem, a useful representation of the results is the analysis of intensity of relationships in the network that shows the key factors influencing the complex system. Every parameter is described by its passive and active sum. This sum is calculated by evaluating the passive or active influence of each parameter on the others by designated values from one to three. Within this matrix, arbitrary limits can be fixed and so four regions can be created (**Figure 1.b**).

Active elements region: The effect of these elements is really significant. They play an important guiding role and have an outstanding influence on the others elements. In the present case, such elements are mostly located in the technical sub-domain and are related to the specifications of the reservoir, like “height of the dam, “surface of the reservoir” or “depth of water in the reservoir”.

Passive elements region: These elements have a rather small influence and are little influenced by other elements. They can usually be neglected. In the underlying study, such elements are mostly elements coming from peripheral objects like “Use of green energy” or “Immigration”.

Reactive elements region: These kinds of elements that are coming mostly from the sub-domain “Nature” are strongly influenced by other elements, e.g. “Quality of Water” or “Nutrification”. These elements should be used as indicators.

Critical elements region: They have strong influence and are strongly influenced. Used as levers, the manipulation of such elements must be carefully done. Otherwise a chain reaction could be provoked. In the test case, “Ecological NGO part” and “Hydroelectric energy production” are critical elements.

3.4 Effect of measures to reduce GHG emissions

In order to influence the critical factors for gas emissions, new terms are implemented in the network. Apparently these factors have an effect on the relation between different elements. Therefore a new network has to be developed. The network was revised once by considering the possibility of cutting trees before their submergence in the reservoir. Furthermore, the involvement of NGO in the early state of the project definition is discussed, on technical characteristics of the project e.g. height of dam. The fact of cutting trees and NGO participation is added in **Figure 1.a** (gray boxes with white text).

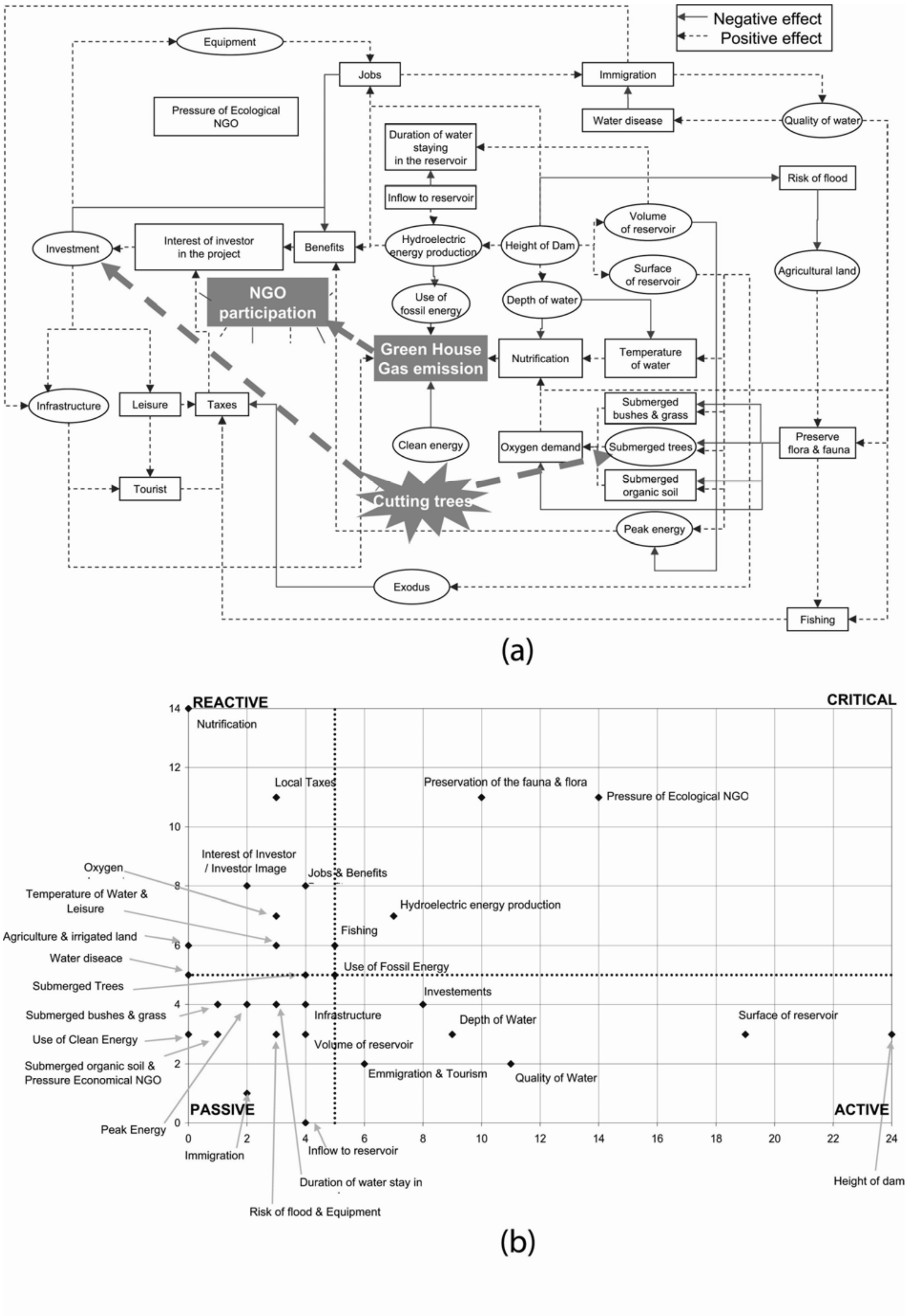

Figure 1: (a) Interaction and inter-reaction between parameters influencing the problematic of green house gas emission of large reservoirs; Influence of cutting trees and participation of NGO on the network is shown with gray boxes with white text; (b) Key factors influencing the complex system when a new dam is planned

In this figure it can be seen that cutting trees will decrease the amount of submerged trees that are responsible for the raise of oxygen demand, the eutrophication process and production GHG emissions. The influence of this factor on the situation of key factors is depicted in **Figure 2.a**.

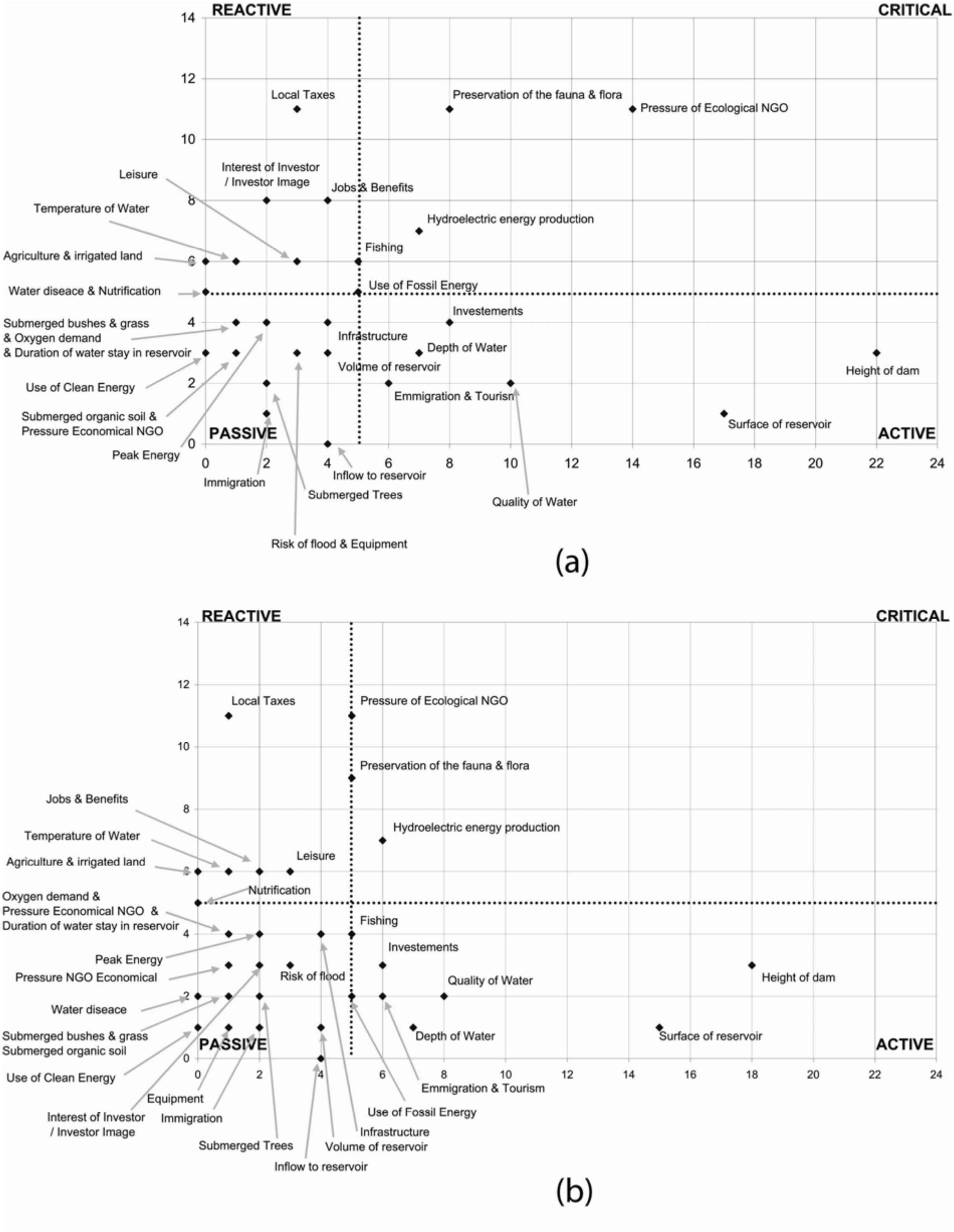

Figure 2: (a) Effect of cutting trees on key factors influencing GHG emission; (b) Effect of NGO (ecological) participation in early project stages on key factors

In **Figure 2.b** the effect of NGO participation is shown. These organizations can provide restricting conditions for dam construction projects that may lead to decreasing of dam height or reservoir surface. Therefore less organic materials are submerged into the water and the amount of GHG emissions will reduce.

4 Conclusions

This paper has looked at GHG emissions from reservoirs in the tropical area and their potential impact. The network thinking approach of Gomez and Probst has been applied and some possible solutions and their effect to reduce GHG emissions are pointed out. Cutting trees is a reasonable measure to reduce the GHG emissions from a planed reservoir, because there is a significant contribution of pre-existing biomass to produce CH_4 and CO_2. However, this choice must be analyzed from the economic point of view. For example the timber can be later used for building houses and bring benefits. The participation of ecological NGOs in the reservoir planning will usually result in a resizing of the project and hence indirectly in reduction of GHG emissions.

Literature

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