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Monetary Valuation and Internalization of Externalities in German Agriculture Using the Example of Nitrate Pollution: A Case-Study

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Abstract: Plants are dependent on nitrogen for their growth. However, if more plant nutrients are deposited than the plant can absorb, the excess nitrogen seeps into the soil where it accumulates as nitrate. About 74% of the drinking water produced in Germany comes from groundwater. The legal limit of 50 milligrams of nitrate per liter of fresh water is exceeded frequently in Germany, especially in agricultural areas. High levels of nitrate in drinking water can quickly lead to health issues, under certain conditions. The nitrate problem is omnipresent in Germany. However, studies which determine the externalized costs of nitrogen eutrophication are mostly missing. The present study closes this gap by combining the results of a transdisciplinary investigation from hydrological analyses and environmental-economic calculations. Water samples were taken from a deep well in Hauneck, which is a municipality in Hesse (Germany). Afterwards, an isotope analysis was carried out to determine the groundwater residence time and possible sources of nitrate. Thus, in addition to the sources of pollution, concrete social costs were determined, using a damage cost approach as well as an avoidance cost approach. For Hauneck, it was found that about 54% of the drinking water price is directly linked to the externalization of costs. These are borne via the principle of the common burden. In addition, the isotope investigations have shown that the removal of excess nitrate will continue for decades, which will lead to long term external costs. The paper reveals how the internalization of these costs can contribute to the conservation of water resources.

Keywords: internalization of external costs; negative externalities of nitrate; environmental economics; agriculture; conservation of water resources

1. Introduction

The Nitrate Directive (91/676/EEC) has been in force at European level since 1991. It aims to improve water quality in Europe by protecting groundwater and surface water against nitrate (NO_3) pollution from agricultural sources [1,2]. After France had already been sanctioned in the past for non-compliance with the directive, the EU Commission also sued Germany in 2016. In particular, the problem of over-fertilization with liquid manure, dung, and artificial fertilizers in agriculture were identified as causes [3,4]. In 2019 the European Commission urged Germany to implement the judgment on breach of EU rules on nitrates [5].

In principle, plants are dependent on nitrogen (N) for their growth. However, if more plant nutrients are deposited than the plant can absorb, this leads to considerable problems. The excess N that is not absorbed by the plants cannot be stored in the soil and seeps into the groundwater, where it accumulates as NO_3. NO_3 causes various ecological and social consequences, namely eutrophication of water bodies, an acceleration of climate change, and effects on human health [6–9]. High NO_3 levels in drinking water can quickly lead to health issues, which is why Germany has a legal limit of 50 milligrams NO_3 per liter of fresh water [10]. These requirements can be found in the Drinking Water Ordinance (TrinkwV). Exceeding the limit value according to Annex 2 to § 6 Section 2 TrinkwV can be regarded as pollution. Twenty-eight percent of all groundwater measuring points in the German EU NO_3 monitoring network for agriculture, which includes 697 monitoring sites, exceeded this value in the period from 2012 to 2014. Regions with high livestock densities are particularly affected [11].

The considerable environmental challenges resulting from over-fertilization with N in Germany were identified already in the 1980 s [12,13]. Although the condition of the water in Germany has improved both quantitatively and qualitatively since then, it is still far from the requirements of the EU Water Framework Directive. An assessment of the chemical status of groundwater in Germany in 2014 shows that 37% of all aquifers are in poor chemical status. The main causes are diffuse pollution from nitrate and pesticides from agriculture [11].

The NO_3 pollution of groundwater leads to negative externalities (e.g., [6–9]). Externalization occurs when the preference order (benefit situation) of an economic entity includes real variables that are directly dependent on the activities of other economic entities, i.e., without mediation by the market mechanism [14–16]. A distinction can be made between production and consumption and between positive and negative externalities [17]. Externalization through over-fertilization with mineral fertilizers and liquid manure and the associated groundwater pollution can be characterized as a negative production externality, since the production possibilities of one economic subject are influenced by the behavior of another economic subject. The increased N inputs accumulate NO_3 in the soil, which is then discharged into the groundwater. About 74% of the drinking water produced in Germany comes from groundwater and spring water reservoirs [18]. If the legal limit of 50 milligrams NO_3 per liter of drinking water is exceeded, the water can be technically treated or mixed with water from other sources. This results in increased costs for the water suppliers, who must subsequently increase the price of drinking water. It is clear here that the costs of initial over-fertilization are not borne by the polluter himself (polluter-pays-principle) [19], but ultimately by the consumer in accordance with the common burden principle. Even though the recognition of the negative externalities associated with N is growing, the damage costs of N to air, water, and climate remain largely unquantified [20]. Because these costs are often borne by society, they can be called social costs [20,21]. Waterworks pay for the removal of pollutants from water, which usually leads to a higher water price. Nature conservation authorities pay to counteract the progressive erosion of soils [9], and health insurance companies are sued for the health consequences of polluted air and chemically contaminated products. Ultimately, future generations are also affected by these externalities, as they have to pay for the consequences of climate change, for example.

The return of externalized costs to the allocation mechanism of the market is achieved through the internalization of external effects [22,23]. The internalization pursues the goal of harmonizing private and social rationality, by aiming to an optimum of Pareto. This best possible state is reached when it is no longer possible to improve one (target) property without simultaneously worsening another. For this purpose, the prior determination of the optimal level of emissions is required. According to this, the externality caused by the emission is internalized just when the optimal level of the emission is reached. This is done by charging the external costs, i.e., by feeding them back into the allocation mechanism. The aim here is to eliminate the misallocation (market failure). To this end, the activity that triggers an external effect must be limited so that the net benefit of the limitation is maximum. The net benefit results from the reduction of the gross benefit by the costs of the cap [14].

Within the framework of the internalization of external effects some strategies have been developed. These include damage-oriented instruments such as negotiations according to Coase [21], environmental liability law, or the Pigou tax [24]. Pigou's theory puts the state at the center, as it should influence the behavior of those who cause negative external effects through taxes. On the other hand, those causing positive external effects should be favored by subsidies. The assessment of taxes or subsidies should be made in such a way that the polluter will try to carry out his activity at the socially optimal level in his own interest [24]. On the other hand, standard-oriented instruments of environmental policy such as certificates, levies, and conditions have become established. The instruments mentioned are not explained in detail because they are of little relevance to the case study at hand. The internalization of external effects requires a high level of information, especially about the scale and distribution of benefits and costs of N-related damages, which is why N management is one of the critical environmental challenges of the 21 st century [20,25,26].

Since a monetary evaluation of the economic damage requires a very high level of information, it has only been quantified precisely in a few cases. The best-known international study on the subject is by Jules N. Pretty et al. and is entitled "An Assessment of the Total External Costs of UK Agriculture" [27]. The publication from the year 2000, which has since been revised several times, calculated external costs for Great Britain at 82 € per inhabitant or 298 € per hectare, which can be directly justified by agriculture. Pretty et al. (2000) [27] distinguished in the calculation between effects on natural resources such as air, soil, water, or biodiversity and effects on human health. For the period from 1990 to 1996, the authors calculated total annual costs of approximately €5.2 billion for the UK. The most significant costs were identified in the area of greenhouse gas emissions and drinking water pollution. In another paper, Pretty et al. (2001) address the policy challenges and priorities for the internalization of external costs in agriculture [28]. In a French study from 2011, Bommelaer and Devaux calculated that the complete remediation of the French groundwater body from pesticide and fertilizer inputs would cost more than €522 billion [29].

For Austria, a study from 2013 is available [30], which uses the benefit transfer method [31,32]. Without going into detail about this approach, it should be mentioned that this is an instrument that transfers the initial model of an existing study to a new study. For the Austrian paper, the British paper by Pretty et al. was used as a baseline study, based on which certain external costs of Austrian agriculture were calculated. An "adjusted benefit transfer" approach was chosen for the transfer. Here, the values from one country are adjusted according to the most important known factors that differ in the original context and in the study context. Accordingly, Austrian per capita income was included, and the utilized agricultural area was adjusted.

A study from the United States replicates the study by Pretty et al. (2000) with US data. Tegtmeier and Duffy examined the external costs of agricultural production in the United States by reviewing and revising valuation studies to compile aggregate figures [33]. External costs are estimated at $5.7 billion to $16.9 billion annually. Another study quantifies the external costs of pesticides in Thai agriculture using two methods: Pesticide environmental accounting (PEA) and an actual cost approach [34]. The paper by Praneetvatakul et al. was published in 2012 and provides not only calculations of external costs but also concrete proposals for internalization. A cost–benefit analysis for the European Union was presented by Van Grinsven et al. in which both the follow-up costs and the benefits of N from agriculture were quantified and monetized on the basis of metadata for the reference year 2008 [35,36]. The social cost of impacts of N in the EU27 in 2008 was estimated between €75–485 billion per year.

Based on Van Grinsven et al. (2013), Gaugler et al. (2016) have transferred the methodology to Germany and made corresponding calculations [37,38]. For the reference year 2008, the actual reactive N emissions in Germany were added up, resulting in external costs of approximately €11.53 billion. Although Gaugler et al. calculate external costs approximately, the Federal Organic Food Industry Association (BÖLW) stated in 2015 that there are no studies in Germany in which the external costs arising from non-sustainable agricultural production are precisely determined [39]. This means that there is no holistic survey that quantifies the entire German agricultural sector against the background of externalization. However, there are individual publications that deal with various related sub-areas of this topic. For example, a report by the Federal Environment Agency entitled "Quantifying the costs caused by agriculture to secure drinking water supply" appeared in 2017 [40]. In this report, the agriculturally caused costs incurred by water suppliers in the context of drinking water supply were analyzed. In particular, the nitrate problem was focused on. With the help of model regions, reactive and preventive measures that utilities take in view of nitrate pollution were investigated. The economic concept of the internalization of external costs was not considered. Teufel et al. delivered an analysis of the current situation regarding external costs in agriculture in Germany in 2014 [41]. On the basis of a literature review, it attempts to identify the substantive core of the externalization debate in agriculture and discuss the external costs of unsustainable agricultural practices. It also includes unhealthy diets in the analysis. However, it is also acknowledged here that the overall data situation is very poor and only few studies on the external costs of food production or agriculture have been found.

It could be shown that various international studies on externalization in agriculture in general and monetizing N-related damages in particular are already available. The main focus is usually on approximate extrapolation of external costs within a country, but studies which determine the externalized costs of N eutrophication in a specific application are mostly missing. The case study presented here deals with a concrete area of investigation for which external costs were quantified, through an interdisciplinary approach. The monetization of external costs is helpful because it makes these costs more tangible. In order to be able to generate conclusions for practical application, knowledge of the positive and negative external effects in monetary terms is an important prerequisite. This paper focuses on NO_3 pollution in groundwater and relating external costs combining hydrological and economic methods. The deep well Rotenseef in the study area Hauneck serves as a practical example. Hauneck is a municipality in Eastern Hesse (Germany), where nitrate investigations were already carried out in 2003 on behalf of the competent authority. Isotope investigations have shown that agriculture is the main culprit for excessive nitrate pollution in the area. The present example is intended to show how the costs incurred were externalized and what countermeasures the municipality took. The combination of hydrological and economic studies allows correlations to be established between nitrate residence times and the cost structure. Specifically, the question is how long a certain region needs to recover from external effects from a monetary point of view.

2. Materials and Methods

2.1. Description of the Location and General Approach

The NO_3 content in the water of the deep well Rotensee in the Hessian municipality of Hauneck has been showing an increasing tendency since about 1975, which is why a first investigation was conducted in 2003 in order to assess the aquifer system structure and the process mechanisms of the NO_3 content. The aim was to determine the origin of the elevated NO_3 contents and to find out how long it takes for the NO_3 to reach the deep well. Subsequently, recommendations for action for the community were to be derived. From the 2003 report of results it can be seen that it was recommended to mix the well water with external water from the central distribution system of the nearby town Bad Hersfeld in order to be able to guarantee in the long term that the drinking water limit of 50 milligrams of NO_3 per liter of fresh water can be maintained. The municipality, willing to keep its own water supply infrastructure, followed this recommendation and built a drinking water replacement supply between 2004 and 2007. The 2003 report of results further illustrates that NO_3 signature is characteristic of agricultural areas. This conclusion was proven by isotope investigations, whereby the isotope signatures on NO_3 result from a mixture of different NO_3 components and stable manure (liquid manure) is the dominant source. The nitrate concentrations measured in the period from 1968 to 2017 are shown in Figures 1 and 2.

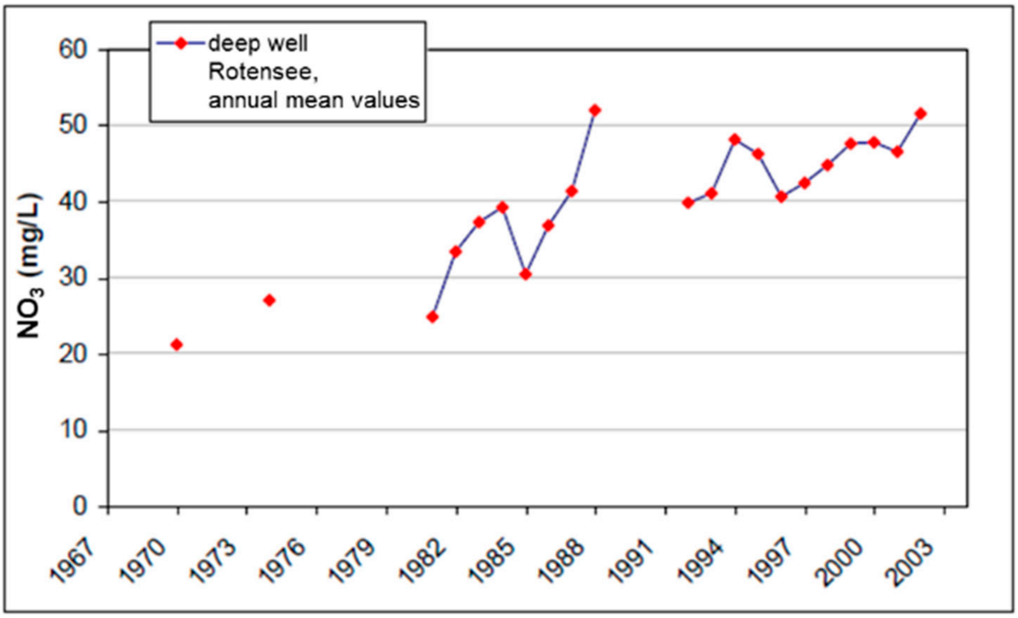

Figure 1. Development of NO_3 levels at deep well Rotensee 1968 to 2002 (source: Municipality data, supplemented with results of own investigations).

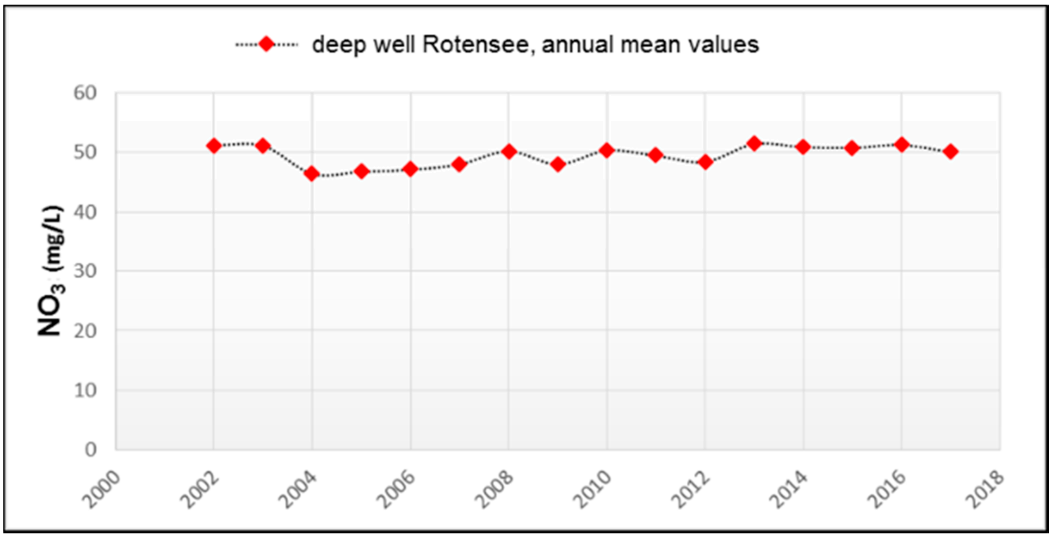

Figure 2. Development of NO_3 levels at deep well Rotensee 2002 to 2017 (source: Municipality data, supplemented with results of own investigations).

The upper edge of the terrain at the drill starting point of the deep well is 269.30 m above sea level. The well itself is 130.40 m deep and the filter tubes range from 39.50 to 93.00 m. As the results of the 2003 baseline assessment show, the water productivity of the well can be assessed as good. The drawdown during withdrawal is between 4.5 m at a withdrawal rate of 20 m^3/h and 12 m at a withdrawal rate of 56.3 m^3/h. Figure 3 illustrates the development of the pump rate in the period from 2001 to 2017. The pump in the deep well Rotensee has been renewed three times since 2001.

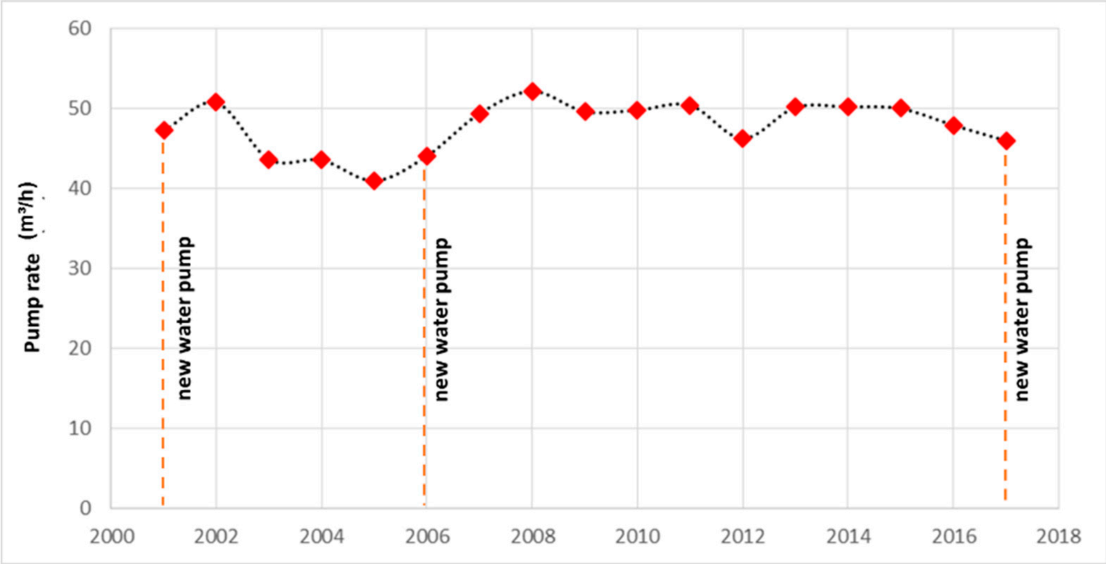

Figure 3. Pump rate in the deep well Rotensee 2001 to 2017 (source: Municipality data).

Agricultural and water management consulting has been taking place in the region since 1992, which also includes the municipality of Hauneck. This is provided by the communal Water and Agriculture Working Group (Arbeitsgemeinschaft Land- und Wasserwirtschaft AGLW) of the town of Rotenburg an der Fulda. The AGLW is financed by the municipalities of the region, EnergieNetz Mitte GmbH, and the local farmers' association. In total, it cooperates with about 350 farmers who operate in 35 water protection areas with more than 2800 hectares of arable land. One of the objectives is to ensure the continued high quality of drinking water and groundwater resources. To this end, the AGLW advises the farmers, e.g., on the correct fertilizing/N application based on field-specific nutrition sampling. The area in which the study area with the deep well Rotensee is located has also been monitored by the AGLW since 1992. As will be shown later, this is also reflected in the results of the current study.

The investigation area can be considered particularly relevant to the topic of nitrate pollution. It has been stated that about 74% of the drinking water produced in Germany comes from groundwater reservoirs [18], which is why the study area can be described as representative. Furthermore, the 2003 survey provides a good data basis for further investigations. In addition, internalization has already begun with the installation of the AGLW in 1992. The long-term effects of this measure can be quantified for the first time by the present study. The avoidance cost approach described in Section 2.3 was used for this purpose. Further scientific methods of the case study can be divided in hydrological and environmental-economic approaches.

Figure 4 provides an overview on the general approach and the used methodology. The figure summarizes the timeline and type of conducted investigations.

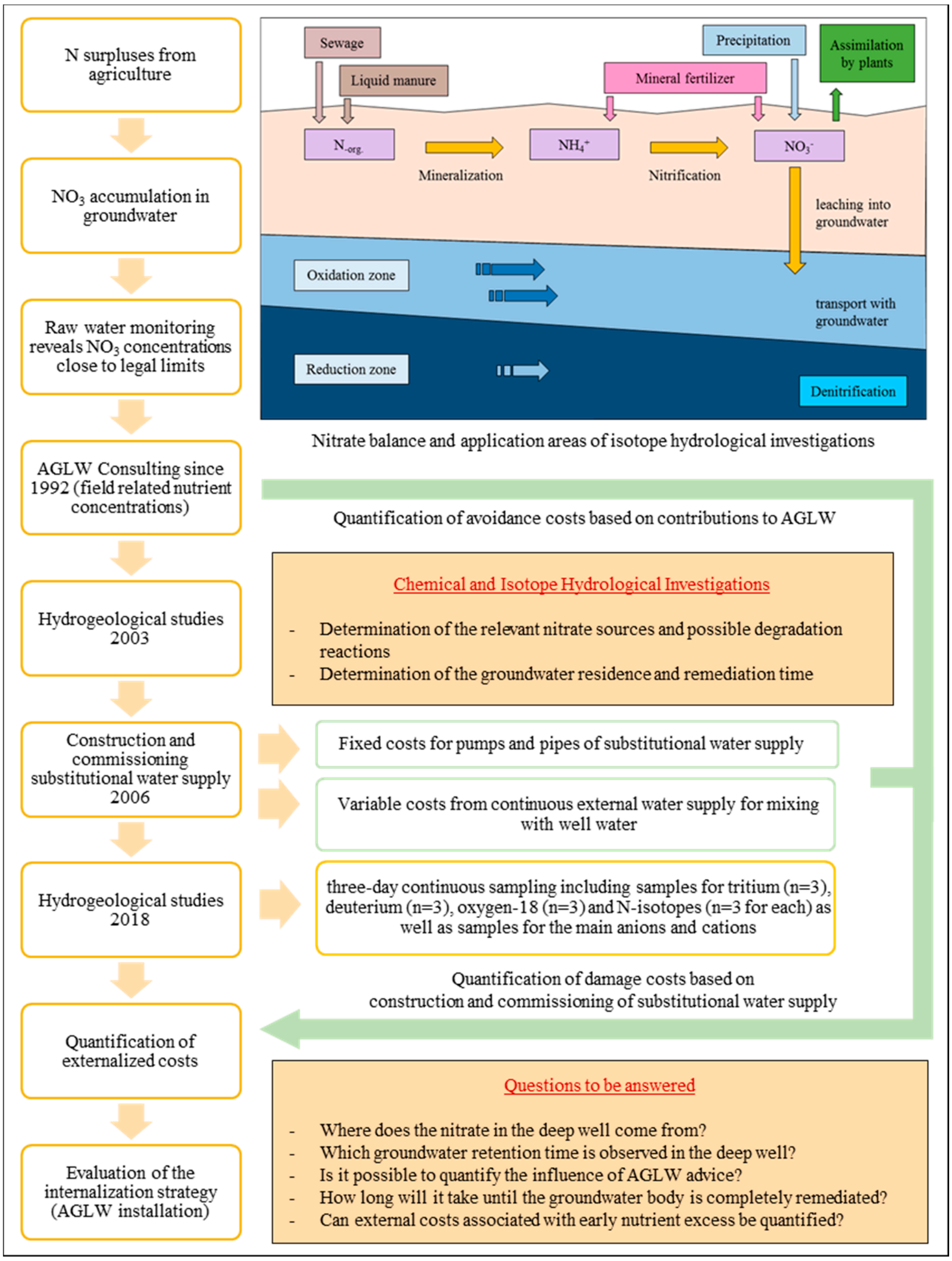

Figure 4. Research scheme consisting of isotope hydrological and environmental economic methods.

2.2. Sampling and Analysis

In order to investigate the possible sources of NO_3 in the water of the deep well Rotensee, water samples were taken during a 72-h pump test in February 2018. Furthermore, samples were also taken to determine the groundwater residence time. The investigation of the stable isotopes oxygen-18, deuterium, and tritium was intended to determine the origin of the waters in the area of the deep well Rotensee as well as the mean residence times of groundwater. Three groundwater samples each were taken during the pump test from the deep well and one sample each of surface water from a nearby field drainage. As a comparable sampling campaign had already been performed in 2003, the present study intended to compare the chemical and isotopic data over time.

The water samples were filled into dry polyethylene (PE) containers. The sample volume of the containers was 1 L for tritium and 50 mL each for deuterium and oxygen-18. The water, which was intended for the determination of N isotopes, was filled into PE containers of 0.5 L sample volume, which had previously been stabilized with a few drops of chloroform. Furthermore, samples were taken for the investigation of the main anions and cations. These samples were filled into dry glass bottles of 100 mL sample volume.

The analysis of oxygen-18 and deuterium was performed after sample preparation using cavity ringdown spectrometry (CRDS). Tritium was analyzed by liquid scintillation counter after previous electrolytic enrichment and N-15 after previous sample preparation by mass spectrometry (IR-MS). The analytical accuracy is 0.15‰ for oxygen-18 and 1.5‰ for deuterium (based on VSMOW standard). The detection limit for tritium is 0.5 TU. The analysis of the ions was carried out according to DIN 38 406 (Na, K, Ca, Mg) and DIN 38 405 (Cl, NO_3, SO_4). HCO_3 was approximately calculated using the ion balance.

2.3. Economic Approach

Two central approaches for quantifying external costs are the avoidance cost approach and the damage cost approach (Figure 5) [42]. The avoidance cost approach measures what it costs to avert or avoid externalities. The damage cost approach calculates the amount needed to compensate for the damage caused by externalities. Both approaches were used in the present study. On the one hand, it was to be shown which damage costs have already been incurred by agricultural processes and how this is reflected in the calculation of the drinking water price in Hauneck. For this purpose, the investment costs for the construction of an external water supply (fixed costs) as well as the current extraneous water supply (variable costs) were determined. The municipality has provided the necessary sources for this. Thus, a comprehensive picture can be sketched of the costs of past over-fertilization. Based on this the percentage of externalized costs in the price of drinking water was calculated. On the other hand, avoidance costs were also calculated which were and are mainly caused by contributions to the AGLW. Financial data from the period 2000 to 2018 were included.

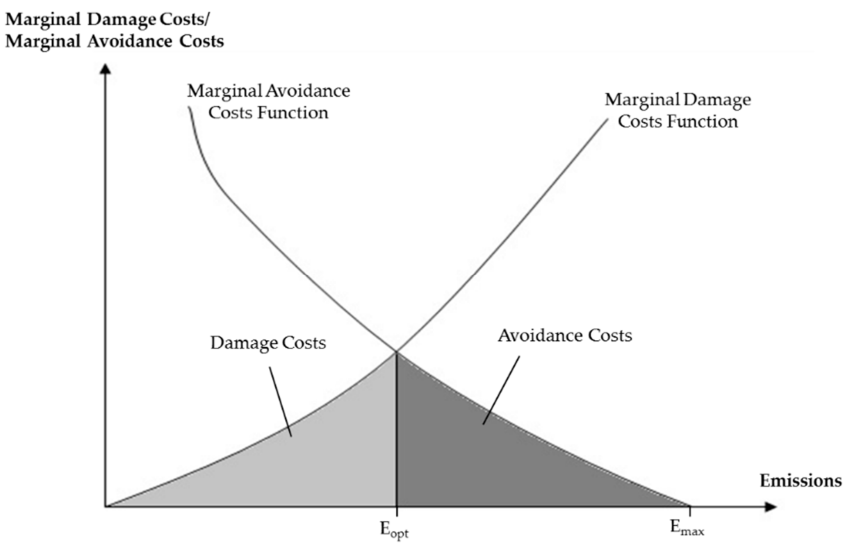

Figure 5. Marginal damage costs and marginal avoidance costs, adapted from Blazejczak [43].

3. Results

3.1. Isotope Hydrological Examination Results

In the course of the investigations, comprehensive hydrochemical and hydrological studies were carried out as can been seen in Figure 4. The results from the analysis of the stable isotopes and tritium are summarized in a simplified form to show the residence times of the NO_3 in the subsurface and when significant changes in the concentrations become noticeable. Furthermore, the input signal of potential NO_3 sources was determined, through isotope investigations according to Section 2.2.

The deep well Rotensee is located in a Buntsandstein aquifer (sandstone) characterized by double porosity. This leads to a groundwater system that is subject to combined hydraulic-hydrochemical reactions. As early as 2003 it was stated that the water of the deep well is a mixture of two groundwater components, but that these are not hydraulically separated from each other. The conclusion of the groundwater mixing system by dilution with a tritium-free component has not only been confirmed in the current modelling but could also be quantified proportionately. Thus, the model of a hydraulic mixing system established in 2003 was validated with the data of 2018 (see Figure 6). While the slowly moving older water component originates from the pore space, the more recent component is transported much faster via joints. It is the latter component that transports the NO_3 hydraulically into the subsoil. The mass transport in the catchment area is subject to a molecular diffusive mass exchange between the joints system and the pore space, whereby the hydraulically transported NO_3 is enriched in the old pore water by the concentration equalization. The double porosity of the sandstone (pore and joint water flow) is hydraulically reflected in the water volume transport. For less reactive water constituents such as NO_3, the molecular diffusive mass transfer causes a concentration equalization between the water-bearing joint system and the pore space in which the old water is stored. This results in a time-delayed reaction of mass transport by at least a factor of 20 compared to the rapid hydraulic flow on the fissures. If one assumes, for example, that the pure flow time of the water between the surface and the well is one to two years, it follows that the NO_3 introduced at the same time only reaches the well after 20 to 40 years. Consequently, the time span in which significant changes in the NO_3 input in the well become visible is also 20 to 40 years. While the NO_3 with the fast groundwater component is transported into the subsoil, the old water with the original NO_3 content is subject to a concentration equalization and slowly adjusts to the current NO_3 concentrations of the young component.

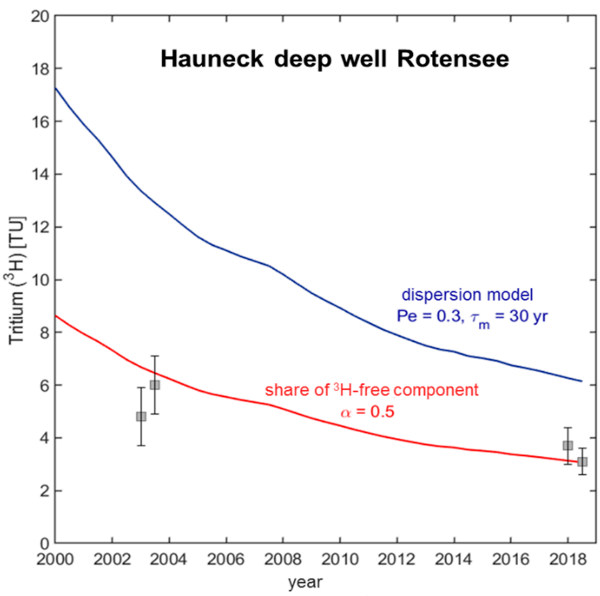

Figure 6. Graphical representation of the results of the tritium modelling using data from 2003 and 2018 (assumption: Dispersion model).

With the help of the isotopes nitrogen-15 and oxygen-18, statements can be made as to whether the NO_3 in the groundwater is of synthetic origin (mineral fertilizer) or is influenced by the excessive application of liquid or solid manure. The δ^{18}O-value (oxygen-18) can usually be used to determine whether the NO_3 pollution is of synthetic origin, while indications of NO_3 from liquid manure, dung, or feces often result from high δ^{15}N-values (nitrogen-15) of the NO_3. The reason for this is the evaporation of ammonia during liquid manure storage and spreading. The δ^{18}O- and δ^{15}N-values increase when NO_3 is degraded. The analytical results of the isotope contents of N compounds from the 2003 and 2018 investigations can be seen in Figure 7 on a plot which includes representative areas of the isotopic composition (δ^{18}O and δ^{15}N) of various NO_3 sources [44,45].

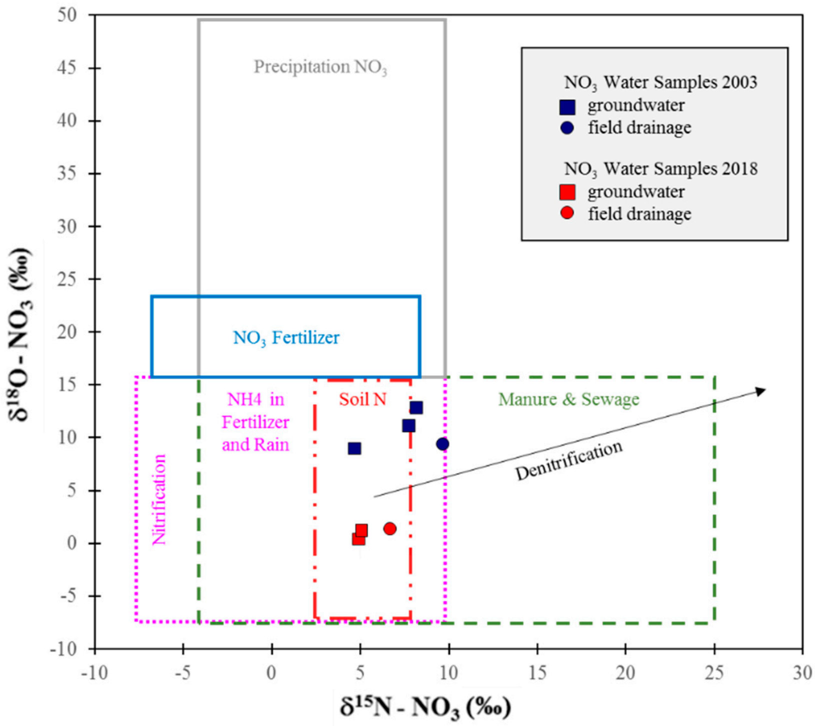

Figure 7. δ^{15}N/δ^{18}O diagram with the isotope signatures of different NO_3 sources and the results from the study area.

Compared to 2003, where the δ^{18}O-NO_3 values in the water samples from the deep well Rotensee were still comparatively high, these are significantly reduced in 2018 (Figure 7). The high values in 2003 led to the conclusion that the groundwater of the deep well was proportionally mixed with mineral NO_3 fertilizer. An organic fertilizer component (liquid manure) was also detected in 2003. The water from the field drainage in the well in the floodplain was mainly characterized by this component. The groundwater of the groundwater monitoring station had very low ^{15}N-NO_3-contents. In addition to the influence of liquid manure, natural soil NO_3 (e.g., in the case of meadow erosion) could have contributed to the NO_3 content of the groundwater. The current figures from 2018 make it clear that an influence of liquid manure is no longer visible. The ^{15}N-NO_3 values determined in the area of the deep well can be explained mainly by the nitrification processes of the soil organic matter, whereby it can be assumed that the water sample from the field drainage also has the same origin as the well water. Furthermore, the fact that the values of the beginning and the end of the pumping test are very close to each other indicates that water was drawn from the same aquifer area at both the beginning and the end.

Figure 7 shows the typical isotope signatures of different NO_3 sources. These are mainly based on literature data and are subject to various influencing variables [44,45]. For example, liquid manure marking describes ammonium that seeps away under a field fertilized with liquid manure. The liquid manure is subject to ammonia evaporation, which means that very fresh liquid manure is shifted further in the direction of ammonia evaporation. To verify this, liquid manure samples were also analyzed for the 2003 study, with 4.4‰ of ^{15}N-NH_4 for cattle manure and 7.8‰ of ^{15}N-NH_4 for pig manure. These underlined the explanations and were within the expected range of the ^{15}N-NH_4 values. Figure 7 shows the values at ^{18}O-contents, which can be expected in the simplest case when ammonium is converted to NO_3. Furthermore, with the liquid manure values it should be noted that the weather conditions at the time of spreading the liquid manure have a decisive influence on whether further ammonia evaporation can occur. If this is the case, an additional accumulation of the $\delta^{15}N$-NH_4 values in the soil can occur.

The water sample from the well in the floodplain corresponds to this slightly higher $\delta^{15}N$ value range of liquid manure NO_3. Overall, the NO_3 isotope ratios determined lie in a range of values that is characteristic of catchment areas used for agriculture, although it is clearly evident that the influence of liquid manure and NO_3 mineral fertilizers has decreased significantly since the last survey. While stable manure (liquid manure) was still identified as the dominant source of NO_3 inputs in 2003, this is no longer the case today. The values from 2018, i.e., those of the continuous sampling at the deep well Rotensee as well as the field drainage below, which are all very close together, are all typical for a NO_3 isotope signature which is characterized by nitrification processes within the soil organic matter. The reason for this development is probably the increased agrotechnical advice to the local farmers since 1992 as well as a general decrease of agricultural activity in the surrounding area.

3.2. Environmental Economic Calculations

As already described, the study area has been subject to increased N inputs in the past, especially from mineral NO_3 fertilizers and liquid manure. The present study reveals that the influence of liquid manure is hardly recognizable and that of mineral fertilizers has significantly decreased. As a consequence of the high N input in the past, the NO_3 levels in the deep well Rotensee are still in a persistently high range, as the degradation processes are subject to lengthy processes, as explained. A problem of externalization can be assumed, which becomes particularly evident when the costs resulting from N overload are analyzed. In order to comply with the drinking water limit of 50 milligrams per liter of fresh water, the municipality had a drinking water replacement supply installed between 2004 and 2006/07. This connected the drinking water network of Bad Hersfeld with that of Hauneck. The motivation of Hauneck municipality was to keep the drinking water supply from own sources in order to not get dependent on water resources that are not of their own. The scope of the drinking water replacement supply was to add NO_3-free water into the Hauneck water supply to ensure that the drinking water limit is guaranteed. For this purpose, a water pipe of about 8 km length was built and connected to the Hauneck waterworks. The costs associated with the replacement drinking water supply are shown in Table 1.

Table 1. Calculation of Costs for Substitute Drinking Water Supply.

Fresh Water Supply from Bad Hersfeld, Distributed to Hauneck (Current Expenses)				
Year	**Supply Bad Hersfeld (m^3)**	**Price/m^3 1.19 €**	**+360 € Basic Fee/Year (Net)**	**Plus 7% Tax (Gross)**
2006	3256	3874.64 €	4234.64 €	4531.06 €
2007	13,737	16,347.03 €	16,707.03 €	17,876.52 €
2008	5120	6092.80 €	6452.80 €	6904.50 €
2009	4990	5938.10 €	6298.10 €	6738.97 €
2010	5410	6437.90 €	6797.90 €	7273.75 €
2011	5050	6009.50 €	6369.50 €	6815.37 €
2012	5350	6366.50 €	6726.50 €	7197.36 €
2013	5050	6009.50 €	6369.50 €	6815.37 €
2014	5070	6033.30 €	6393.30 €	6840.83 €
2015	5230	6223.70 €	6583.70 €	7044.56 €
ø	5826	6933.30 €	7293.30 €	7803.83 €
Total	58,263	69,332.97 €	72,932.97 €	78,038.28 €
Substitute Drinking Water Supply (construction costs)				
	Reference Period	No. of Items	Net Amount	Gross Amount
	2004 to 2007	15	323,211.30 €	374,353.55 €
Merging of Variable and Fixed Costs				**Total Costs**
Current expenses since 2006:				78,038.28 €
Fixed costs for construction of Substitute Drinking Water Supply:				374,353.55 €
Total costs until 2018:				452,391.83 €

The costs presented in Table 1 can be divided into variable and fixed costs. The fixed costs are made up of the construction costs of the replacement water supply, consisting of pipes and pumps. The brut construction alone cost the community €374,354. This is evident from invoices provided by the municipality. Furthermore, every cubic meter of external water must be paid for at a price of €1.19 or €1.27 (including 7% VAT). In addition, there is an annual basic fee of €360. Multiplying the price per cubic meter by the annual supply in cubic meters gives the annual supply costs. These running costs can be described as variable costs. For the analysis, invoices for the years 2006 to 2015 were provided, whereby it must be said that the external water supply will continue beyond that date. Since 2006 an average of approximately 5826 m^3 of fresh water has been drawn from Bad Hersfeld every year. Plus taxes, this results in average annual costs of €7804. The total cost of the fresh water purchased for the period 2006 to 2018 is €78,038. Together, fixed construction costs and variable external water procurement costs result in total costs of €452,392. These total costs can be called negative production externalities and can be allocated according to the damage cost approach, described in the methodology. Most of the costs incurred are redistributed to the final consumers. This is done via the price of drinking water. It is not possible to make a statement as to whether the complete 1.19 €/m^3 or 1.27 €/m^3 (including 7% VAT) are redistributed to the inhabitants of the municipality via the drinking water price. For this, the drinking water price calculations of the municipality would have to be available. However, these were not made available for the study. Nevertheless, it can be assumed that the majority of the costs incurred will be distributed among the inhabitants of the municipality in accordance with the burden-sharing principle. Assuming that the complete 1.27 €/m^3 are added to the drinking water price, this would mean that the cost-side share of the external water supply, for an assumed drinking water price of 2.35 € (2015), would be approximately 54% (Figure 8). Nearly half of the drinking water price to be paid results consequently from the admixture of the Bad Hersfeld water (substitutional water supply). As shown, these are externalized costs which the inhabitants would not have to pay without the NO_3 since 2009/10, whereby it must be said that the construction costs have not been taken into account. According to the damage cost approach mentioned in Section 2.3, these externalized costs can be described as damage costs.

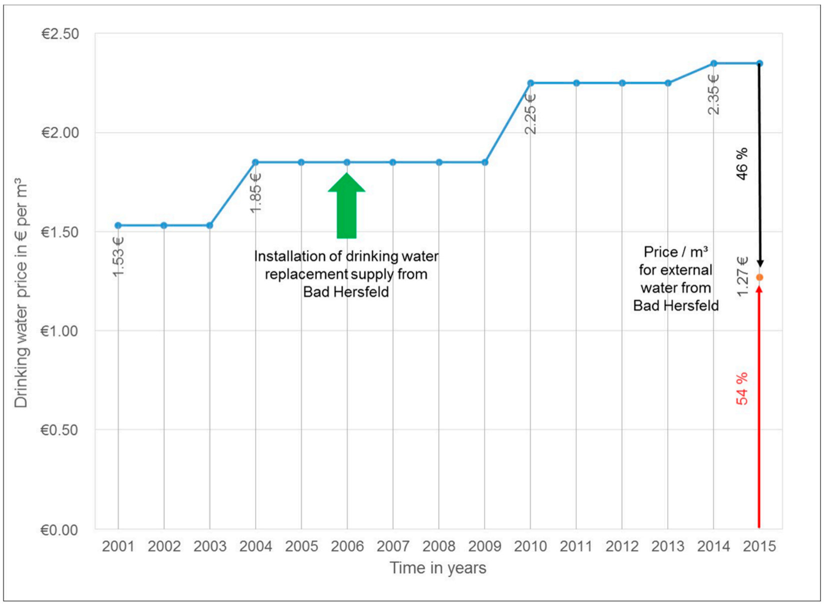

Figure 8. Development of the drinking water price from 2001 to 2015 including the share for external water supply in 2015.

Other costs associated with NO_3 pollution are the pro rata expenses of the municipality for membership of the AGLW. The AGLW has been in existence since 1992 and advises farmers in the member municipalities on fertilization methods and N application, among other things. The contribution rate for the municipalities is based on the percentage of the total population of the AGLW catchment area (Figure 9). For the year 2018, the municipality of Hauneck, with a population of 3175, had to pay a pro rata amount of €10,688 (gross). For this contribution, especially the farmers of the municipality receive a year-round agrotechnical consulting service. The total contributions since 1992 have been extrapolated approximately on the basis of the actual advance payments for the year 2018 and the population development. On average, the municipality of Hauneck has had to pay about €12,207 per year for AGLW advice since 1992. Taking into account the assumptions made, this results in a total sum of €329,597 (until 2018).

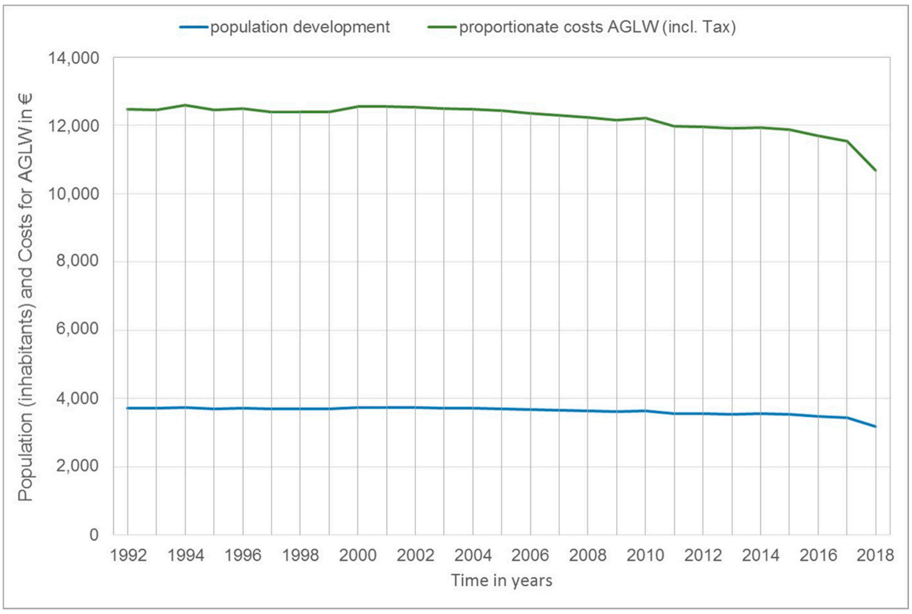

Figure 9. Development of population and proportionate costs for the Water and Agriculture Working Group (Arbeitsgemeinschaft Land- und Wasserwirtschaft—AGLW).

Basically, it must be said that the costs for the AGLW consultation must be qualitatively separated from those for the drinking water supply, according to the described methodology. This is where the avoidance cost approach comes into play. The characteristics of both types of costs are fundamentally different. In the context of the comments on drinking water replacement supply, it was discussed that these are external damage costs. A part of these costs is distributed to the inhabitants of the municipality according to the burden-sharing principle. This does not apply or only applies to a limited extent to the AGLW contributions. The measures associated with the contributions have a preventive rather than a post-care character. Although the N inputs may have played a role in 1992 when the municipality decided to join the AGLW, it can be assumed that the main concern of joining the AGLW is to ensure good drinking water and groundwater quality in the long term. Consequently, the precautionary principle was used to mitigate future externalities. The installation of the AGLW can therefore be understood as an internalization concept [22,23]. Although the municipality also incurs costs as a result, these are lower than the external or overall economic costs. Internalization can be said to occur when external effects are priced in, i.e., fed back into the allocation mechanism of the market, and economic and private costs are harmonized. In the ideal economic case, a Pareto optimum is achieved through successful internalization [14].

The costs incurred since 2006 simply by the installation of the drinking water supply and the feeding of the external water from Bad Hersfeld would have been sufficient to meet the contribution demands of the AGLW from about 1982 until 2018. Although the actions of the municipal administration can in principle be described as exemplary, it can be said that an internalization measure based on the AGLW model would have made sense from an economic point of view 10 years earlier. If one assumes an increasing N load in the deep well Rotensee since the 1960s/70s, it could be assumed that the costs in connection with the drinking water supply would never have arisen. To validate this statement, however, a large number of components, such as the agricultural policy orientation of that time, would have to be included.

For the present externalization problem, it can be summarized that by joining the AGLW the municipality chose a sensible strategy with internalization character already in 1992. Here it must be emphasized that this is not a pure internalization. That requires a causer-oriented allocation of costs and a Pareto-optimal state. However, as the explanations have shown, this allocation of costs is very difficult in the area under investigation. The double porosity of the mottled sandstone causes a very slow release of the NO_3 from the subsoil, which is why the degradation processes in the study area are subject to very long periods of time. It is therefore almost impossible to clearly assign blame to one or more specific farmers. Even if a statement could be made as to which farm is responsible for the inputs, it must still be checked whether this farm acted within the framework of the law and order of the time. One of the classic internalization strategies should therefore not be chosen. For the specific case, the installation of the AGLW as a weakened form of internalization makes perfect sense. Furthermore, the model could serve as a blueprint for comparable regions in Germany.

4. Discussion

Plants are dependent on N for their growth. However, the problem of over-fertilization has been and still is an ongoing problem in Germany. The N surpluses are accumulated in the soil to form nitrate and end up in the groundwater. This causes ecological and social consequences, namely eutrophication of water bodies, groundwater pollution, an acceleration of climate change, and effects on human health [6–9]. Quantifying these effects is often difficult because the relevant information is not available and long periods of time are not studied. Reflecting the results of this case study, it can be stated that it provides a realistic picture of the problem of externalization caused by groundwater pollution with NO_3 in the deep well Rotensee. Due to the fact that hydrological, hydrochemical, and isotope investigations were already carried out in 2003 and the data situation can generally be considered as good, valid statements can be made on the externalization. Based on the data provided, concrete social costs [20] could be quantified. The calculation tables and formulas for the calculation of the drinking water price were not provided by the municipal administration, which is why certain assumptions had to be made in the investigation. Due to the absence of the drinking water price calculation, no final proof could be provided that the complete substitutional water supply costs were actually allocated to the water price according to the overhead load principle. However, the development of the water price allows this conclusion to be drawn.

It can also be stated that the present study was limited to the negative external effects. Agriculture plays an important role in the protection of public interests. Seen in this light, it also has positive external effects, such as landscape design, promotion of food security, and regional development. These positive effects were not taken into account in the analysis. In order to be able to present the cost structure holistically, these would have to be included. Furthermore, the survey focused on N overload and the associated NO_3 problem. Negative external effects, e.g., resulting from the use of pesticides [29,34,46], were not taken into account.

The study also leaves open how the findings can be transferred to other areas. There is a need for action here, also against the background that many areas in Germany are at the level of Hauneck around 1960/70 with regard to the NO_3 situation. This means that in many places there is no consultation according to the AGLW model and livestock numbers and area are still decoupled from each other. The transfer to different areas is one of the future tasks in this field of work. Knowledge of the concrete negative external effects in monetary terms is an important prerequisite for rational policy-making, which is why several studies based on the present model are needed. The AGLW consulting could be understood as a nitrate reduction strategy, among others [47,48].

In principle, it should be noted that an appropriate internalization strategy cannot be based on the direct allocation of costs to individual farmers, which is hardly possible because the NO_3 enrichment in the groundwater is a diffuse pollution. Subsequently, it is not possible to identify who the exact polluter is. The isotope investigations allow a statement to be made about which signatures on NO_3 can be detected [44,45]. In the past it could be deduced from this that the NO_3 originates from agricultural cultivation. The current isotope investigation shows that this influence has clearly decreased. In addition to the difficult attribution to the individual farmer, it must be mentioned that these are subject to enormous price pressure and the market forces them to produce at a correspondingly low cost. Furthermore, they are often within the legally permissible range, which is why it is also necessary to discuss the legislative bodies and agricultural policy [49]. The consumer at the supermarket checkout also has a say in how production conditions can be shaped through his purchasing behavior, which is why it is ultimately logical to redistribute part of the consequential costs to society. This shows that there can be no one-dimensional solution or internalization strategy. In order to achieve environmental relief targets and sustainable agriculture, the various interest groups must work hand in hand.

5. Conclusions

With regard to NO_3 pollution, it must be stated that 'good practice' and the formulation of laws and regulations have not yet led to any improvement in the NO_3 situation. Due to the continuing non-compliance with the EC Nitrate Directive, the Federal Republic of Germany has been sued and already condemned by the EU in 2016. As a consequence, the Federal Republic of Germany amended the Fertilizer Ordinance. The amendment was adopted by the Bundesrat on 27 April 2020 and has been in force since 1 May 2020. The measures for NO_3-contaminated areas will become legally effective from 1 January 2021. It cannot be estimated whether the changed jurisdiction will lead to an improvement in the situation.

The present case study illustrates the external costs that may arise from increased NO_3 pollution in groundwater. This is of particular relevance because about 74% of the drinking water produced in Germany comes from groundwater reservoirs [18]. For the municipality of Hauneck in Hesse, it was determined that almost half of the drinking water price consists of externalized costs. In the concrete example, follow-up costs from the establishment of a drinking water replacement supply and the continuous external water supply totaled €452,392. This is not an isolated case throughout Germany and there are areas with significantly higher NO_3 pollution (e.g., Weser-Ems) [3]. To a certain extent it can be stated that some areas in Germany today are at the same level as Hauneck was in 1960/70. The consequences in terms of the NO_3 problem and other directly related problems are yet to come or are already real, as the complaint of the EU Commission against Germany shows. It is therefore difficult to quantify the total external effects of overfertilization and NO_3 enrichment.

Comprehensive agricultural advice has been provided in the study area since 1992. The resulting decrease in NO_3 pollution is gradually becoming apparent, as has been demonstrated by the present study. The measure has led and continues to lead to a reduction in external costs, i.e., consequently to a harmonization of private and social costs. It can therefore be considered to be internalized. The costs can be described as preventive (avoidance cost approach), whereas the construction of the drinking water supply system and the continuous supply of external water are of a post-care nature (damage cost approach). If these findings are applied to the Federal Republic of Germany, a suitable internalization strategy could consist of making it compulsory to introduce agricultural extension services for farms and/or municipalities along the lines of the AGLW in the form of a state environmental policy requirement. Based on the annual contribution rate of €10,688 (information from the municipality of Hauneck, 2018) and assuming, for example, 100 farms receiving advice, this would result in a flat rate of €107 per company.

The study was also able to confirm the forecasts made in 2003 regarding the residence time of NO_3 in the area of the deep well Rotensee, with the help of isotope investigations. This NO_3 is 30 years in the aquifer. The conclusion of the groundwater mixing system by dilution with a tritium-free component was not only confirmed in the current modelling, but could also be quantified proportionately. From the findings it can be concluded that the NO_3 dwells in the subsurface for a very long time due to complex hydrogeological processes. For this reason, optimization processes only become visible after several decades. Consequently, the follow-up costs of nitrate removal will also accompany the municipality over these long periods.

Overall, it can be stated that the environmental-economic approach of internalizing external effects can provide a good breeding ground for a sustainable environmental and agricultural policy, if the instruments are sensibly coordinated. It could be shown that the site-related particularities of internalization problems and sustainability challenges must be taken into account. Accordingly, the policy mix must be adapted to the respective situation [50,51]. The key issue here is to contain harmful developments and promote positive effects. By pricing in consequential costs, organic farming, for example, can be put in an appropriate light.

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