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Economic Instruments to Combat Eutrophication: A Survey

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Abstract

Eutrophication of aquatic ecosystems is a functional process triggered by excessive nutrient inputs into water courses. It causes disruption to ecosystems, with impacts on associated goods and services, which consequently might not be provided in a sustainable way. These impacts have served to politicize the issue in recent years. In this chapter, we present the main lessons learned from an international literature review on the economic aspects of eutrophication, first with the purpose of managing the problem in France and second in the context of a European research project. This study aims to help public decision-making in the reduction of this water pollution. By analyzing past experiences and the results of recent modeling work, it allows to avoid a number of pitfalls and focus on efficient solutions.

Keywords: economics, eutrophication, regulation, incentive, public policy

1. Introduction

Natural environments are no longer able to assimilate without harming all the pollution caused by human activities. Many rivers, coasts, and water bodies suffer from eutrophication [1, 2]. While the induced costs are difficult to estimate, they must be taken into account in public policies relating to agricultural and urban development. Eutrophication is triggered by excessive nutrient inputs, mainly nitrogen and phosphorus [3], causing increased levels of biomass in aquatic ecosystems. This can result in major disruption to aquatic ecosystems and may also impact associated goods and services, economic activities, and human health. The main sources of this pollution are agricultural activities, discharge from urban waste water treatment plants, and individual sewage treatment systems. The principal economic issues are the following: What is the best way to define and implement acceptable trade-offs by different stakeholders? How can economic activities and eutrophication be balanced in urban and rural territories while respecting the principles of sustainable development in a context of global change?

France is one of the countries affected by this phenomenon [1]. In view of this, the French government asked various research centers to carry out a literature review on the nature of the eutrophication, its causes and consequences, and potential mitigation measures. A total of 4000 documents (books, peer-reviewed articles) were analyzed in early 2017. In this article, we present part of this work, focusing exclusively on the economic aspects of public policy relating to this problem. For this purpose, 932 articles were selected from the Econlit and Scopus databases. Only the 382 most relevant of those were selected, following a review of their abstracts. More recent works were added later in the context of the Collaborative Land-Sea Integration Platform (COASTAL) research project.

In this chapter, we will focus exclusively on methodological works, using examples from case studies to illustrate a number of points. This will allow us to learn valuable lessons concerning the possible tools that could be developed for public decision-makers. In Section 2, we present general issues surrounding eutrophication prevention, namely, difficulty in defining a clear objective, difficulty in carrying out cost-benefit analyses, and the associated uncertainty and irreversibilities. We will also examine the consequences of combined pollution, both in terms of causes and effects. In Section 3, we explore possible ways of reducing pollution, followed by a more detailed presentation of the tools that can be used to deal with both diffuse and point source pollution in agricultural and domestic areas. The conclusion, in Section 4, summarizes the main lessons that can be learned from this work.

2. Difficulties in combatting eutrophication

2.1. Defining objectives

First of all, objectives have to be defined: without this first stage, it is difficult to rank possible actions and to subsequently evaluate the efficiency of policies. As shown by Naevdal in [4], there is generally an optimal level of eutrophication, which is neither the search for a total absence of eutrophication, which would involve too great a cost for society (lack of economic activities, high purification of water), nor the acceptance, without seeking improvement, of harmful levels of eutrophication. From an economic point of view, the most effective control of a pollutant is achieved when the marginal abatement costs are equal among all those responsible for discharges and when these costs are equal to the marginal benefit of a better water quality (see also Iho et al. in [5]).

That said, in most cases, information on marginal benefits is not available, and biophysical sciences (e.g., natural sciences) will set emission reduction targets based on environmental motives. In this case, the problem is how to achieve (for the best price) a given level of total discharge (or a water quality level), which is agreed upon through political channels. Further complicating the picture, eutrophication is most often linked to threshold effects (concentration levels for different pollutants), and once these thresholds are exceeded, ecosystem dynamics evolve, making it difficult to define optimal policies.

In this situation, as Xepapadeas observes in [6], it is better to couple ecological models and economic models. Such a representation makes it possible to take into account and combine elements such as strategic interactions between economic agents, non-convexities induced by nonlinear loops, different spatial and temporal scales, and the representation of different spatial and temporal dynamics. However, this may require the implementation of complex models. A new form of arbitration must then be found between the simplicity of representations and their realism. Neglecting the phenomena of bifurcation or irreversibility can thus lead to economically or ecologically undesirable states.

2.2. Cost-benefit analyses

Two objectives can be pursued: maximizing the net benefit of actions or minimizing costs with a given objective (see, e.g., Gren in [7] for a comparison of two possibilities applied to the Baltic Sea). Bryhn et al. insist in [8] that the costs of actions foreseen must in any case be compared to the expected benefits: for example, the Baltic Sea Action Plan signed in 2007 appears to have costed € 3 billion per year. It is then important to minimize the risk of waste of such big sums for more or less effective measures.

However, Huppes stressed in [9] that the direct and/or indirect costs of environmental policies are quite complex to define and calculate. For the latter, for example, public authorities bear the costs of control, the disputes arising from them, the costs of research needed for effective actions, companies bearing the costs of constraints, administrative costs, litigation costs, etc.

Additionally, these costs generally have a dynamic aspect (variation over time) that further complicates decision-making. Finally, transaction costs (negotiation costs, consultation costs, system administration costs, decision-making costs, etc.) are often far from insignificant but depend on intervention by public authorities, especially for diffuse pollution (see, e.g., McCann and Easter in [10]).

For policies relating to the agricultural community, von Blottnitz et al. recall in [11] that the way in which policies are implemented also impacts agricultural employment and business linked to the sector, as well as income and production for farmers (see Arata et al. in [12] for an example of reduction of livestock).

It is also necessary to determine who will bear these direct and indirect costs: Modifying certain practices (conditions of the use of fertilizers in agriculture, crop rotation as studied by Power et al. in [13], wastewater treatment modalities) will be reflected in prices (of agricultural products) and taxes (for local water purification) and may also result in a modification of the risks incurred (e.g., risk on the level of the agricultural income, on the quantity of production of food products, with repercussions going beyond the prices). In cost-benefit analyzes, it is essential not to put more emphasis on the present costs but to take better account of the long-term benefits to the environment through a judicious choice of the discount rate that must also incorporate uncertainties (see Ludwig et al. in [14]).

As regards the benefit side, the task is not easy either. For example, the assessment of the environmental or social benefits linked to less eutrophication are the subject of numerous papers (see [1]); but due to a lack of space, we cannot develop this aspect here.

The challenge is to find a method to fight eutrophication that is either incentivizing or binding and which will result in an acceptable balance for all parties (farmers, taxpayers, those benefiting from water quality, etc.), while taking into account the constraints that apply to everybody (agricultural markets fluctuating, overall tax burden compared to other countries, etc.).

2.3. Uncertainties, irreversibility, and robustness of solutions

The results of the various studies are generally derived from models or reasoning subject to numerous uncertainties. Some uncertainties affecting decision-making are described by Singh et al. in [15]: it may take the form of the impossibility of defining a single probability distribution for the most important parameters for the underlying model or to have a single well-defined objective to capture the simultaneous and divergent interests of the main stakeholders. This was already highlighted by Wladis et al. in [16], although it is often ignored by decision-makers.

Turner et al. in [17] also emphasize this fact in a context of scientific uncertainty. One management objective may be to maintain a certain stability of the environment, with parameters remaining within certain limits.

Lempert and Collins in [18] work in a completely different context, which involves making a decision in uncertainty when the links between actions and their consequences are relatively unknown. No attempt is made to seek the optimality of the solution in the context of the assumptions made and of the supposed value of the parameters. The objective is to have a solution that may be less efficient but more robust, namely, less sensitive to assumptions and satisfactory for a relatively wide range of future parameters and conditions, while keeping some options open.

Another difficulty is how to take into account fluctuations in pollutant emissions over time and not just take into consideration average values. This can lead to the simultaneous introduction of a number of different instruments, each pursuing a certain goal (reduction of average pollution, peak pollution).

An adaptive management model is described by Bond and Loomis in [19], where agents use small-scale experiments to test assumptions about global system responses. It is therefore necessary to arbitrate between collecting information and managing the system to achieve the objective (e.g., to move toward an optimal level of pollution). Agents can thus voluntarily deviate from the optimum trajectory for this purpose. Generally, it is understood that this method leads to better and more informed decisions when there are significant uncertainties.

It was within this framework that Ludwig et al. in [20] implemented a profit optimization model related to agricultural activities minus the costs associated with the eutrophication of a downstream lake. They show that the interaction of slow and fast variables can create resilient or vulnerable systems. To manage such a system, the solution may be to monitor appropriate slow variables and take action before it is too late. An approach based on quasi-option values (see Henry in [21]) would lead to a reduction in pollutants so as to remain below this possible limit that would induce a changeover. This is the case here with the potentially slow dynamics of phosphorus in sediments.

2.4. Cross aspects of pollutions

There are many sources of eutrophication, and these sources may interact or have cross impacts. Gren et al. show in [22] how simultaneously taking into account nitrogen and phosphorus to control pollution in the Baltic Sea reduces the overall cost of abatement by about 15% compared to a separate approach.

Kuosmanen and Laukkanen recall in [23] that reducing pollution requires a compromise between the reductions of these different pollutants. For example, the Helsinki Convention set 50% reduction targets for nitrate and phosphate emissions to combat eutrophication in the Baltic Sea. From an economic point of view, there is no reason to expect such uniform rates to produce a socially optimal reduction.

Given a source of pollution, its effects can take different forms, and it is preferable to take all of them into account in calculations. For example, von Blottnitz et al. indicate in [11] that the effects of the use of nitrogen fertilizers are climate change due to the production of these fertilizers, other pollutants emitted into the atmosphere during this production, the greenhouse effect induced by the application of fertilizers, eutrophication, drinking water pollution, and damage due to the emission of volatile substances (especially NH3) from these fertilizers.

In addition, Brink et al. describe in [24] how emissions of one pollutant may have impacts (positive or negative) on emissions of other pollutants. Some of them have local effects (e.g., on the eutrophication of rivers), while others have only an overall effect (greenhouse gases). These indirect effects, as well as their local or global nature, are most often ignored by decision-makers, whereas taking them into account would reduce the total cost of environmental protection, for a given objective.

3. Means to reduce water pollution

3.1. Different tools

Different instruments can be used to reduce water pollution: generally they will consist in incentives, regulations, physical facilities (e.g., buffer zones), or a combination of these. Within the framework of a “command and control” system, the regulator indicates the technical measures that should be taken and verifies that they are effective. For example, different types of standards can be related to agricultural inputs or individual treatment systems. Several problems emerge, all more or less linked to the information that the regulator has on the effectiveness of the measures imposed, the reality of their implementation, the diversity of local situations, and their impact on that effectiveness.

Latacz-Lohman and Hodge showed in [25] how the first generation of European agri-environmental measures have used this method, for example, with dates and concentrations of livestock manure application on agricultural land, while more recently market instruments have been put in place. However, as early as 1998, Cowan insisted in [26] that economic instruments, such as those presented later in this chapter, generally have a better potential in terms of cost-effectiveness than command and control methods.

Setting taxes and subsidies is less prescriptive, since the economic agent can refuse the subsidy or agree to pay the tax and continue as before. It provides incentives for the implementation of environment-friendly measures or discourages certain actions. In the case of subsidies, or payments for environmental services such as those described by Ma et al. in [27], arises the question of the financing capacities, and of "who bears the costs in the end".

In addition, a general problem emerges: Is it legitimate to finance the reduction of pollution, and is it not contrary to the polluter-pays principle? One possibility is to require the polluter to satisfy certain constraints in order to receive subsidies for other objectives (e.g., different agricultural subsidies). This is not a question of funding pollution reduction, but of making it a prerequisite for public aid.

One of the problems generally observed is that these constraints, whose costs to public authorities seem to be low, are often not very targeted or too general in their definition, making them largely ineffective. On the other hand, a certain inequity is created between the beneficiaries of the subsidies, since the cost for satisfying the constraints is not always proportional to the amount perceived.

For sites of specific interest, for example, of great environmental value, it is possible not to pay the owner for the opportunities foregone in protecting the environment, but to make reprehensible the actions harmful for the environment. In other words, the right to property is now accompanied by a duty to protect the natural environment in which that property is located (see Latacz-Lohmann and Hodge in [25]), and payments are made only for positive actions in favor of the environment.

As Romstad points out in [28], these subsidies can also be used to set up buffer zones or to protect wetlands, thus benefitting biodiversity and landscapes and lending less weight to the impression that polluters are subsidized. As for the establishment of wetlands, Byström et al. show in [29], theoretically and with an application in southwestern Sweden, that because the source of pollution is random (seasonal and annual variations), the efficiency of the wetlands is then also random.

In a very different region such as the Mississippi Basin, Roley et al. study and compare in [30] the cost and effectiveness of different measures such as wetlands, intermediate crops, and ditches in reducing nitrogen leakage. It must be noted that the combination of these various means is quite possible. As regards the parameterization of such actions, the system may evolve gradually as direct and indirect effects are observed, as available techniques evolve, and as the level of general pollution develops.

These subsidies, along with taxes, can be applied to inputs such as fertilizers used, and in this case, they are often easier to set up (because of lower transaction costs). The main problem comes from the fact that what is harmful is the pollutant, whereas what is taxed or subsidized is an input, and between the two, there is a whole process of transformation, which can differ from one agent to another. In addition, the impacts of pollutants can be very different from one geographical location to another. It is quite understandable (see, e.g., Taylor et al. [31]) that there is no single optimum instrument for all farms and that the choice of an instrument remains largely dependent on resource conditions and production potentials that impact the costs of reducing pollution. Finally, in the agricultural sector, for example, inputs may differ from one farm to another: the use of chemical fertilizers will be taxed, while the use of fertilizers produced by the animals of the farm will not. Sometimes, it is useful to differentiate measures according to the activities or circumstances in which pollution is generated.

Tradable permits are another option, namely, permits to emit a pollutant that can be sold or bought on a market. These permits are either issued free of charge or initially sold by public authorities (entailing an additional cost for involved stakeholders). Von Blottnitz et al. outline in [11] the properties of this type of instrument. Gren and Elofssen present in [32] different variants, their potential interests, by applying these instruments to their case study (the Baltic Sea). This instrument is more flexible than a command and control system and does not require a lot of information about the polluter. With permits, pollution is immediately reduced, although the level needed for pollution reduction is initially unknown. But if the price of permits on the market is to be equal to the marginal cost of pollution reduction, the regulator should regularly adjust the quantity of permits issued until a socially acceptable situation is achieved. Similarly, Mitchell describes in [33] a system of permits for spreading poultry manure in the Illinois Basin.

It should be noted that spatial heterogeneity has important effects on the level of benefits that can result from the exchange of permits to pollute, and this dimension must be taken into account in implementing such a system (see Lankovski et al. in [34]).

In addition, Akao and Managi show in [35] the importance of taking into account inter-temporal aspects in order to have an efficient system. A free-rider phenomenon (i.e., some people benefit from the effort of others) can arise at different scales: at the macroeconomic level, for example, around the Baltic Sea, some countries may expect their neighbors to make the first efforts, thus diluting the overall impact of pollution. The same effect applies at the local level for activities or people within the same watershed.

3.2. Toolkits for diffuse pollution

3.2.1. General information

Nonpoint source pollution is defined by the fact that the emissions of each agent are not directly observable at a reasonable cost. Xepapadeas describes in [36] three possible methods for reducing domestic and agricultural diffuse pollution, which are difficult to regulate due to information asymmetry between the polluter (who understands the effort needed to reduce effluents and the associated costs) and the regulator (who does not know them) and the random aspects between the polluter's actions (e.g., manure spreading) and the pollution measured in downstream watercourses:

- The first is to consider that pollution is a function of certain production factors (inputs) and the developed instrument is a system of taxes, sometimes subsidies, to reduce these inputs. Rougoor recalls in [37] that the interest of a tax comes from the ease of implementing and the associated transaction costs that are generally low. Negative aspects come from the absence of targeting in the case of problems restricted to a local area, where the scope of application of the tax does not correspond to that of pollutant emitting and more generally to the risk of a competitiveness decrease of the agricultural sector since production costs increase.

- The second is to observe pollution, for example, downstream (at the outlet) of a small watershed, to set an acceptable threshold, and to implement an ambient tax, or a global fine paid by all potential polluters irrespective of actual pollution, when it cross the defined limit; a subsidy may also be awarded where the measure gives a result below the threshold. Compared to a more systematic method of taxation, the first aim is to have a more efficient action because it is adapted to a more accurate geographical area and, on the other hand, to introduce collective responsibility of the farmers or inhabitants concerned. Conditional voluntary contracts can thus be set up, giving that way interest to everyone to respect the contract (e.g., reduction of pollution against subsidies).
- The third is to establish, where it is feasible and cost-effective, a system to control individual pollution and to tax any inappropriate behavior or excessive pollution. This means transforming nonpoint source pollution to point source pollution, which is already the case, for example, for the control of individual septic tanks. It is also possible to allow the polluter to demonstrate the true level of effort he is willing to contribute by choosing from a set of possible contracts or subsidies, the most suitable one for him.

Each option has advantages and disadvantages: for example, measuring inputs can cause excessive information costs in addition to other costs to reduce pollution but is anyway fairer than ambient tax. The latter are an easy way for the regulator to move the problem to a lower geographical level, relying on social control that is more possible within a smaller group. This system of collective punishment remains however particularly unfair and thus may be unacceptable. For this reason, when the third possibility is reasonably possible, it is generally preferred. Otherwise, measurement of inputs, if not too expensive, is a good second choice.

3.2.2. Nonpoint source agricultural pollutions

Agriculture is often an important source of nonpoint source pollution that because of its characteristics should be tackled in a particular way. Generally, solving diffuse agricultural pollution problems cannot rely on any one single solution: Pretty recalls in [38] that agriculture is, by definition, multifunctional (in the sense that it produces different goods together) and possibly the source of different negative externalities but also positive ones (landscapes, carbon sequestration, limitation of floods, etc.). The variety of situations and problems to be solved leads to various deftly articulated solutions to encourage certain practices and to dissuade others, ranging from advice to regulatory or legal measures, and to the use of various economic instruments. As Saysel shows in [39], it is sometimes simply a matter of giving regular and relevant information to agents, for example, on the judicious use of fertilizers depending on the situation. For farmers, financial variables (notably income) are the main basis on which measures are adopted or refused. On the other hand, those located in the most at-risk areas for eutrophication are not necessarily the most likely to adopt them. Grammatikopoulou et al. in [40] have shown for Finland that it is more efficient to implement targeted measure, e.g., for farmers who are the most able to reduce their emissions, although the cost of implementation is therefore much higher. Fezzi et al. worked in [41] on the costs for farmers of different measures to reduce eutrophication: They show, on a case study of watershed in England, the impact of the choice of a measure, especially the variability of this impact from one farm to another. In parallel, they recall the importance of the heterogeneity of soils and agricultural practices on the effects of such measures, as did Konrad et al. in [42] for the Odense Fjord in Denmark.

In the case of the Baltic Sea, Turner et al. [43] show that if the reduction of inputs is the most effective measure, uniformity of reduction measures is not optimal because of different situations between basins.

It is therefore important to think carefully as much about the local application modalities as the choice of an instrument. Konrad et al. use in [43] a spatialized agro-economic model to estimate the effect of different measures (Fjord Odense watershed) and show in particular that geographically targeted measures can lead to high transaction costs, in comparison with uniform measures, if only to define and then monitor their implementation. Xu et al. show in [44] how a well-chosen land use change, and modified agricultural management strategies, may lead to an efficient phosphorus emission reduction.

Three types of incentives for preserving permanent grasslands or converting cultivated land into wetlands on the west coast of Sweden are compared by Gren in [45]: a lump sum payment for the areas concerned, a set of contracts from which the farmer will choose the most attractive for him (thus revealing information about his costs of preservation or conversion), or finally a mutual agreement negotiation that is generally eliminated because it is too time consuming. The choice between the two first possibilities depends on the form of the cost and benefit functions of the farm.

The use of nitrogen fertilizers is studied in [46] by Williamson in the United States. He reminds us that their use depends on the price of fertilizers, the cost of agricultural products, and the way in which farmers manage risks, along with their knowledge of the real need of crops for fertilizers. Hansen and Hansen develop in [47] an interesting method for controlling eutrophication induced by phosphorus pollution: rather than simply taxing phosphorus inputs, they suggest taxing the difference between imports of inputs and exports in the form of agricultural products. Although their model does not take into account hazards, it provides an interesting perspective, especially since it includes storage of phosphorus in soil.

A system of nonlinear taxation and subsidies for reducing agricultural nonpoint source pollution is described in [48] by Bontems et al. Farmers differ according to dimensions such as common knowledge (knowledge shared by a group of agents, in which everyone knows that they all share it), spreading areas, level of production, or private knowledge on the way to limit pollution for equal production. In this framework, the authors look for ways to compensate farmers who implement costly practices but lead to pollution reduction; a system of payments revealing private information on each farmer efficiency makes it possible to improve the effort distribution between farms to reduce pollution.

The payment of subsidies for the adoption of measures to reduce pollution may also be conditional on the outcomes. In that respect, Talberth shows in [49] that payment for grass strips under condition of performance is superior, in the sense that it allows to obtain a better reduction of nutrients for the same budget allocation.

It is also important to avoid falling victim to deadweight effects, with high-cost measures and questionable effectiveness. This is mentioned by Dupraz et al. [50], who note that there is often an advantage to be gleaned from putting in place measures aimed at avoiding limit effects, e.g., applying to a minimum proportion of the farm's surface area or a minimum of intensity. Their model shows that this risk is increased by the information asymmetry that exists between regulators and farmers.

Changes in plowing practices are much more difficult to encourage, as shown in [51] by Orderud and Vogt in a study on an area southeast of Oslo, Norway. For the authors, the solution is to increase farmers' knowledge on the environmental issues and on the phosphorus cycle so that farmers could understand the complexity of the process and not be discouraged by immediate inconclusive results.

Kling presents in [52] an agro-economic model linking land use and resulting nitrate and phosphate pollution. The model is applied on two watersheds feeding the Mississippi River (USA) and makes it possible to test the effects of intermediate crops aiming at reducing eutrophication. He stresses the advantage of linking this type of model with a representation of farmers' behavior.

Establishing drinking water catchment areas with farming constraints that are compulsory and not financially compensated, and other areas where proposed measures are voluntary and financially compensated, is an option examined in [53] by Osborn and Cook, with a case study in the island of Thanet in the Northeastern part of Kent (UK). The authors address the issue of scale when defining zones: it should be not too coarse, so as not to unnecessarily penalize agriculture, and not too refined, for example, only around drinking water catchments for effectiveness purposes. Similarly, Balana et al. in [54], using an environmental, agronomic, and economic model applied to an agricultural area in eastern Scotland, determine the costs and effectiveness of implementing buffer zones along watercourses. They show, on the one hand, that for the same effectiveness in terms of phosphorus reduction, induced costs can be reduced by about 20% just by varying the width of these zones, rather than imposing buffer zones of a uniform width. They show that costs increase exponentially as a function of the amount of nitrate withdrawn.

3.2.3. Domestic diffuse pollution

Withers et al., working on five case studies in Europe (England, Ireland (two cases), Scotland, Norway), show in [55] that the number of individual treatment systems for domestic wastewater such as septic tanks is generally undervalued, which in turn makes other potential sources of eutrophication, in particular agriculture, responsible for the pollution observed.

Beyond the number, the performance of this type of treatment system is difficult to assess, because of a lack of information on their technical characteristics (implantation, age, level of maintenance, proximity to a watercourse, etc.). Although these systems often represent a small part of the nutrient load (mostly less than 10% on annual average in case studies), they can provide significant concentrations during certain periods, particularly in summer, and periods of low water. Increased owners' awareness of the need to properly maintain their sewage treatment facilities can be a fairly effective and inexpensive way to substantially improve the situation.

Motivations of Swedish owners for changing their individual treatment facilities, for achieving a better sewage treatment in order to reduce eutrophication, are examined in [56] by Wallin et al. Owners are motivated more by broader benefits (e.g., an improved functioning of their treatment system) and by fairness relative vis-à-vis other owners (that should not be exempted from the same changes), than by environmental concerns. In this context, economic incentives should work, while increased inspections would contribute to a sense of equity in addition to communication means on the merits of such changes.

3.3. Tools for point source pollution

Domestic, agricultural, or industrial sewage treatment plants are the main sources of point source water pollution, defined by the fact that the emissions of pollutants into the environment come from an identifiable source. Therefore regulations and incentives are generally easier to implement than in the case of diffuse pollution.

Moreover, wastewater can be reused for agriculture or green areas, in compliance with current water quality regulations. In this context, Verlicchi et al. provide in [57] a cost-benefit analysis of the implementation of a post-treatment zone of sewage by planted filters for the city of Ferrara (Italy). Overall, the result of the cost-benefit analysis is positive, despite the use of a discount rate of 5%. It is particularly interesting from an environmental point of view, by reducing the effluent discharged into the watercourse, and also at the urban level by the creation of recreational spaces.

With respect to wastewater treatment, Piao et al. compare in [58] different ways of treating sludge from sewage treatment plants and their indirect effects on eutrophication but also on their potential for global warming, toxicity to humans, and acidification of the natural environment. The incineration of sludge, with ultimate waste treatment, seems to be the best method for these four dimensions.

3.4. Practical conditions for implementation of measures

In most cases, implementing measures is not straightforward because of the different stakeholders involved and the various sources of pollution. Löwgren describes in [59] a process of stakeholder consultation, as called for by the European Union, in the form of two meetings of 1 day, each with a few dozen people, on measures to be taken to combat eutrophication in a watershed in Sweden. The author indicates that the results obtained are not representative in any statistical sense. Farmers are commonly referred to as the guilty party in cases of eutrophication, and they tend to defend themselves by drawing attention to shared responsibility with other professionals. While it is relatively easy to identify the impacts of agriculture, it is much more difficult to assess their benefits: food production, support for certain types of biodiversity, cultural heritage, and open spaces are often seen as given, and farmers no longer draw credit from these externalities either in monetary terms or even in the context of this kind of reflection.

However while cooperation between residents, businesses, and farmers is particularly important in order to combat eutrophication, Iwasa et al. show in [60] from a general model that this can lead to complicated dynamics in the natural environment. This is because the willingness of each stakeholder to cooperate depends on the cooperation of others, as well as on the overall environmental concerns of society. In the model, two factors will affect the decision of each agent: the cost of action for the environment and social pressure. For a lake, social pressure will generally increase with the level of pollution. In total, there are different positive or negative return forces, involving potentially varied dynamics.

Should then decisions be decentralized? Elofsson, working on pollution in the Baltic Sea, recalls in [61] that regional agencies managing water in a basin generally have a more detailed knowledge of local conditions than structures operating at a wider geographical scale, such as the European Union for this case study. It would therefore be interesting to decentralize decisions when assessing the means of reducing eutrophication. On the other hand, there is a risk that regional agencies will act according to their own interests rather than those of the higher-level structure. The model developed actually shows, for the case of the Baltic Sea study, that this effect is not particularly marked.

On this basis, what is the best way to decentralize? Kroiss examines in [62] various empirical strategies for protecting the Danube Basin and shows that much of the technical problems of water protection can be solved through national, regional, or local initiatives.

He mainly distinguishes two possible approaches: definition of an environmental standard or a precautionary method. The environmental standard indicates a minimum level of water quality, which must be satisfied everywhere, and the effectiveness of each treatment is thereby deduced, in particular from the dilution capacities of the natural environment. For the precautionary method, a minimum reduction in pollution or effluent quality must be achieved, regardless of the quality of the watercourse or its dilution or retention capacity.

Both approaches have their advantages and disadvantages (the precautionary approach being preferable for international problems, since the definition of environmental standards is more suited to the management of national basins or where the administration of a basin is centralized). In practice a combination of both would seem preferable. In fact, for the Danube, the main problem is not the translation of these methods in the texts but their actual implementation in practice.

4. Conclusion: lessons to be learnt from past experiences

In defining policies to combat eutrophication, the objective should be defined by models that simultaneously combine biophysical and economic aspects, and not by setting objectives for the state of the system, and then trying to minimize the costs of actions to be carried out. Other approaches can be taken, such as attempting to improve the current situation (e.g., Lake Apopka in Florida described by Fonyo and Boggess in [63]). For the economy, benefits must be compared to costs, whatever the tools used for the implementation of public decisions: command and control, regulation from taxes and subsidies, taxes depending on the results obtained locally (“ambient taxes”), and emission permits distributed free of charge or sold in auction. Uniform measures, such as a percentage reduction of emissions, are generally inefficient, and free-rider behavior is to be expected among some stakeholders.

Five main factors of the problem are often underestimated, as shown above or in practical examples described in the literature but which we do not have the place to present here:

1. The temporal dimension, with irreversibility in particular that may arise when crossing certain limits (e.g., a concentration level of a pollutant). This phenomenon can be taken into account with an appropriate representation of the systems.

2. Pollution often has several causes, and the choice to fight against one or several of them simultaneously or alternatively is far from being neutral on economic results. This is true both for the choice to take action against nitrogen and/or phosphorus in agriculture and to act preferentially or simultaneously on the domestic or agricultural sector or even to arbitrate between diffuse pollution and point source pollution.

3. Pollutions are often multiple (eutrophication, greenhouse effect, etc.), and efficiencies can be gained by taking that into account. Conversely, by taking into consideration the multiple benefits of reducing pollution, it is possible to consider alternatives that would otherwise be unprofitable.

4. The random nature of emissions modifies their effects in terms of eutrophication and may lead to the simultaneous introduction of different instruments. Furthermore, in this case, it may be preferable to seek certain robustness for these solutions, rather than optimality in one direction or the other. There will always be uncertainties, particularly those related to an imperfect knowledge of biophysical phenomena. It is not possible to wait until everything is known before acting. Adaptive management (by updating objectives, tools, or parameters, through experiments) can be a solution in this context.

5. The heterogeneous nature of sources, of the agents concerned, etc. cannot be neglected.

On the whole, it is not conceivable to copy a solution that has proved its worth in one context to solve another problem. On the other hand, lessons can be learned from successes or failures in very different situations. Ecological engineering solutions, apart from the development of buffer zones and wetlands, can have quite risky indirect effects. Sometimes, the question should be asked as to the comparative advantages of modest measures across large geographical areas or more substantial ones in smaller areas.

Finally, it should be noted that throughout this bibliographical analysis, the absence of ideal solutions and the interest of targeted policies designed for particular situations were highlighted. It is often case-driven instruments that can help to solve problems if they have been first properly identified and analyzed and if the solutions under consideration have been assessed in their different implications.

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Conflict of interest

We have no pecuniary or other personal interests, direct or indirect, to declare in relation with the subject of this work.

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