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Department of Economics

On-site Sewage Treatment Facilities, Unacceptable Quality or too Small to Count?

Cost-Benefit Analysis of on-site sewage treatment facilities and the zero-eutrophication target

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Independent project · 15 credits · Basic level
Agricultural Programme - Economics and Management
Degree project no 1109 · ISSN 1401-4084
Uppsala 2017

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Credits: 15 hec
Level: G2E
Course title: Independent project in economics
Course code: EX0808
Programme/education: Economics and Management – Bachelor's Programme
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2017
Title of serie: Degree project/SLU, Department of economics
No: 1109
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: Cost-benefit analysis, eutrophication, The Swedish Environmental Code

Acknowledgments

I would like to acknowledge the help from my supervisor Justice Tei Mensah, especially the guidance he provided when choosing and structuring the thesis' subject. Also, since a cost-benefit analysis like this one relies on a lot of different data and works from other authors, I like to acknowledge that without their work the calculations made in this thesis would not have been possible.

Abstract

Private on-site sewage treatment facilities are only a small part of the Baltic Sea eutrophication problem, but it have caught attention due to its high share of deposition of nitrogen and phosphorus in comparison to the more efficient public sewage treatment plants. The treatment of sewage wastewater is regulated by the Swedish Environmental Code. In this thesis a cost-benefit analysis was conducted to estimate if the improvement of on-site treatment sewage treatment facilities from a non-approved standard to an approved standard is an efficient way to achieve the zero-eutrophication target. The results show a negative value with high costs. However, as the identified impacts were limited, another outcome is possible with another objective together with a broader framework than just eutrophication and the pure efficiency target.

Table of Content

Tables

Formulas

Abbreviations and definitions

CBA – Cost-Benefit Analysis
CPI – Consumer Price Index. (Swedish translation: KPI)
EPA – Environmental Protection Agency, in this thesis the Swedish EPA (Swedish translation: Naturvårdsverket)
On-site facility – Authors choice of shortening on-site sewage treatment facility which are any solution of sewage treatment that are not connected to a public sewage treatment plant. (Swedish term: Enskilda avlopp).
N – The chemical element nitrogen (Swedish translation: kväve)
P – The chemical element phosphorus (Swedish translation: Fosfor)
SEK – Swedish Kronor
WTA – Willingness To Accept
WTP – Willingness To Pay

1. Introduction

This chapter starts with some background to introduce the relationship between sewage waste and eutrophication. Previous studies of interest to this thesis are presented in the literature review. The research question and the objectives are introduced as well.

Background

Sewage wastewater contains many different polluting substances such as medical waste, heavy metals and eutrophicating materials (EPA, 1, 2012). Two eutrophicating substances from sewages wastewater are nitrogen and phosphorus. Nitrogen is essential for the rate of primary production. Where nitrogen is limited growth can increase by higher nitrogen concentrations, which is the basis of many fertilizers. Where nitrogen are abundant more nitrogen can cause environmental degradation, loss of biodiversity and acidification. Most aquatic systems are also dependent on phosphorus. Adding to much can cause eutrophication with heavy algal growth that develop toxic conditions. In severe cases, like the Baltic Sea, it can cause large dead zones on the sea bed (Cain, Bowman & Hacker 2014). Zero-eutrophication is one of Sweden's environmental objectives. It is one of the largest threats to the Baltic according to the Swedish Environmental Protection Agency, EPA. It also affects rivers, lakes and soils, particular in the south of Sweden (EPA 2012b).

Modern sewage treatment plants were mainly built in Sweden during the 60's and 70's to manage increasing eutrophication. Almost every city and municipality was connected and the results were observable on lakes and rivers. An estimated 700 000 household that is not connected to the public sewage system have some kind of on-site treatment facility (EPA 2012a). The cleaning efficiency of those varies. Three spokesmen for the Baltic Sea 2020 project argued that the households with an on-site solution, although only making up 10% of all sewage treatment, emits as much phosphorus as the remaining public treatment plants (Kumblad, Rydin & Stralka 2016).

The discharge of wastewater is classified as an environmentally hazardous activity by the Swedish Environmental Code. In section seven, it is stated that wastewater shall be purified or treated by an appropriate method in such a way that risk to human or the environment is detriment (SFS 1998:808). Further on the Environmentally Hazardous Activities and Protection of Public Health ordinance no discharge of wastewater is allowed if it only have been surpass to a sludge separation (SFS 1998:899).

Improvement of on-site treatment facilities could be an important step to achieve the zero-eutrophication objective. On the other hand, installation are expensive to the individual (Avloppsguiden 2017). In a reply to Kumblad, Rydin and Stralka, a represent for private house owners writes that there are larger emissions that would be cheaper to reduce than the ones from on-site facilities (Werner 2016). Other sources of eutrophication are industry, agriculture and shipping (EPA 2012b).

Purpose and objective

According to the Swedish Agency for Marine and Water Management half of all private sewers fail to fulfil the criteria of sufficient treatment by the Environmental Code. Of that half another half is violating the ordinance by only treating the wastewater by sludge separation (The Swedish Agency for Marine and Water Management 2013). New measures against eutrophication are heavily debated, this thesis aim to determine if the existing measure in the Environmental Code is efficient. Hence the research question:

Are improvements of on-site sewage treatment facilities a cost-efficient way to contribute to the environmental objective of zero-eutrophication?

The research question will be answered by conducting a cost-benefit analysis that acknowledges all benefits and costs to society when enforcing private homeowners to comply with the minimum standard currently set by Swedish law. The results could be of importance to policy makers whether it is worth ensuring compliance with Environmental Code or if the section regarding on-site treatment facilities need to be altered.

Literature review

Most literature about on-site sewage treatment facilities are written for government agencies. They concern technical aspects of functionality, treatment quality and deposition loads. Connection to eutrophication is treated by authors writing about eutrophication, often on a larger scale, calculating the loads from all depositions. In this section relevant works will be presented and how this thesis aims to contribute to earlier research.

A study by Hennlock *et al.* (2013) written for the Swedish Agency for Marine and Water Management conducted an impact assessment analysis as a base for a proposition on policy instruments regarding on-site facilities. The report assessed various policy instrument and the available technical improvements and their respective cost-effectiveness. The assessments provided a guideline to policymakers to where the most effective solutions regarding this specific sector could be made to contribute to the zero-eutrophication target. The different technologies were displayed in a McKinsey diagram which ranked them by cost-effectiveness. Every technology were given a cost per kilogram for nitrogen and phosphorus. The policy instruments were assessed with cost and consequences for different actors and three different scenarios involving different policies, techniques and levels of abatement (Hennlock *et al.* 2013). The study contains important information of which measures are the most cost-efficient. This study hopes to contribute by determining if it is beneficial to society to perform these measures.

Gren, Jonzon and Lindqvist presented in 2008 a working paper with valuable calculations on abatement costs for nitrogen and phosphorus. The objective of the paper was to present calculations of measures reducing nutrient loads to the Baltic Sea. The authors used previous research in the field and brought in some new data to compare minimum-costs solutions related to different target formulations concerning nutrient reductions to the Baltic Sea (Gren, Jonzon & Lindqvist 2008).

The calculations were made for deposition loads of phosphorus and nitrogen from both public and private sewage, industry and agriculture. Cost-effective solutions were calculated based on impacts and costs related to specific targets, mainly set by the Baltic Marine Environment Protection Commission. For emissions sources located at the coast the average emissions were used. For sources located upstream in the drainage basin, transportation and retention data had to be used. To avoid underestimating the costs the measures of reductions where classified into two categories, reduction at the sources and reduction through leaching and retention. This was done because of the interdependence between the measures (Gren, Jonzon & Lindqvist 2008).

For nitrogen reductions the solutions with the lowest costs were related to land use issues such as small reductions of fertilizer, creation of wetland and catch crop cultivation. For phosphorus reductions it were cheaper to target the original source, for example to reduce the phosphorus concentrations in detergents or increase cleaning at sewage treatment plants. Marginal costs for private sewers where relatively large (Gren, Jonzon & Lindqvist 2008).

The authors calculated costs of measures for reducing loads to the Baltic Sea, 14 for nitrogen and 12 for phosphorus. The marginal costs varied significantly for different target formulations. The results for on-site facilities are presented in table 1.

Table 1 Marginal costs for on-site facilities by Gren, Jonzon & Lindqvist (2008).

On-site facilities	Nitrogen (SEK/KG)	Phosphorus (SEK/KG)
Marginal costs	509 – 766	2397 - 4522

The authors also calculated marginal costs from other measures of reduction. By only calculating marginal costs the authors focused on cost-effectiveness which is useful when choosing between different options but it does not tell if the options are socially beneficial or not. This thesis used similar calculations in the context of society.

Another report of value, although it does not provides any economical insights, calculates the deposition loads of nitrogen and phosphorus to the Baltic Sea. Brandt and Ejhed published in 2002 a report for the EPA, the TRK-report or *Transport – Retention – Källfördelning*. The objective was to calculate the loads of nitrogen, phosphorus and metals and to estimate a long-term mean for the first two. The nitrogen load were calculated using methods based on simulation programs that adjusts for surface runoff, nitrogen retention (mainly natural denitrification) and specific land use. The nitrogen load was calculated by subtracting the retention from the gross load, except for where the deposition was made directly into the sea. The load for phosphorus was calculated from the gross load from direct emissions and diffuse emissions. Since the loads vary each year depending on both climate and emission the results were normalized to a longer time period (Brandt & Ejhed 2002).

The report presented the results from various sources and made an estimation of the total pollution load. Most relevant for this study were the estimations of pollution load from on-site treatment facilities. Those results are presented in table 2 which shows loads of nitrogen and phosphorus in tonne per year and their respective share of the total anthropogenic load.

Table 2 Depositions of nitrogen and phosphorus from on-site sewage treatment facilities in tonnes per year and percentage of total load. (Brand & Ejhed 2002).

Swedish seas	Nitrogen (gross)		Nitrogen (net)		Phosphorus	
Bothnian Bay	200	3,6%	100	2,3%	30	2,5%
Bothnian Sea	900	5,1%	600	4,3%	130	5,9%
Baltic Sea	1900	4,8%	1000	4,3%	260	21,8%
Öresund	100	1,3%	100	1,7%	20	16,7%
Kattegatt	1300	3,2%	800	2,9%	180	13,7%
Skagerrak	200	5,7%	200	7,4%	30	18,8%
Total:	4600	4,0%	2700	3,4%	640	10,3%

The results in table two by Brandt and Ejhed were calculated by using standard values from the EPA that estimated the deposition to 13,5 gram nitrogen and 2,1 gram phosphorus per person and day. It was assumed that 60% of all on-site facilities were of approved standard. These estimations together with real estate taxation data, retention simulations and usage estimations were the basis for the calculations. Results were presented for both sector and total depositions (Brandt & Ejhed 2002). Although subjected to several assumptions the study contained detailed results and a serious effort trying to account for the retention factor. This thesis will not be able to use any of the authors' previous data and will be more focused on the economic perspective. Their results can be used to evaluate the deposition calculations in this thesis.

Gren, Elofsson and Jannke (1997) focused on the eutrophication problem in the Baltic Sea on a large scale. The objective was to calculate the share and the size for reductions of phosphorus and nitrogen for all of the states surrounding the Baltic Sea. The hypothesis tested was that there would be different minimum cost from different policies, implying different shares between countries when looking for a minimum cost solution.

The basis for the calculations were estimations of nitrogen and phosphorus depositions. Some general assumptions had to be made since the data for land deposition and the effect from retention were limited. The impacts on the Baltic Sea and the potential nutrient reduction measures determined the cost-effective reductions. Minimum costs were calculated from different policy scenarios, allowing for different reductions of phosphorus and nitrogen and different shares between countries.

The main results were that the countries with the lowest marginal costs and the highest nutrient loads would undertake a relatively larger share of the total reduction. Poland would account for about 40% of the total reduction of nitrogen. However, as the countries undertaking larger share of reduction loses from the policy it was questioned whether or not such a policy would be accepted. It was also noted that the results were sensitive to several assumptions, mainly for nutrient loads and transports (Gren, Elofsson & Jannke 1997). Even though the actual calculations were limited by the available data the main finding, the different distributions, were still most likely to be true. This thesis will not improve the underlying data but will in detail study one of the measures, the improvement of on-site treatment facilities, with potential of being a cost-efficient measures against eutrophication.

During the literature review conducted for this thesis it was noted that there exists several estimates on cost-effective measures to the Baltic Sea. These can provide guidance when choosing between cost-efficient measures. However, there is a lack of studies estimating if these measures are beneficial to society. This thesis intend to address that issue by combining cost estimations with benefits measures such as willingness to pay for eutrophicating improvements.

2. Methods

This section contains first the conceptual framework with a description of the purpose with the method and how the method can be perceived in the context of society. The second part describes the method and how it was applied in this thesis.

2.1 Conceptual framework

A cost-benefit analysis, CBA, is a tool that can be used in decision and policy making. The most essential purpose is to determine if the benefits of a proposed project exceeds the associated costs. The standard CBA is *ex ante* which evaluates a project before it is implemented. A CBA that is conducted for an on-going project is called *in medias res* and can just like an *ex ante* analyse influence whether or not the project should continue (Boardman, Greenberg, Vining & Weimer 2011). The CBA in this thesis was *in medias res* as the project is an environmental law that is statutory, the results could be used in future decision making to decide whether or not it is efficient ensuring compliance with the law.

A CBA appraise investment projects with respect to market failures. It provides a net value when all the costs from a project or a change in government policy has been subtracted from all the associated benefits (Perman, Ma, Common, Maddison & McGilvray 2011). This thesis evaluated the efficiency of an existing policy, the SFS 1998:899 and SFS 1998:808, which sets the standard for the disposal of wastewater.

A definition of efficiency is necessary to answer the research question. Economics is often described as the allocation of scarce resources. The efficiency concept is described as the allocation of resources where it is not possible to improve the situation for one person without making it worse for another person. Such a state is called Pareto efficient (Perman, Ma, Common, Maddison & McGilvray 2011).

The basic efficiency concept of a CBA is that a project is efficient if the benefits exceeds the costs. When several projects are proposed, the project that maximizes the positive difference between benefits and costs should be chosen (Brent 2006). Accounting for distributional effects, the decision rule is to only adopt a policy where the winners will fully compensate the losers of the policy. In applied cases the winners should only have the potential to compensate the losers without the actual compensation occurring. This criterion is called the Kaldor-Hicks criterion, also known as the net benefits criterion. It is an important practical application of the Pareto efficiency criterion. The Kaldor-Hicks criterion makes it possible to evaluate a policy without the need to analyse exactly which individual is going to compensate the other, hence avoiding burdensome transaction costs (Boardman, Greenberg, Vining & Weimer 2011).

A CBA uses a social approach that differs from the normal market equilibrium. The social approach of a CBA is used to include mainly three objectives. First, it is used to acknowledge that all the individuals in society can be effected, not only the parties directly involved. Secondly it is empathized that it is a social and not strictly economical approach, accounting for distributional effects within the efficiency effects. Third the social price is the market price adjusted for imperfections (Brent 2006).

The social price may differ from the normal market equilibrium as it accounts for positive and negative externalities. An externality exists when the utility from one individual affects another individual's utility (Brent 2006). The disposal of wastewater and the emission of nitrogen and phosphorus is an example of a negative externality where the individual can enjoy functioning sewers without concerning where the wastewater is disposed.

In economic theory the net social benefits can be calculated from consumer surplus, producer surplus and government surplus. The effects from a policy change can be calculated rather easy if knowledge of supply and demand curves are known (Boardman, Greenberg, Vining & Weimer 2011). In reality it is very hard, if even possible, to measure an individual's preferences. The theoretical approach is therefore adjusted to better reflect the present reality. The steps used in this thesis are presented in the next section.

2.2 Method

The cost-benefit analysis process is thoroughly described by Rosén *et al.* in the Swedish Environment Protection Agency's report 5836 on cost-benefit analysis. The main steps are definition, identification, quantification and calculation (Rosén *et al.* 2008). These steps can further be expanded into nine steps (Boardman, Greenberg, Vining & Weimer 2011).

1. Specify the set of alternative projects.
2. Decide whose benefits and costs count
3. Identify the impact categories
4. Predict the impacts quantitatively over the life of the project
5. Monetize all impacts
6. Discount benefits and costs to obtain present values
7. Compute the net present value of each alternative
8. Conduct a sensitivity analysis
9. Make a recommendation

This thesis followed the four main steps with support from the more detailed nine steps.

Defining Alternatives

For an *in media res* CBA the status quo alternative is the current policy. In this thesis it was defined by the Environmental Code. This is the opposite of an *ex ante* study where the status quo would be the null alternative to the proposed alternative (Boardman, Greenberg, Vining & Weimer 2011). The alternative policy was to abandon the policy. It can be argued that in reality there is a small difference between these alternatives as the current improvement rate is low and might be in need of higher efforts, however since the Environmental Code is a Swedish law it is assumed to be efficient enough to compare with an alternative where the law do not exist.

The eutrophication of the Baltic Sea is caused by all of its surrounding countries. However, this thesis was geographical limited to Sweden because of the focus on the Environmental Code. The zero-eutrophicating goals is set for the entire Sweden, not only the Baltic Sea, as it also affects land, rivers and soils (EPA 2011a). The time period is limited to the expected lifetime of 20 years for the improved on-site facilities (VISS 2015a).

Identification

The identification step is an empirical step where all impacts related to the policy were identified. They were then classified as positive or negative costs to society. For a socio-economic review these impacts could be ranked after importance (Rosén *et al*. 2008). In this thesis they were only classified as negative or positive. For the actual cost-benefit analysis only the impacts that were possible to quantify within the scope of this research were used. The identified impacts are presented with the results.

Quantification
In the quantification step the identified impacts should be monetized. This can be done through separate indicators of the impacts real value. The values also have to be discounted to their present value to account for the fact that costs and benefits will occur in different times (Rosén *et al.* 2008).

The two main reasons why the values need to be discounted include opportunity costs and rate of time preferences. The resources needed to improve the treatment facilities could be used in another project. Time preferences are important as most people prefer to use their money in the near present rather than in the future (Boardman, Greenberg, Vining & Weimer 2011).

The discount rate that was used was 4%. All the monetary values were adjusted to the current price level in April 2017. 4% has previously been used by the Swedish Transport Administration until they lowered it to 3,5% in 2016 (Swedish Transport Administration 2016). The EPA recommends to always conduct sensitivity analysis, but have also for some purposes recommended 4% (EPA 2006).

Calculation
The quantified impacts were summed up to receive a net present value of the policy. The data estimations and assumptions chosen for the analysis were the ones that were considered the most plausible within the scope of the research. These estimates were the base case. To acknowledge the fact that there were many uncertainties in the data a sensitivity analysis were conducted (Boardman, Greenberg, Vining & Weimer 2011).

An intuitive way of estimating the sensitivity in the calculations could be to take every critical value and try with a lower or a higher value. However as there were at least 19 different data inputs that could be varied with for example three different values it would require over a billion outputs. Instead a combination of partial sensitivity analyses and a best-case scenario analysis were applied. In a partial analysis only the most important and the most uncertain estimates are varied, it can also be made to try to find a break-even. A best-case analysis is where the input data are altered to its range values (Boardman, Greenberg, Vining & Weimer 2011).

The discount rate can have a major influence on projects where the environmental impacts are spread out over a long time period or occurring far away in the future. A high interest would imply that any environmental impacts in the future are valued less today (Perman, Ma, Common, Maddison & McGilvray 2011). Besides from the discount rate, WTP and installation costs were expected to be especially critical values. The calculations for the sensitivity analysis can be reviewed in appendix C and the outcome was presented with the results.

2.3 Data
There are different approaches possible to retrieve the relevant data. For the deposition loads earlier studies such as Brandt and Ejhed in 2002 and Hennlock *et al.* in 2013 combined real estate taxation data and population statistics to estimate actual utilization of the affected houses. Both used different approaches to account for retention, although both requiring estimation of the land's retention capacity and geographic location. To process that amount of data was considered out of the scope of this research. Instead the deposition was estimated by a more basic approach. The factors that were used to calculate the deposition loads were the average residents per household, livings days, average emissions of nitrogen and phosphorus per person and the share and number of permanent or leisure property. These calculations can be reviewed in appendix B**.**

The costs were estimated from the installation costs when going from a non-improved system to an approved system. The average costs were gathered from the national database VISS and the specific measures were improvements from unapproved standard to normal standard for permanent and leisure properties with on-site facilities. VISS is an abbreviation for Vatteninformationssystem i Sverige, which is a national database for all possible actions for better water quality provided by the water authorities. It is a collaboration of many authorities like the EPA, SMHI and the Swedish Board of Agriculture (Vattenmyndigheterna 2017). The cost templates used in VISS are based on an impact assessment report by the Swedish Agency for Marine and Water Management. The report assesses various policy instrument and the available technical improvements and their respective cost-effectiveness for on-site facilities (VISS 2015a).

The data for the number of on-site sewage treatment facilities were provided by the report *Uppdatering av kunskapsläget och statistik för små avloppsanläggningar* written for SMED, a national database for emissions, by Olshammar *et al.* in 2015. A research questionnaire was sent out to all of the 245 Swedish municipalities. The response rate was 84% and the total number of on-site facilities were estimated to 625 000, of them 26% are facilities with only sludge separation. This was compared to the official records in the real estate taxation registry with a total of 691 000 (Olshammar *et al.* 2015). The 26%-share were anticipated to be true for the real estate taxation registry as well and gave a total of 145 000 facilities relevant for this thesis. The full calculations of the costs can be reviewed in appendix A.

The benefits were assumed to be corresponding to the reductions of nitrogen and phosphorus and how much the affected individuals would be willing to pay for that improvement. The reductions can theoretically be monetized by its corresponding shadow price. A shadow price is the social evaluation of an input. It can be defined as the marginal increase in welfare resulting from a marginal change of the input or output. A shadow price can theoretically be derived from each affected individual's willingness to pay, WTP, for the improvement (Brent 2006).

Kinell, Söderqvist and Hasselström presented a report for the EPA in 2009 with monetary values for a number of different environmental changes. Based on five previous contingent valuation method studies and three previous time value of money method studies an average, median and interval for willingness to pay for reductions of nitrogen and phosphorus was presented. These can be seen in table 3.

Table 3 WTP for reduction of nitrogen (N) and phosphorus (P) by Kinell, Söderqvist and Hasselström 2009.

	WTP SEK/kg reduced N	WTP SEK/kg reduced P
Average	74,42	2410,83
Median	40,76	1579,91
Interval	11,07 – 210,74	382,39 – 6420,49

The data in table 3 were used to estimate the benefits. However, also pointed out by the authors of the study, the WTP-measures were estimated for a 50% reduction of all eutrophicating substances to the Baltic Sea. The results in this thesis were therefore subjected to sensitivity analysis.

The input data for the calculation of depositions were
- Residents per household
- Living days for permanent and leisure property
- Deposition of nitrogen per person and day
- Deposition of phosphorus per person and day
- Number of on-site facilities, permanent residency and leisure property

The calculated deposition loads are presented in table 4.

Table 4 Data on deposition loads

Data on deposition loads	
Nitrogen	783781 kg
Phosphorus	121922 kg

The deposition loads in table 4 were combined with their corresponding WTP to get an estimate of the monetized benefits. These are presented with the results.

The participants in the WTP-studies were informed that they would have to make the payments for their rest of their life. In regard to this the benefits could be discounted as a perpetuity, but as the expected lifespan of the improved facilities were only 20 years the same time period was used for the benefits as well.

To adjust for inflation the consumer price index CPI by Statistic Sweden was used. The costs from the VISS-database were originally estimated in 2009 and the WTP by the EPA was adjusted to CPI in 2006. These values were in this thesis adjusted using their respective CPI-year average to the CPI for April 2007. The indexes from Statistics Sweden's are displayed in table 5

Table 5 Consumer price index (Statistics Sweden 2017b).

	Consumer price index
2006 Average	284,22
2009 Average	299,66
2017 April	321,44

The current price level used in the calculation was calculated by multiplying the CPI for 2017 April with the original price and then dividing the result by the CPI from the earlier year. (Statistics Sweden 2017a).

2.4 Expected results

The net present value from the costs and benefits could potentially provide a guideline for policymakers. Earlier studies like Gren, Jonzon and Lindqvist 2008 have estimated high marginal costs for improvement of on-site facilities. Compared with measures with lower marginal costs this policy is more likely to be inefficient, but when concerning the relative low treatment capacity of on-site facilities compared to public treatment plants there might still be room for improvement.

Limitations

In comment to the expected results it is important to note that there are several limitations of cost-benefit analysis. Uncertainties in data or analytical resources are technical limitations that can alter the Pareto principle that requires that all costs and benefits are monetized. The relevance of a CBA is also dependent on the relevance of the efficiency criteria, distributional effects or other goals that for some policies weigh heavier (Boardman, Greenberg, Vining & Weimer 2011). The Kaldor-Hicks criterion applied in this thesis made it almost certain that the house owners who are the ones who bear the costs would lose on the policy. If there were a positive net present value it would be up to the decision-maker to decide if the house owners should be compensated. However if the transaction costs were accounted for from a potential compensation it would change the results.

3. Results

In this section the identified impacts are presented, first as positive or negative and then with the monetized values. Finally the overall result with the net present value is presented.

These were the impacts identified from the literature review when improving the standard of on-site facilities.

- Positive impacts
  - Reduced eutrophication
  - Reduced risk of contaminated groundwater
  - Improvement of local water quality for outdoor life
- Negative impacts
  - Installation costs
  - Government supervision and compliance enforcement.

These impacts were provided by Hennlock *et al.* in 2013 except for the reduced risk of contaminated groundwater and improved local water quality for outdoor life which were possible positive effects identified in the analysis. The general problem with contaminated groundwater has for example been dealt with by Sweden's National food agency (2017). The improvement of on-site facilities were assumed to only have a marginal effect on the local water quality, in contrast to a complete lack of sewage treatment. In that regard marginal effects locally were also assumed to affect the major impact of reduced eutrophication and was not accounted for as it might have been counted twice.

The monetized impacts were reduced eutrophication measured as the reduced deposition of nitrogen and phosphorus, and the installation costs. Any actions by the government were not monetized. Neither was the reduced risk of contaminated groundwater because of the limited studies on the connection to on-site facilities and how to value it. The costs and benefits calculated in appendix A and B are summed up in table 6.

Table 6 CBA - Results

CBA - Results	
Benefits	2 664 066 774 SEK
Costs	8 112 008 548 SEK
Net Present Value	-5 447 941 774 SEK

The benefits were calculated to 2 664 million SEK and the costs to 8 112 million SEK, the net present value was a negative value of 5 448 million SEK. The outcome implied by table 6 was that the policy is not effective and should not be continued.

3.1 Sensitivity analysis

To test and demonstrate the sensitivity in the analysis the calculations were adjusted for different social discount rates and different levels of costs and benefits. The new rates were 0% and 10%, the effects on the results compared to the original 4% rate are shown in table 7.

Table 7 Sensitivity analysis, discount rates.

Discount rate	0%	4%	10%
Benefits	3 920 533 924 SEK	2 664 066 774 SEK	1 668 885 769 SEK
Costs	8 710 180 872 SEK	8 112 008 548 SEK	7 638 227 969 SEK
Net Present Value	-4 789 646 948 SEK	-5 447 941 774 SEK	-5 969 342 200 SEK

The 0% rate gave a negative present value of – 4 790 million SEK and the 10% rate gave a negative result of – 5969 million SEK. The discount rates were on their own not enough to change the overall outcome to a positive result.

A second test was conducted to estimate a best-case scenario. The assumptions made was 0% discount rate, 50% higher WTP and 50% lower installation and annual costs. The results are shown in table 8.

Table 8 Best-case scenario.

CBA - results	
Benefits	5 880 800 886 SEK
Costs	4 355 090 436 SEK
Net Present Value	1 525 710 450 SEK

The changes in the second test were enough to give a positive net present value. The net present value in table 8 was 1 526 million SEK. Given these results the policy should be continued.

The alternative policy were to abandon the section of the Environment Code about on-site sewage treatment facilities. Given the impacts identified in this thesis it would imply zero investments costs and zero benefits. That implies a higher net benefit than the original outcome but lower than the second test in the sensitivity analysis.

4. Discussions and conclusions
This section contains an interpretation of the results. Comparisons with other studies are made and relevance of the main findings are discussed. The section is divided into discussions and conclusions.

4.1 Discussions
The first outcome in the results was a negative net benefit. This would imply that the current policy, the status quo, should be abandoned. The alternative policy which had both zero investments costs and zero benefits should be accepted over the current policy. However there is, as was stated in the defining alternatives, critiques against that the improvements of on-site facilities are going to slow, e.g. from Kumblad, Rydin and Stralka (2016). To accelerate the improvements additional measures might be needed even though there already is a statutory law. It can therefore be argued that the CBA should not have been conducted *in media res* but *ex ante* instead to include future actions and policies.

Even with the short time period, limited by the expected life time of the treatment facilities, the discount rate influenced the calculations, but they did not change the results on their own. Only one set of assumptions did make a positive net benefit in the sensitivity analysis, but it is unlikely that all of the assumptions would happen at the same time. A positive net benefit would imply that there is room for compensation to the house owners who have to bear the burden of the installation costs. Such a compensation of the distributional effects is decided by the decision-maker. It should be noted that any compensation is associated with transactions costs that were not accounted for in the CBA.

The calculation of deposition loads were made without consideration of the retention factor. Olshammar *et al.* 2015 did not account for retention either because of uncertainties, but Brandt and Ejhed 2002 tried to account for retention by using simulation models. The importance of nitrogen retention was emphasized in a report by Arheimer and Pers preceding a lawsuit against Sweden from the European Commission. The concern was that Sweden did not achieve the minimum standard of nitrogen removal specified by the European Union’s Urban Waste Water Treatment Directive. However, as was clarified in the report, the need of nitrogen removal by Swedish sewage treatment plants are compensated for by the nitrogen retention capacity of the surroundings. The wastewater from a treatment plant in Sweden’s inland can flow through many lakes before reaching the sea, resulting in reduced levels of nitrogen for each lake (Arheimer & Pers 2007). Even though the European Commission claimed that this process is too unstable to account for the final judgement in the case C-438/07 in 2009 approved the method.

Olshammar *et al.* 2015 calculated the total load of nitrogen to 3066 tonnes per year and the total load of phosphorus to 295 tonnes per year for all on-site sewage treatment facilities. A rough estimate using the 26% share for unapproved facilities would equal 797 tonnes of nitrogen and 76 tonnes of phosphorus per year. Accounting for the lower reduction capacity for the unapproved facilities these estimate are likely to be too low, however there is a possibility that the houses with unapproved treatment facilities are used less, hence why they have not bothered to improve their facilities, which would instead make the loads lower. The estimates used in this thesis were lower, 549 tonnes of nitrogen per year 37 tonnes of phosphorus per year. If the loads in fact are higher the benefits would be higher as well.

The WTP estimates were essential for the estimations of the benefits. There are mainly three fundamental issues with using WTP, failure to fulfil the scenario in the WTP-survey, dependence of wealth distribution in society and which individuals' WTP to include (Boardman, Greenberg, Vining & Weimer 2011). The scenario for the WTP estimate was a substantial reduction of eutrophicating substances which the authors of the study assumed to be 50% to make the results comparable (Kinell, Söderqvist and Hasselström 2009). Because the improvement of on-site facilities only is a small part of all the actions needed to improve the state of the Baltic Sea it is likely that the WTP is overestimated. However, if the geographical area is expended to all of the Baltic Sea, more people would benefit from the improvements. Any distributional effects are expected to have a higher influence on the results if more countries are included as the WTP varies among the wealth between countries.

The relative short time period of twenty years also affects the WTP estimates. The WTP might be lower regarding that the effect only lasts for twenty years, however it might also be higher because the payments are paid for a limited time period in contrast to the individual's entire life which the original study assumed. There could also be a problem with hypothetical bias. The participants in the questionnaire survey might overestimate their WTP because they know it is unlikely that they actually would have to make the payments (Boardman, Greenberg, Vining & Weimer 2011).

In respect to the polluter-pay-principle of the Environmental Code the willingness to accept measure, WTA, might serve better than the willingness to pay measure, WTP. In theory the difference between them are small. However when there are limited possibilities for substitution WTA can exceed WTP substantially (Perman, Ma, Common, Maddison & McGilvray 2011). If the participants of the WTP-studies were asked how much they would be willing to be paid by someone wishing to avoid installing new treatment facilities, the amount would most likely be much higher. This can be illustrated by the scenario where a house owner would ask the neighbours how much they would need to be paid to accept that the first house owner is releasing untreated sewage water. The change from improving an on-site treatment facility is not as visual as the example, but it can be assumed that the WTA is exceeding the WTP and that the benefits in that case would be higher than in the thesis.

When the impacts can be quantified but are hard to monetize, like in this case, a cost-effectiveness analysis might be more appropriate than a cost-benefit analysis. It will not be possible to conclude if the policy is efficient to society but the policies can be ranked in efficiency order to help decision-makers (Boardman, Greenberg, Vining & Weimer 2011). This have been done by e.g. Gren, Jonzon and Lindqvist in 2008. If reduced eutrophication is an accepted target the decision-makers can chose between the most efficient measures without concerning the overall efficiency to society.

4.2 Conclusions

The substantial negative net benefit implied that, according to this CBA, improvements of on-site sewage treatment facilities are not a cost-efficient way to contribute to the zero-eutrophication target. It could also be concluded that the Environmental Code's regulation of on-site facilities is not effective in regard to the zero-eutrophication target. However one scenario in the sensitivity analysis showed a positive net benefit. It should also be noted that for the Environmental Code the zero-eutrophication target is not the single factor, other objectives such as good water quality and a decent living environment matters as well. The results in this thesis are not alone enough to recommend a change in the Environmental Code regarding on-site treatment facilities, however with other studies it could provide guidance of the sector's overall efficiency.

The difficulties with estimating a WTP that can be used for different scenarios make the results from a cost-benefit analysis delicate to interpret. This was especially true in this case where the WTP was estimated for eutrophication in the Baltic Sea but used in this thesis to eutrophication in the entire Sweden. Further studies applying CBA to this problem might have to develop a model with a WTP that includes a larger area.

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Appendix A

This appendix contains the calculations for cost of nitrogen and phosphorus reductions.

In the data section the number of houses with only sludge separation were estimated to 145 000. The averages costs were gathered from the national database VISS and the specific measures were private sewers for permanent and leisure properties improved from unapproved to normal standard. The specific choice is shown in table 9.

Table 9 The specific measures used in the VISS national database.

	Measure in database	Database ID
Permanent property	Fritidshus EA åtgärdat från IG till N	VISSMEASURETYPE000704
Leisure property	Permanent EA åtgärdat från IG till N	VISSMEASURETYPE000702

The data provided by VISS for the measures in table 9 are presented in table 10.

Table 10 Costs provided by the VISS national database, both permanent (VISS 2015b) and leisure property (VISS 2015b).

	Installation costs	Annual maintenance cost	Expected lifespan
Permanent property	44000 SEK	600 SEK	20 years
Leisure property	44000 SEK	600 SEK	20 years

It was noted in table 10 that the same costs and expected lifespan were expected for both permanent and leisure properties. For calculation of present value the installation costs were assumed to all occur in the first year and the annual maintenance occurring every year for the entire lifespan. The formula used for calculating the present value is shown below, the rate was set to 4%.

$$\textit{Present value} = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$

Formula 1 The formula used to compute the net present value (Boardman, Greenberg, Vining & Weimer 2011).

The results in table 11 were calculated by first adjusting for inflation, then discounting the annual costs, adding the installation costs and lastly multiply by the number of properties.

Table 11 All costs discounted to their net present value.

	Number of properties	Social discount rate	Net present value
Permanent and leisure property	145 000	4%	8 112 008 548 SEK

The total costs in table 11 were calculated to a net present value of 8112 million SEK. The result is presented together with the benefits in table 6.

Appendix B

This appendix contains the calculation of deposition loads and the associated benefits.

The average residents per household were estimated to 2,22 for the year 2012 (Johansson 2014). The average depositions loads were 13,5 gram nitrogen and 2,1 gram phosphorus per day and person. The values were estimations by the EPA (1995).

In the real estate taxation data used by Olshammar *et al.* the share of leisure properties were 32%. This share was assumed to be the same for the properties with only sludge separation. This assumption was important as there were less deposition loads from leisure properties than from permanent living properties as the former are used less. The usages are measured as living days and were estimated to 237 days for permanent living and 60 days for leisure properties (Olshammar *et al.* 2015). The data which were the base for the deposition loads are presented in table 12.

Table 12 Input data deposition loads

Residents/ household	Living days, permanent living	Living days, leisure property	Deposition of nitrogen kg/day	Deposition of phosphorus kg/day	Number of private sewers, permanent residency	Number of private sewers, leisure property
2,22	237	60	0,0135	0,0021	98600	46400

The data in table 12 were used to calculate the total deposition and total value shown in table 13.

Table 13 Deposition loads and values

	Total depositions (kg)	Post treatment non-approved	Post treatment approved	Net benefit (kg)	Average WTP, CPI adjusted	Total value
N	783 781	705 403	548 647	156 756	84 SEK	13 193 497 SEK
P	121 922	103 633	36 576	67 057	2 727 SEK	182 833 199 SEK

The values in table 13 were calculated from the data in table 12 where the estimated loads were calculated separately for permanent and leisure properties and then summed up. The total depositions were then being subjected to the estimated treatment efficiency. These were 15% for phosphorus and 10% for nitrogen for non-approved facilities and 70% and 30% respectively for a treatment facility with normal capacity (Ek *et al.* 2011). The difference between these two was the net benefit in kilograms from installing new treatment facilities. The net benefit were then multiplied by the average WTP to receive a monetized total value.

The payments, the WTP, are occurring every, and therefore had to be discounted to their net present value, this was done using formula 1 used in Appendix A. The net present values for the benefits associated with reduced nitrogen and phosphorus with a 4% discount rate are shown in table 14.

Table 14 The benefits discounted to their net present values.

	Social Discount Rate	Time Period (years)	Net Present Value
Nitrogen	4%	20	179 303 928 SEK
Phosphorus	4%	20	2 484 762 856 SEK

The net present values of the reductions was calculated to 179 million SEK for nitrogen and 2 485 million SEK for phosphorus. The net present values of the benefits are presented together with the costs in table 6 in the results section.

Appendix C

This appendix contains the calculations for the sensitivity analysis.

The sensitivity analysis for the different discount rates were calculated using formula 1 in appendix A. The calculations where tested for 0% and 10% discount rates besides the original 4% discount rate. The results are presented in table 7.

A combination of partial sensitivity analysis and worst- and best-case analysis was used in the second test. Computing the net benefit by using the extreme values provides a guidance of whether or not the base case might actually change, however it should be noted that the probability of that scenario with extreme parameters is very small (Boardman, Greenberg, Vining & Weimer 2011). A discount rate of zero was also included to compute a best-case scenario were the policy might have a positive benefit.

Assumptions made for the best-case scenario:

- 0% discount rate
- 50% lower installation cost and annual costs
- 50% higher WTP

Except for the alternative assumptions the calculations followed the procedure in appendix B. The results are presented in table 8.