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Addressing Micropollution by Linking Problem Characteristics to Policy Instruments

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Abstract

What characterizes micropollution as a policy problem and which policy instruments are adequate to regulate micropollution, given the specific problem features? In this article, problem characteristics of micropollution are systematically analyzed and linked to potential policy solutions. The findings show that micropollution is a particularly complex policy problem with many remaining uncertainties. Because of the varied sources and entry paths into the aquatic environment, a mixture of appropriate policy instruments is needed. Linking problem characteristics to policy instruments helps to identify an appropriate policy mix. The analysis therefore systematically contrasts the characteristics of micropollution with policy instruments of water pollution control. This way, an overview is provided about what chracterizes micropoollution as a policy problem and which policy instruments are best suited to regulate it. The results show that end-of-pipe solutions are adequate to mitigate pollution from multiple sources up to a certain level, but further source-directed regulatory or economic instruments are needed to eliminate particularly toxic or persistent substances. Additionally, research is necessary to control concentration levels in waters and to identify concentration limits for pollutants. The paper demonstrates that the nature of the policy problem matters for pre-selecting appropriate policy instruments. It concludes that focusing policy analysts' attention on the policy problem can generate further insights into the impact of the issue at stake on policy choice.

Keywords: micropollution, water pollution control, Rhine river basin, policy problems, policy instruments

1 Introduction

In the past two decades, technological progress in chemical analysis has enabled the detection of chemical substances in surface waters at very low concentration levels ($\frac{\mathrm{ng}}{\mathrm{L}}$ to $\frac{\mu\mathrm{g}}{\mathrm{L}}$). This phenomenon, called micropollution, originates from agricultural, industrial and also from everyday uses, such as personal care products, pharmaceuticals, or cleaning agents (Hollender et al 2008, Schwarzenbach et al. 2006). Finding ways to reduce micropollution in waters is important because even these low concentrations can have severe environmental impacts as well as further expected impacts on humans, such as genotoxic, immunotoxic, carcinogenic and fertility-impairing effects (Cunningham et al., 2009; Touraud et al., 2011).

However, the regulation of micropollution is complex because there is no uniform policy solution for the diversity of substances, uses and discharges. To disentangle this complexity the present article addresses the question of how suitable are conventional policy instruments of water pollution control for the reduction of micropollution in surface waters. To answer this question the focus is on the link between the characteristics of policy problems and instrument choice. It is intuitive to believe that certain policy instruments are more adapted to respond to some policy problems than others. The theoretical argument consequently is that problem characteristics matter for instrument choice in that they limit the available options to a reduced number of policy instruments adapted to achieve a defined policy goal. Once this pre-selection has taken place, other forces than problem characteristics can influence instrument choice, e.g. institutions, preferences, learning, parliamentary majorities or policy styles. I argue that analyzing the characteristics of a policy problem provides useful insights into the applicability and adequacy of policy instruments. Therefore, the article reviews a comprehensive list of policy tools that have been put forward by political scientists or practitioners to control water pollution. Out of this conventional canon of pollution control tools, those policy solutions that respond best to the characteristics of micropollution are identified. The aim is to provide an ex ante overview on suitable policy solutions for the regulation of micropollution.

To do so, the paper is divided into four parts. First, a literature overview on characteristics of policy problems is provided as well as an own theoretical framework based on four general problem characteristics (chapter 2). Second, a typology of policy instruments for water pollution control is presented (chapter 3). Third, the four general characteristics of policy problems are applied to the issue of micropollution (chapter 4). This sheds light on the multiple causes and effects of micropollution as well as the prevalence of the problem in the Rhine river basin. The fourth part links the characteristics of micropollution to suitable policy instruments for its regulation (chapter 4). In detail, the ability of policy instruments of water pollution control to respond to the problem characteristics of micropollution is discussed and strength and weaknesses of policy instruments to reduce or mitigate micropollutants are evaluated.

2 The Problem of policy problems

2.1 Existing concepts

Most theories of public policy analysis draw attention to how policy problems enter the political agenda, but neglect the inherent characteristics of policy problems. According to the policy cycle (Easton, 1965), one of the most fundamental concepts of public policy analysis, the definition of a policy problem, is the first step of every decision-making process. In this stage, the existence of a public issue and the necessity of governmental intervention is recognized. Thus, the definition of a problem can have important repercussions on the final political decisions. However the policy cycle analytically focuses on the mechanisms of agenda setting; on how issues are selected for government attention and why some policy problems enter the political agenda and others do not (Schubert and Bandelow, 2009, p. 86); But, the policy cycle neglects what defines a policy problem. Another public policy theory, the punctuated equilibrium theory (Baumgartner and Jones, 1993), specifies problem definition by introducing the concept of framing. Framing is a process in which an issue is portrayed and given a certain image, e.g. a technical image or one linked to general values like equality or freedom (Cairney, 2012, p. 185). This way, framing determines the scope of public interest and involvement. Framing can also have policy consequences by limiting the feasible set of policy responses. For instance, unemployment can be framed as a consequence of deficient education, economic recession or an individual's lack of willingness to look for a job. Depending on the frame, a reform of the education system, measures stimulating economic growth or cutting unemployment benefits, seems the most adequate policy response (Knill and Tosun, 2012, p. 98). However, the punctuated equilibrium's main focus is not on how framing characterizes policy problems, but rather on how triggering events can re-frame policy problems so that punctuated policy shifts are initiated in usually stable policy agendas. The multiple streams theory (Kingdon, 1984) goes somewhat further in characterizing policy problems and claims that causality matters, a process in which responsibilities about who is to blame and who is responsible for solving the problem are assigned (Cairney, 2012, p. 186). Following Kingdon, causality is an important part of framing and thus, shifts in causality also prompt shifts in public policy. Kingdon also stresses the solubility of policy problems, i.e. the fact that a solution to the problem exists. His main argument is, however, not that policy problems differ to the extent to which they can be solved, but rather that policy problems for which a well thought out solution exists, have a higher chance to enter the political agenda. Among the few scholars who established more fine-grained ideas about policy problems are Rochefort and Cobb (1994, p.15-23), who distinguish seven different ways of framing a policy problem, which they label as causality, severity, crisis, proximity, incidence, novelty and problem populations. Depending on how severe, proximate, frequent or new a problem is portrayed, or whether it is termed a crisis, determines to what extent it gains political attention. 'Problem populations' refers to how target groups are portrayed. For instance, framing disadvantaged populations as "helpless" or as "personally failed" will lead to different welfare policies. Rochefort and Cobb's intention is to explain the rhetoric of problem definition and the relationship to agenda setting; they do not aim at defining what distinguishes policy problems from each other.

As demonstrated above, analytical frameworks that aid understanding the policy problem at stake are less developed. However, recent empirical studies suggest that the policy problem is decisive for instrument selection (Sager, 2009, p. 553). When asking policy actors about their instrument preferences, the general answer is: "It depends" (Linder and Peters, 1998). Respondents claim that there is no policy instrument type that is generally preferable to another, but that solutions have to be adapted to the particular problem at hand (Peters and Hoornbeek, 2005, p. 79). For policy analysts, it is therefore important to understand first and foremost the policy problem, which will then provide useful information about the situation to which policy instruments are applied.

Among the few scholars who recognize the necessity to theorize on the characteristics of policy problems, are Peters and Hoornbeek (2005). The authors argue that the nature of a social problem itself pre-determines the choice of adequate policy instruments. They attribute seven characteristics to policy problems, which they term complexity, scales, scope, solubility, divisibility, monetarization and interdependencies. Peters and Hornbeek's approach represents the first steps necessary to characterize policy problems, but some of their seven attributes are analytically problematic because they typify the policy process or policy instruments, and not the problem itself. With political complexity, for example, the authors refer to the idea that political problems vary in their degree of involvement of policy actors in the policy process. In fact, Peters and Hoornbeek characterize the policy process as complex and not the policy problem itself. Another example of this analytic blur is what Peters and Hornbeek term "divisibility". Divisibility refers to the distribution of benefits and costs of a policy. The authors argue that when those who bear the cost also profit from a policy, it is politically easier to solve a policy problem than if the target group and beneficiaries are distinct. Thus, divisibility is clearly an attribute of a policy instrument and not of a policy problem. In the next chapter I will therefore constrain the analysis to attributes of policy problems and not to policy processes or instruments (Peters and Hoornbeek, 2005).

2.2 A new approach: Four general characteristics of policy problems

Conventional public policy theories consider policy problems as a matter of definition. I argue that policy problems, once on the political agenda, have inherent characteristics. Hence, a comprehensive characterization of policy problems provides useful information about the applicability and adequacy of policy instruments. To do so, I propose four characteristics of policy problems, which are inspired by the above presented theories and theoretical concepts.

2.2.1 Causation

Causation refers to distinguishing policy problems according to their causes. In contrast to Kingdon's idea of framing causality, which is independent of the real causes, the idea here is that policy problems can be attributed to actors or factors causing the problem, based on scientific proof. For the choice of appropriate policy instruments, it makes a difference if a problem is due to a single or multiple causes, and whether the problem is anthropogenic or naturally occurring. Analyzing the causes of a problem is not only intuitively, but also scientifically an important step in understanding the policy problem at hand and in finding appropriate solutions.

2.2.2 Prevalence

Knowing the causes of a problem is not sufficient for comprehending the magnitude of the causes of a policy problem. Prevalence is therefore concerned with the scope of the activities or factors that contribute to the creation of the problem, and if the source of the problem is seasonal, all-year-long, local or even global (Peters and Hoornbeek, 2005, p.96-98).

2.2.3 Effects

Policy problems are diverse in terms of their effects or impacts. The idea behind is to analyze in detail what is being negatively impacted by a policy problem, which can be as diverse as the environment, humans, economy, diplomatic relations between countries, security or peace. Understanding the effects of policy problems is politically relevant in that policy instruments can well address the effects of a problem, as opposed to the causes.

2.2.4 Scales

Policy problems differ to the extent to which they produce effects. Where policy problems have negative effects only on a local or regional scale, smaller-scale solutions seem adequate. Some policy problems can be disaggregated into single aspects, which can facilitate decision-making because parts of the policy problem can be addressed step-by-step. But where the policy problem is of a more significant magnitude, comprehensive or all-or-nothing types of solutions are needed (Peters and Hoornbeek, 2005, p.93-94).

The previous chapter dealt with the question of what characterizes policy problems. On the basis of a literature overview in chapter 2.1, an own approach to analyzing the characteristics of policy problems was developed in chapter 2.2. The next chapter provides an overview on possible policy instruments for the regulation of aquatic pollution.

3 Policy instruments for water pollution control

Policy instruments are tools with which governments address public problems by influencing societal processes in order to realize political goals (Salamon, 2002; Braun and Giraud, 2009). There is a vast body of literature on policy instruments. From its roots in instrument typologies (Lowi, 1964; Hood, 1986; Howlett, 2005) the literature progressed to focusing on the choice of policy instruments (Linder and Peters, 1989; Varone, 1998; Ingold, 2008; Howlett, 2009). The latter addresses the question of why governments choose a certain type of policy instrument over another to deal with a policy problem. The question of instrument choice is one of the most central topics in policy analysis because it aims at understanding the factors that influence policy-makers decisions. Understanding these selection mechanisms can give important hints about the conditions under which policies are effective in pursuing defined objectives.

In this article, a conventional typology developed by Howlett & Ramesh (1995) is applied that distinguishes types of policy instruments according to their coerciveness, i.e. the degree to which a policy instrument restricts individual or group behavior. Simplified here, the typology classifies regulations, i.e. prohibitions and restrictions, with the highest degree of state intervention followed by economic incentives such as taxes, fees or charges. Voluntary measures and information are at the lower end of the continuum of state involvement. In addition, Christopher Hood distinguishes tools based on their objectives, which can involve either changing social behavior or monitoring it.

I apply both elements of classifying policy instruments, coercion and objectives. When the objective of a policy is to reduce aquatic pollution one can distinguish two general strategies: first, addressing the source in order to avoid pollution and, second, considering the end-of-the-pipe to filter pollutants from wastewater. By contrast, a third strategy does not aim at the reduction of emissions, but at controlling the amount of pollution in waters (table 1, p. 8). As the previously stated definition suggests, policy instruments aim at "influencing societal processes" in order to make a change. Therefore, I further sub-categorize policy instruments according to where changes will be made. In the case of water quality regulation this change can either be with regard to people's behavior, e.g. by changing the consumption or production behavior; furthermore the composition of chemical substances can be altered by replacing compounds with less hazardous substitutes; or changes can be made by improving filtering technology (cf. table 1, p. 8). It has been stated above that policy instruments are also classified according to their degree of coerciveness. Here, this element of classifying policy instruments is applied to the rank order of the policy instruments in table 1 (p. 8). First regulatory instruments, such as bans, restrictions or other requirements are listed, then economic instruments such as charges or subsidies and finally information campaigns. The overview on possible strategies, changes and policy instruments to reduce aquatic pollution provided in table 1 (p. 8) will be explained element-by-element in the next sections. This way, the conventional canon of pollution control instruments is comprehensively reviewed.

Table 1: Overview on policy strategies, changes and policy instruments for water pollution control

Strategies	Changes	Instruments
Source directed	Changes to chemical substances	Substance ban Authorization restriction
	Behavioral changes	Best environmental practice (BEP) Disposal requirement Product or substance charge Subsidy for behavioral change Information campaign
End-of-pipe	Technical changes	Best available technique (BAT) Subsidy/fee for improved wastewater treatment
	Behavioral changes	Effluent charge
Control		Emission limit Environmental quality norm (EQN)

3.1 Source-directed strategies

3.1.1 Changes to the composition of chemical substances

Substance ban or authorization restriction: Substance bans lead to a complete prohibition of a certain compound and thus to a cease in pollution. Authorization restrictions, by contrast, do not completely prohibit hazardous substances but constrain their placement on the market up to a tolerated cap. Both coercive measures can be extremely effective in reducing or even eliminating pollution from specific substances. Empirical testing, however, shows that improvement is not guaranteed. Herbicides atrazine and simazine have been banned in Germany since 1990, but it took ten years before loads in the Rhine were satisfactorily reduced (Bach and Frede, 2012, p.550). Researchers mainly attribute the input of these banned substances into surface waters to recent illicit applications. This result shows that the implementation of such regulatory instruments must be controlled and infringement sanctioned in order to ensure compliance. Bans or restrictions are therefore also called “command-and-control instruments,” where controlling is a resource-demanding task and the capacity of governments often reaches its limit (Carter, 2007, p. 325-326).

3.1.2 Behavioral changes

Best environmental practice: Best environmental practice (BEP) refers to defining mandatory codes of conduct (Dosi and Zeitouni, 2001, p.137). Most commonly BEP are applied to the correct application of pesticides in order to reduce run-off from agricultural fields. Additionally, BEPs can be formulated to guide all sorts of behavior that can affect water quality, e.g. the appropriate dosing of cleaning agents in private households. BEP are said to avoid excessive costs (Carter, 2007, p. 328). However, controlling compliance with the codes of environmental practice can be a resource-consuming task for the regulator. But if there is no control by the regulator, those being regulated might not feel much obligation to comply with best environmental practices (Dosi and Zeitouni, 2001, p. 138).

Disposal requirement: Disposal requirements are similar to BEP in that they target the behavior of consumers or producers and formulate codes of correct waste disposal. In the case of water pollution control, disposal requirements can be directed, for instance, towards households to ensure that chemical waste, such as paint residues or pharmaceuticals, is not discharged through the toilet (ICPR, 2010a,c).

Substance or product charge: To reduce aquatic pollution a charge can be levied on substances or on final products, that contain hazardous compounds. The advantage of the charge is that it respects the polluter pays principle according to which, those who use the environment as a sink for pollutants face a cost for the damage imposed on the rest of society. This way, it induces a change in consumption behavior towards less hazardous products or substances. Without a charge, products which are causing greater harm to the environment than others are often less expensive. Only when internalizing the costs for water treatment the price of a good fully reflects the total costs of production including the use of water as an emission sink (Carter, 2007, p.333). The revenue raised through the charge can be reinvested in subsidizing water protection measures, e.g. investments in pollution control technologies (Andersen, 1994).

Economists have put forward that such economic instruments are more efficient than command-and-control instruments since the market will regulate itself by suppressing the use of hazardous substances in a cost-effective way. To do so, the charge has to be set at the correct level. When purely levied on the sales the product charge takes the quantity of manufactured substances as a proxy for the environmental impact of a certain type of pollution (Dosi and Zeitouni, 2001, p.134). However, the amount of consumed or manufactured substances is not necessarily in line with input dynamics and the harm it may cause to the aquatic environment. Two industrial companies might use the same amount of chemicals in their production process, but the technology used or the production process might differ so that the input of harming substances into water bodies would differ, too. In that case, a pure sales charge for chemicals would not induce companies to invest in filtering technology or optimize production processes in order to avoid that pollutants are assimilated into water. To circumvent this false incentive, the regulator can take into consideration technology or practices when setting the charge. If a company adopts a technology with a higher efficiency (either fewer chemical substances are needed to produce the same outputs or fewer substances get in contact with water), the tax rate is reduced. But, technological heterogeneity renders such economic incentives very difficult to implement and a simple sales charge – even if charge rates are sub-optimal – are probably more feasible.

However, setting the charge at the correct level, deciding on which substances to charge, and registering all products containing these substances is a resource-intensive task for bureaucracies. The transaction costs associated with registering products and levying charges are high.

Subsidy for behavioral changes: While charges are designed to penalize polluters for some negative behavior, subsidies reward "green" action. They provide for governmental support in return for environmental commitment by the private sector. Hence, subsidies do not give any incentive to refrain from polluting, but can promote environmental-friendly behavior. Subsidies are generally financed via tax revenue and, hence, are a form of governmental expenditure. The eligibility for governmental support can be accredited according to different schemes. Financial support can be granted for mitigation measures that are obligatory to the private sector but pose too much of a financial burden; it can also be made dependent upon the enrolment in an otherwise voluntary scheme.Subsidies can be contingent on attaining environmental standards, i.e. environmental quality norms or emission limits. Alternatively, exceeding a given environmental standard can be a condition for subsidization. Another possibility is the reward system which foresees polluters' subsidization according to observable reduction of effluent-discharges (Dosi and Zeitouni, 2001, p. 135). In the case of aquatic pollution, companies or farmers can be compensated for mitigation measures, e.g. for reducing the use of substances or changing to environmentally more benign substances or optimized production processes.

Governmental expenditures, however, are constrained by the limited ability and willingness of tax payers to support such programs.

Information campaign: Information campaigns deliver insights to consumers, farmers or firms about how to avoid aquatic pollution and, thus, encourage voluntary action. Examples include campaigns on the negative impacts of certain substances on the aquatic environment, the correct application or dosage of products like cleaning agents or on how to avoid runoff of hazardous substances from gardens or agricultural field into waters (ICPR, 2012c). The only leverage information campaigns have is to appeal to morality. Nevertheless this can be a very powerful tool.
A more targeted form of an information campaign is to consult farmers or firms in optimizing their management or production practices to reduce the use of hazardous substances or their input into waters.

3.2 End-of-pipe strategies

3.2.1 Technical changes

Best available technique: While measures to address the problem of aquatic pollution at its source aim at reducing pollution before hazardous substances enter waters, end-of-pipe measures reduce pollution by filtering harmful substances after the input into wastewater. One such end-of-pipe measure is the definition of a technical standard by the regulator. The so-called best available technique (BAT) obliges operators of sewage plants to adapt the technical standard of treatment plants to the one defined by the BAT. If a sewage plant does not comply with the BAT, operators must upgrade their plants with a further treatment step. Examples of advanced technical solutions for wastewater treatment, which can filter very small concentrations of pollutants, include ozonation, activated carbon treatment, or membrane filtering (Reungoat et al., 2011; Altmann et al., 2012).

Waste water fee: In general, a fee is levied in order to cover the costs that arise from a specific service provided, e.g. wastewater treatment. In order to finance advanced sewage treatment the regulator can increase the wastewater fee. This fee is irrespective of the individual impact on water quality and because of its uniform increase administratively easy to calculate. Consequently, increasing the wastewater fee is a common way of financing investments in advanced sewage treatment technology. However, it does not give any incentive for reducing pollution. In fact, consumers who invest in “cleaner” products or make an effort to reduce the consumption of hazardous substances pay the same amount of fees.

Subsidy for improved wastewater treatment: Where the cost of taking remedial action is too high for individual firms or households, governmental support can help reduce aquatic pollution. Governmental support in form of a subsidy can be granted to sewage plants to encourage investments in advanced treatment technology. Of course, limited tax revenues constrain the potential of such incentives.

3.2.2 Behavioral changes

Effluent charge: An effluent charge is paid by those who discharge (treated) wastewater into streams. This way, an effluent charge puts a price on using the environment as a sink (Dosi and Zeitouni, 2001, p.134). Compared to a uniform increase of the waste water fee, the effluent charge system respects the individual impact on water quality. The amount due is calculated according to the quantity or the quality of pollutant emissions. An alternative to charging the amount of emissions is to charge the deviation between the measured emissions and the desired emission standard. In that case, the probability of exceeding quality targets can be calculated and defined to not exceed a certain level. A price can then be set for the risk of exceeding the limit. However, an effluent-charge system is only effective if the regulator is able to monitor the target groups‘ emissions. As an alternative and in order to overcome the administrative difficulties of measuring effluents, the charge can be based on modelled emissions instead of measured ones. The models can estimate the effluent loads based on farming practices, production processes, consumption habits or transport, and provide prediction of emissions attributable to an emitter. However, calculating charges based on models requires the collection of all sort of data, which is a costly and time-consuming endeavour and might not be possible without democratic legitimization.

3.3 Control strategies

End-of-pipe as well as source-directed strategies both aim at reducing pollution. Control strategies, on the other hand, do not abate pollution but provide administrations with information about pollution concentrations, consumption or production practices.

Environmental quality norm: Environmental quality norms (EQN) place limits on the total concentrations of pollutants permitted in waters (Carter, 2007, p. 323). This way, EQN allow controlling the chemical status of the aquatic environment, but if a norm for a certain substance is exceeded it is not possible to identify the source of the pollution. So EQN promote collective responsibility for water quality, but also give leeway to free ride on those who make the effort of reducing pollution.

Emission limit: Emission limits restrict how much an individual source can emit to a defined cap and thus can provide strong incentives to reduce emissions. The advantage of setting pollution concentration standards is that polluters have great flexibility on how to abate. Changes in agricultural or industrial production processes can be made where most effective and cost-efficient in reducing pollution. And, in contrast to EQN, emission limits allow conclusions about the source of pollution. However, they do not give any information about overall water quality and provide no incentive to emitters to reduce beyond the defined emission limits.

Both types of standards, EQN and emission limits, have to be set at the correct level, which requires ecotoxic testing and can be a challenging task.

Other examples of control measures include the extension of monitoring programs or registries to a greater number of pollutants. In case of registries, the regulator obliges consumers or producers to report the use of defined compounds causing pollution to a public authority. Such data can help to create pollution models and to estimate effluent loads. Additionally, a subsidy can encourage producers to invest in monitoring equipment and improve self-monitoring.

3.4 Voluntary measures

Next to governmental regulations, companies or individuals can engage in voluntary measures to reduce aquatic pollution. Voluntary measures are neither required by law nor encouraged by financial incentives (Carter, 2007, p. 329). If there is real commitment to mitigation, voluntary measures can be extremely effective and cost-efficient. However, by relying on voluntary measures only, one cannot guarantee that environmental goals are met and, in fact, deficits are common.

One example of a voluntary measure is private-public partnerships (PPP), which are non-legally binding treaties negotiated on a case-by-case basis between single firms and a public authority. PPP fix a certain type of commitment to pollution abatement by the firm. Usually there are no sanctions if commitments are not fulfilled. PPP give producers the freedom to decide how to best meet goals and put almost no regulatory burden on the private sector by the state, but all too often compliance is low.

Other examples of voluntary measures include: increased distance requirements to rivers, a cease of pesticide use, investments in monitoring or treatment technology or public-public partnerships, where different levels of government negotiate agreements about environmental goals.

4 Case selection and data

4.1 Case selection

The issue of micropollution has only recently been considered a policy problem on political agendas and is particularly relevant to study because it requires decision-making under conditions of uncertainty. Policy makers have to decide if they want to take imminent action based on the precautionary principle or if they want to wait until further research results possibly reveal the humanotoxic danger of micropollution. Because of the huge number of substances, pollution sources, entry points into the aquatic environment, as well as the effects of micropollution, there is no uniform policy solution. Instead, a variety of policy instruments can be applied to reduce aquatic micropollution. This renders the question of what characterizes micropollution as a policy problem and how can governments respond all the more relevant.

The geographical focus of this article is the Rhine river basin. With 200,000 km^2 the Rhine catchment area is one of Europe's biggest river systems, where large scale economic activities as well as the population density along the Rhine continue to pose great pollution threats. The Rhine basin offers a unique case study setting not only because micropollution is a particularly relevant policy problem in the Rhine but also because it is on the political agenda. The International Commission for the Protection of the Rhine (ICPR) with its member states, Switzerland, France, Germany, Luxembourg and The Netherlands, has been addressing pollution problems in general since the 1960s, and is one of the first basin organizations addressing the issue of micropollution. During the conference of Rhine ministers in October 2007, the project group MIKRO was created and charged with developing a "joint and comprehensive strategy for reducing and avoiding micropollutant inputs from urban wastewater and other sources into the Rhine and its tributaries" by 2012.[1]

4.2 Data

This article builds on information from an in depth document analysis and semi-structured expert interviews. The definition of "micropollution" was established through a review of chemical science literature (Hollender et al., 2008; Schwarzenbach et al., 2006). Greater understanding of the multi-faceted nature of the problem – from the detection and risk assessment of concerning chemicals, to the various input pathways and time dynamics, to the multitude of human activities that have caused their presence – was gained through further environmental science literature, as well as from the publications of international water agencies.[2] To assess the effects of micropollution, a review of the possible environmental and human health hazards was performed by means of human- and ecotoxicological literature as well as through resources of the World Health Organization.[3] In order to establish the extent of the micropollution problem in the Rhine river basin, environmental science literature (Bach and Frede, 2012; Sacher et al., 2008) and special reports of the ICPR were consulted (ICPR, 2003, 2010b,c,d,f, 2011a,b, 2012a,b,c). Recent monitoring results for the Rhine water quality (2010 annual report of the international Rhine monitoring station in Weil am Rhein, consultation with the department of environmental chemistry's (Uchem) analytical research group at the Swiss Federal Institute for Aquatic Science in 2012) provided additional insights into the extent of pollution by certain substances along the Rhine (Müller, 2011). These sources also served as references to identify six chemicals of particular importance as contaminants to the Rhine river basin today, i.e. the pharmaceuticals diclofenac and carbamazepine, the herbicides isoproturon and chlortoluron as well as the industrial chemicals diglyme and perflourinated compounds (PFOs).

In contrast, political science literature was used to gather information about policy instruments in general (Braun and Giraud, 2003; Ingold, 2008; Carter,

[1] http://www.iksr.org/index.php?id=317&L=3

[2] (Bendz et al., 2005; Brown, 2012; Buser et al., 2006; Clarke and Smith, 2011; EEA, 2011; EUWID, 2012; Götz et al., 2010; IAWR, 2007; Kortenkamp et al., 2007; MacManus-Spencer et al., 2011; Miao et al., 2005; Richardson and Ternes, 2011; Rowney et al., 2009; Schriks et al., 2010; Touraud et al., 2011; Van den Brink and Mann, 2011; Von der Ohe et al., 2011; Wittmer et al., 2010; Valiente Moro et al., 2012)

[3] (Bercu et al., 2008; Cunningham et al., 2009, 2010; Holbech et al., 2002; Hummel et al., 2006; Johnson et al., 2008; Kidd et al., 2007; Knox et al., 2011; Länge et al., 2001; Manikkam et al., 2012; Martínez, 2008; Mostafa and Helling, 2002; Schwaiger et al., 2004; WHO, 2008, 2012)

2007), and more specifically about instruments for the reduction of aquatic pollution (Dosi and Zeitouni, 2001). Moreover, I consulted ICPR reports (ICPR, 2010b,c,d,f, 2011a,b, 2012a,b,c), European and national water legislation of the Rhine countries just as regional water strategies (e.g. Programm Rheine Ruhr NRW) or water management plans of the Rhine sub-basins (published by Hessen, Bayern, Baden-Württemberg) to gain insights about water quality regulation. The strength and weaknesses of different policy instruments were discussed in personal semi-structured interviews with administrative personnel, practitioners and researchers. From April to September 2012 a total of eleven personal interviews and eight telephone interviews were conducted; there was intensive email exchange with another four people. The interviewees were from national or regional administrations responsible for water quality or chemical regulation in Switzerland, Germany, France, Luxembourg and The Netherlands. Operators of waste water treatment and drinking water plants were interviewed in order to obtain information about practical issues of micropollution. Finally, researchers were consulted for their knowledge in water law (Wasserrechtsinstitut Trier, Germany), in wastewater treatment, ecotoxicology, (Eawag, Switzerland) or chemical regulation (CRP Henri Tudor Luxembourg).

5 Analysis: Linking problem characteristics of micropollution to policy instruments

Previously, four characteristics of policy problems - causation, prevalence, effect and scales - were presented. Subsequently, these four elements are applied to the characterization of micropollution as a policy problem. Building on these insights, those policy instruments, from the conventional canon of pollution control tools, are identified, that are best suited to reduce different parts of the policy problem.

5.1 Micropollution causation

Following the technical definition, micropollutants can be synthetic or naturally occurring. When considering micropollution as a political problem, one may reasonably consider them to be synthetic substances of anthropogenic origin. Hence, micropollution is considered here a problem of man-made origin where pollution from human activities is considered for regulation. As an anthropogenic problem, micropollution is complex because of its multiple causes, including substances, pollution sources, and discharges (cf. table 2, p. 19). In Europe, there are about 100.000 synthetic substances in use. Every year 1000 new chemicals enter the market (Götz et al., 2010; EUWID, 2012, p. 38). The broad range of uses includes: pharmaceuticals (both human and veterinary), hormones, medical imaging contrast agents, plant protection products (pesticides, herbicides, insecticides), detergents or other cleaning agents, personal care products (cosmetics, personal hygiene), industrial chemicals (plasticizers, solvents, dyes, lubricants, etc.) and metabolites, many of which may be as dangerous as the parent compound (cf. table 2, p. 19). Entry paths to the environment are via diffuse or point-source pollution. Diffuse refers to surface runoff from agricultural fields, urban areas, or roads because of rain; diffuse also refers to the movement of water through permeable rock, known as percolation (Wittmer et al., 2010). Point source pollution, on the other hand, originates from wastewater treatment plants. Despite the high standards of wastewater infrastructures, numerous micropollutants are not vulnerable to treatment and are therefore steadily transported from municipal and industrial wastewater into the aquatic environment (Miao et al., 2005). Additionally, after heavy rain, wastewater can be discharged directly into waters without treatment due to insufficient size of storm water tanks. Incorrect disposal or spills can also be point-source forms of entry paths into the environment.

Policy instruments and multiple pollution sources: As elaborated above there are multiple sources emitting micropollutants. Finding an appropriate solution for diverse parts of the problem is politically challenging and the question arises about which policy instruments are suited to reduce micropollution stemming from diverse origins. Where households and their consumption of care products or detergents are the emission source a *product charge* can reduce the consumption and thus the input into wastewater of micropollutants. Additionally *information campaigns* can be a good tool to appeal to peoples' morality and *induce voluntary action*, such as reducing consumption of hazardous products.

Whenever the input of micropollutants can be attributed to incorrect waste disposal, it is necessary to regulate such activities with *disposal requirements*. One such example are pharmaceuticals in wastewater that seem to originate, among others, from households that discharge their old pharmaceuticals through the toilet (ICPR, 2010a). In these cases, it is necessary to define mandatory disposal requirements to prohibit throwing pharmaceuticals into the toilet. However, when households' waste disposal practices are difficult to control for the regulator, emission reductions might not be successful.

Micropollutants arising from industrial manufacturing processes can be reduced by *emission charges*. When the charge is levied on effluents, firms have an incentive to invest in filtering technology or optimize their production processes to reduce the amount of emissions or chemicals used. Charges, however, do not guarantee that emissions are restricted to a defined cap. To do so, binding *emission limits* are most suitable. Since reducing discharges or optimizing production processes can be a resource-demanding task for the industry, the regulator can provide *expert advice* about reduction measures. Where industrial hazardous waste is the source of the pollution, *disposal requirements* can work well when firms are required to deliver proof of compliance.

An end-of-pipe way of regulating industrial emissions is the definition of *best available techniques* in order to improve wastewater treatment. The regulator can promote investments in advanced sewage treatment technology with *subsidies*. Less constraining to the industry are the reliance on *voluntary measures* or *private-public-partnerships* between a governmental body and an industrial company.

Agricultural emissions can be contained at the source by *product charges* on plant protection products. Product charges have the advantage that they respect the polluter pays principle because those who use less plant protection products pay less charges. Another policy instrument adapted to reduce the use of chemicals in agriculture is the definition of obligatory *best environmental practices*. When micropollution can be attributed to a defined agricultural management practice, *consulting* farmers about more environmentally-benign practices can be an effective instrument as well as *subsidizing* those management practices to compensate for higher costs.

Policy instruments and multiple entry paths: Micropollution is not only characterized by the fact that discharges originate from multiple sources, but also by the fact that they enter waterways via diverse entry paths (diffuse and point). In the case of diffuse pollution, which is difficult to treat because of geographical dispersion, *source-directed strategies* are generally preferable to end-of-pipe solutions (Dosi and Zeitouni, 2001, p. 130). Complementary, it is reasonable to define *environmental quality norms* to control concentration levels of diffuse pollution in waters.

In comparison to source-directed strategies, *end-of-pipe measures* are more effective in removing microcontaminants stemming from point sources, i.e. all those discharging into wastewater collection. Since sewage treatment can be very effective in remedying damage from diverse sources of wastewaters, it is the most common solution to water quality issues. However, prescribing to a *best-available technique* can create false incentives since treatment plants have no reason to improve technical standards and reduce their emissions beyond what is required by law. Upgrading sewage plants also increases the demand in energy of waste water treatment, which is contrary to the general turnaround in energy policy. In addition, experts put forward that for some treatment technologies, i.e. ozonation, reactions could lead to by-products which are just as toxic as the parent compound, thus increasing effluent toxicity (Altmann et al., 2012). Furthermore advances in sewage treatment increase costs because of the investments needed. To realize this, means of financing have yet to be found.

Table 2: Micropollution - sources, polluters and entry points into aquatic environment

Substances by usage	**Polluters**	**Entry paths to the environment**
Pharmaceuticals (human and veterinary) Hormones Medical imaging contrast agents	Households, agriculture Hospitals	Point, diffuse Point
Plant protection products (pesticides, herbicides, insecticides)	Agriculture, urban areas	Diffuse
Cleaning agents (detergents)	Households	Point
Personal care products (cosmetics, personal hygiene)	Households	Point
Industrial chemicals (plasticizers, solvents, dyes, lubricants, etc.)	Industry	Point
Metabolites (degradation products)	All	All

5.2 Prevalence of micropollution

When characterizing a policy problem it is reasonable to reflect on the magnitude, frequency or prevalence of the factors causing the problem. To do so, I elaborate on domestic, agricultural and industrial emission sources of micropollution in the Rhine river basin, which gives a good impression of the magnitude of the policy problem.

In 2004, the European Water Framework Directive (WFD) mandated a large-scale inventory of the Rhine river basin. The results suggest that the major challenge for the Rhine river basin is the reduction of chemical pollution. In fact, the chemical status of the Rhine is not sound in 88% of the water bodies.

Various micropollutants are widespread and exceed threshold values (ICPR, 2010e).
These results are not surprising considering that the Rhine basin is with its 58 million inhabitants a very densely populated catchment area.[4] High consumption volumes of pharmaceuticals due to the densely populated urban areas are a major contributor to the $\frac{\mathrm{ng}}{\mathrm{L}}$ to $\frac{\mu\mathrm{g}}{\mathrm{L}}$concentrations consistently detected in Rhine surface water, in some cases exceeding EQN limits. Over 3,000 different pharmaceuticals are legally in use in the European Union; 30,000 tons are consumed every year in Germany alone (Touraud et al., 2011; ICPR, 2010a). Swiss use of the top forty products is on average 100 mg per person, per day. Dutch pharmaceutical consumption is predicted to rise 20% by 2020, and in general, trends suggest increased Rhine area consumption in the future, both more drugs and by more people, especially given the aging of populations. Out of four of the most popularly consumed drugs that are routinely monitored, bezafibrate, sulfamethocazole, carbamazepine and diclofenac, the latter two have been detected at comparatively higher concentrations (ICPR, 2010a).

In the case of estrogens and antibiotics, intensive livestock-raising in the agricultural lands along the Rhine is another source of pharmaceutical micropollution. Dutch emissions of estrogens are an estimated 17,000 kg/year, more than ten times the total hormone contamination from human consumption (ICPR, 2011a). The even more significant contribution of the Rhine agricultural industry to micropollution is its use of plant protection products. 52,100 tons of organic pesticides, equating to more than 500 different active substances, were used in France in 2009 (Stephan et al., 2011). In 2000, the nation used 5,033 tons of phenylurea herbicides, including chlortoluron, one of the most popular due to its long half-life in soil (30-40 days). This property unfortunately also translates into a long half-life in water, more than 200 days. Herbicides remain one of the most important groups of plant protection products in the Rhine basin, used in great quantities on agricultural land and appearing often in surface water as a result (Valiente Moro et al., 2012). 2011 monitoring results from Müller taken at Rhine at Weil showed concentrations of <10 to <50 $\frac{\mathrm{ng}}{\mathrm{L}}$ for the herbicides bentazone, simazine, atrazine, isoproturon, metazachlor, chlortoluron, MCPA, and mecoprop. The challenge of mitigating plant protection product contamination is matched, however, by the large industrial sector present all along the Rhine.

The Rhine basin contains the greatest density of industrial plants on its shores of all the major international river basins. There are six main industrial centers distributed along the course of the Rhine from Switzerland to the

[4] http://www.iksr.org/index.php?id=26&L=3&cHash=455fdab52ce6eafbf6f72632159564bf

Netherlands such that concentrations of persistent industrial chemicals only increase as one travels down the river: Basel is famous for its medicinal chemical manufacturing sector and, along with neighboring Mulhouse and Freiburg, is host to leading corporations of agro-chemicals, the food industry, textiles, metals, nanotechnology, biotechnology, materials, construction, and personal care products [5]. Strasbourg is known for textiles, food and metals. The Rhine-Neckar area, consisting of the cities of Karlsruhe, Heidelberg, Mannheim, and Ludwigshafen, well represents the chemical industry. Frankfurt-Rhine-Main produces chemicals, rubber, electrical materials and metals. Cologne, Düsseldorf, and Duisburg in the Rhine-Ruhr region are famous for petrochemicals, refineries, metals and automobile production. Finally, plants in Rotterdam-Europoort produce chemicals, automobiles, and metals; and refineries operate there as well.

Moreover, micropollution is not only a matter of geographical spread but also of seasonality. Usage in society affects pollutants' input dynamics (Hollender et al., 2008). Cleaning agents and pharmaceuticals, for example, are used and produced continuously throughout the year and wastewater treatment effluents are constantly being dumped into surface water. Plant protection products, in contrast, have time-sensitive dynamics. They are applied seasonally and are more prone to sudden run-off from changing weather patterns or due to spills and improper disposal. Some urban products exhibit this seasonality as well when they are used in private horticulture (Wittmer et al., 2010).

Policy instruments and omnipresence of causes: The above outlined population dynamics and agricultural or industrial activities in the Rhine catchment show that causes of micropollution are omnipresent and deep-seated in the riparian societies. A complete elimination of the causes of micropollution is thus an enormous challenge. Prioritization can help to focus towards the most common and dangerous substances or towards the main pollution sources. Control measures, such as *environmental quality norms* are an appropriate policy instrument to gain information about concentration levels of micropollutants and, thus, to define priorities. EQNs seem most appropriate for indicator substances, where one compound is a proxy for pollution by a whole substance group or jointly consumed compounds. *Emission limits* provide an appropriate way to control the amount of emissions from agricultural or industrial point sources. Where concentration patterns are constant, large-scale policy solutions are reasonable. Peak concentrations, on the other hand, require periodic or occasional solutions.

[5] http://www.iksr.org/index.php?id=231&L=3

Policy instruments and seasonality: It has also been stated above that the prevalence of certain substances can vary depending on the season. In such a case, the regulator may rely on formulating *best environmental practices* which can incorporate time-sensitive dynamics by formulating codes of conduct depending on weather patterns or the season.

5.3 Effects of micropollution

The label "micropollutant" already suggests that the negative effects are aquatic pollution in small concentrations. To decide whether chemical compounds warrant the label of "pollutant," mainly depends on its toxicity, which is the harm caused to aquatic organisms and humans who encounter the substance (Schwarzenbach et al., 2006). Because uncertainties remain with regard to the ecotoxicology and human toxicity of aquatic micropollutants, policy makers may have difficulty deciding whether or not to take policy action. In the following section, I give a first impression of scientific knowledge on the toxicity of micropollution by taking the example of six widely used compounds of pharmaceutical, agricultural and industrial use.

In the 1990s UK scientists published findings about the "feminization of fish" that had been exposed to wastewater effluents. The team was able to prove that the hormone system was affected by a synthetic estrogen typically found in contraceptive pills (Sedlak et al., 2000). The alarming results of the effects of 17α-ethinylestradiol on fish populations have helped to identify pharmaceuticals as one of the primary groups of emerging pollutants. Subsequent research on the impact of human hormones on fish populations conducted after the publication of the British study supports the original findings (Länge et al., 2001). In a seven-year study in the Experimental Lakes Region of Ontario, Canada, a lake receiving 17α-ethinylestradiol (EE2) inputs, at levels comparable to those observed in untreated and treated municipal wastewater, was compared to the controls of the other lakes in the region. After only two seasons of EE2, the fish experienced a reproductive failure, i.e. no fish were born resulting in a near-extinction of the species from this lake (Kidd et al., 2007). The inability to reproduce was due to the disruption of gonadal organs that produce ovaries and testes, and the presence in some individuals of intersex, having both male and female gonadal tissues (Kidd et al., 2007). In a recent publication, the tranquilizer oxazepam has been found to alter the behavior of wild European perch, which showed increased activity, reduced sociality, and higher feeding rate, at concentrations encountered in effluent-influenced surface waters (Brodin et al., 2013).

There remains a great deal of uncertainty regarding these contaminants, however, and quantitative studies completed thus far have found no appreciable adverse effects on human health due to trace amounts of pharmaceuticals consumed in fish or drinking water, or due to exposure in aquatic environments (Touraud et al., 2011; Johnson et al., 2008; Rowney et al., 2009; Cunningham et al., 2009; Bercu et al., 2008). Exposure assessment has demonstrated that many pharmaceuticals have observed environmental concentrations significantly below their lowest observed effect concentration (LOEC) (Richardson and Ternes, 2011). There were several notable exceptions for which wastewater effluent concentrations were similar in chronic toxicity: 17α-ethinylestradiol, diclofenac, and carbamazepine (Richardson and Ternes, 2011). Carbamazepine is used to treat bipolar disorder and epilepsy (specifically an anti-convulsant, analgesic, anti-manic) and diclofenac, an anti-inflammatory drug (NSAID), are both widely consumed in Europe. Rainbow trout exposed to diclofenac were found to have accumulated diclofenac in the liver, kidney, gills and muscle tissues causing particular damage to their gills and kidneys (Schwaiger et al., 2004). A subset of pharmaceuticals, antibiotics, provoke an entire set of additional questions, with micropollution now thought to be connected to the global challenge of antimicrobial resistance (Martínez, 2008). Nevertheless, the literature does not yet address most of the pharmaceuticals in use (Richardson and Ternes, 2011). In fact, thousands of compounds are not yet rigorously examined and great uncertainty remains about their behavior and toxicity to humans and the environment. Additionally, addressing the problem of micropollution requires examining more than the sum of the many chemicals appearing in surface water; the chemicals affect each other and possibly entire ecosystems. Even if a given substance is at a concentration too low to be harmful, when mixed in water with other chemicals, the combined effect can be devastating. In most of the case studies examined by Kortenkamp et al. (2007), mixtures of pharmaceuticals contained a joint toxicity greater than individual toxicities.

Examples of herbicides which are widely applied in agriculture are isoproturon and chlortoluron. Even though there is little data on their effects on humans (WHO, 2012, 2008), it is not surprising that they negatively affect algae poplulations in acquatic environments by suppressing the growth of algae (Mostafa and Helling, 2002; Valiente Moro et al., 2012). By intent, herbicides are manufactured to inflict harm on living organisms. Damage to microalgae is not only harmful for their own populations, but also for the entire ecosystem, as algae are the basis of the food chain and perform other important functions, including the degradation and recycling of decaying organic matter.

Diglyme is an industrial chemical solvent typically used to manufacture semiconductor chips (electronics), adhesives, paints and sealants. Occupational exposure studies of female workers in semiconductor factories showed an elevated risk for spontaneous abortions and subfertility defined as requiring more than one year of intercourse to conceive (WHO, 2002). From these studies it can be concluded that diglyme has significant negative endocrine and fertility effects on humans. Perflourinated compounds (PFOs), used in the production of polymers, dyes, varnishes, oxidants, reductants, detergents, corrosion inhibitors, semiconductors and biocide, are generally accepted as endocrine disruptors, with several studies providing evidence to support this. Recently published is the Lopez-Espinosa et al. study of the effects of perflourinated compounds on over 10.000 children living near a chemical plant in the Mid-Ohio Valley in 2005-06. PFOs were positively associated with higher thyroid hormone levels and thyroid disease, usually hypothyroidism. Other scientific studies also establish the risk of thyroid disruption or even damage as a result of exposure to PFOs (Knox et al., 2011; Melzer et al., 2010).

Policy instruments and toxicity risks: The preceding paragraph demonstrated that there remain uncertainties about the effects of micropollution on humans and the environment. In the face of such knowledge gaps, political decisions are taken under uncertainty. If one cannot eliminate the potential for micropollution to pose significant risks to humans or to the ecosystem at current toxicity levels, political measures, which mitigate the risk, are in compliance with the precautionary principle - also known as the safety-first approach. It is a political decision to take such precautionary measures or to wait until even more studies prove or disprove the risk of micropollution.

For those substances that pose a significant toxicity risk to humans or the aquatic ecosystem, *substance bans* or *authorization restrictions* may be an effective way to reduce, or even to eliminate, particularly hazardous micropollutants. Prohibiting substances is a particularly appropriate tool where substitute substances exist that are less toxic than the parent compound. But where uncertainties about effects remain, it is most adequate to adopt instruments that improve knowledge gaps, i.e. promoting *research*.

5.4 Scales of micropollution

Micropollution produces risks on varying scales since pollutants differ to the degree to which they are persistent and bioaccumulating. Persistent compounds resist natural decomposition and therefore remain in their original form in aquatic systems for a long time, sometimes posing problems hundreds or thousands of kilometers from the contaminant source (Schwarzenbach et al., 2006). Compounds can also be of high concern to living organisms if they are bioaccumulating – incorporated into living tissue - thus remaining in the or-

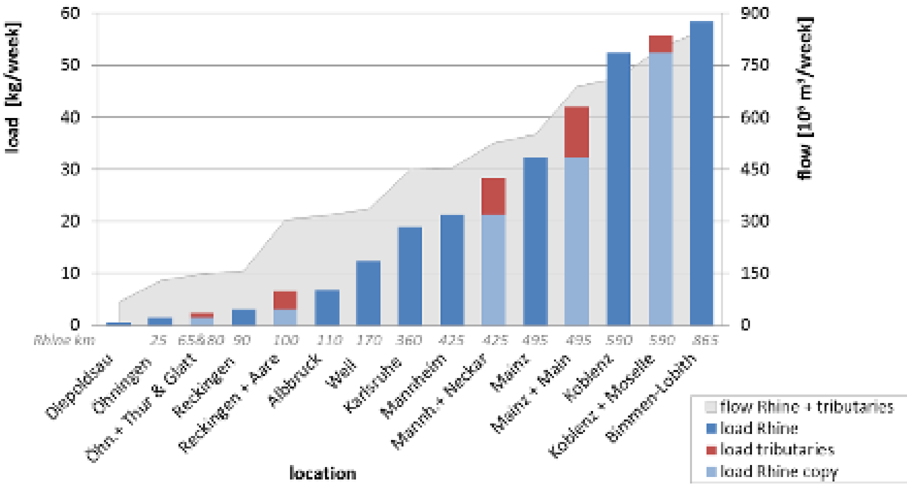

Figure 1: Weekly load of carbamazepine in a spatial pattern of the Rhine and its main tributaries (Source: Müller 2011)

ganism and found in progressively greater amounts higher up the food chain. Bioaccumulating compounds are often also persistent, and therefore are likely to be problematic both throughout an entire waterway and in living organisms. In figure 1 (p. 25) monitoring results for carbamazepine, a widely consumed pharmaceutical, demonstrate this accumulation. Each measurement station along the Rhine (shown on the x-axis by both city name and number of kilometers from the river source) reveals progressively higher concentrations. These statistics confirm that concentrations of micropollutants often increase with greater distance from the river source, strongly suggesting persistence. All residents and economic activities in the basin contribute to the presence of contaminants, and the effects are cumulative.

Policy instruments and persistence / bioaccumulation: Where hazardous compounds are persistent throughout an entire waterway, there is the need of a basin-wide commitment to act and to coordinate regulatory measures amongst the entire Rhine community. Thus, a large-scale policy solution, i.e. *internationally coordinated substance bans or restrictions*, is needed for persistent substances. Certain substances, in contrast, can be present only in a part of a water body because of specific industrial branches that do not exist elsewhere, local agriculture or a particular consumer behavior. In these cases, targeted measures have to be adapted to the regional specificities and smaller-scale solutions can be more proportional to the extent of the policy problem.

The question of scales reflects the multi-level governance aspect of micropollution, where a one-size-fits-it-all sort of solution does not exist. Instead, policy measures can benefit from greater acceptance if they are proportional to the scale of the problem, which means acting on different political levels and adopting different policy instruments on different levels.

To sum up, Table 3 (p. 27) provides an overview on the characteristics of micropollution as a policy problem and the policy instruments adapted to reduce or mitigate pollution.

6 Conclusion

While there is a huge body of political science literature on policy instruments and an increasing amount of publication on micropollution by ecotoxicologists, there is a gap in research when it comes to the link between both scientific communities. This article contributes to close this research gap by linking the characteristics of micropollution to potential policy instruments. The aim of this paper is to characterize micropollution as a policy problem and, based on this knowledge, to discuss the ability of different policy instruments to reduce micropollution.

To summarize, the above-presented discussion about the characteristics of micropollution suggests that it is an umbrella term, which includes varied smaller policy problems. Characterizing micropollution also reveals that it is a complex issue because of the diversity of pollution sources, the remaining uncertainties with regard to the eco- and humanotoxicology, the transboundary effects of micropollutants and its multi-level and multisectoral governance aspect. Whenever substances pose significant toxicity risks to humans or the ecosystem at the levels at which they are present, political measures are clearly needed to mitigate that risk. With their varied sources and uses, micropollutants enter surface waters through many different pathways, necessitating a mixture of appropriate policy solutions addressing the source of pollution and the end-of-the-pipe. Linking problem characteristics to instrument features can help identifying an appropriate policy mix, which responds to the diverse characteristics of micropollution as a policy problem. In this regard the paper was successful in proposing an instrument mix particularly suitable to address different parts of the policy problem. The analysis suggests that a balanced policy mix builds on end-of-pipe measures such as formulating BAT for sewage filtering technology in order to cope with the fact that micropol-

Table 3: Overview on policy problem characteristics, characteristics of micropollution and policy instruments for pollution reduction or control

Problem characteristics	**Characteristics of micropollution**	**Policy instruments well suited to address problem characteristics**
Causation	Multiple sources:	
	Household discharges (from cosmetics, detergents, pharmaceuticals)	Product charge, voluntary measures, information campaigns, disposal requirements
	Industrial discharges	Emission charge, emission limits, consulting, disposal requirements, BAT, subsidies, voluntary, PPP
	Agricultural discharges	Product charge, BEP, subsidy, consulting
	Multiple entry paths:	
	Diffuse	Source-directed measures, EQN
	Point / wastewater treatment plants	End-of-pipe measures, BAT
Prevalence	Omnipresence of causes	EQN, emission limits
	Seasonality	BEP
Effect	Toxicity risk	Bans, authorization restrictions
	Uncertainties about effects	Research
Scales	Persistence, bioaccumulation	Internationally coordinated bans, authorization restrictions

lution is caused by multiple sources. Additionally, source-directed measures such as bans or authorization restrictions are nevertheless necessary to reduce or eliminate particularly toxic or persistent substances. While economic instruments, such as product or emission charges and subsidies, can induce behavioral changes from households, industrial and agricultural emitters, the control of pollution levels via EQN or emission limits is of particular importance. In addition, research is needed to close the existing knowledge gaps concerning toxicity risks of micropollution. And finally, information campaigns and consulting can promote the reduction of micropollution through voluntary behavior.

On a theoretical level the paper demonstrates that the effectiveness of policy instruments also depends on the nature of the policy problem. It is in line with the theoretical argument "policy problem matters" to argue that different parts of the policy problem require different policy solutions. Further research can build on these insights and formulate hypotheses on the links between problem characteristics and instrument choice.

Finally, this paper is a contribution to the general aim of policy analysts to achieve more efficient and optimal policy results by providing a better understanding of the nature of policy problem and the potential solutions in terms of policy instruments. However, the paper is a preliminary and basic analysis. Further research can establish a more systematic overview on which policy instruments respond best to different aspects of policy problem characteristics.

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