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Environmental and economic performance assessment of the integrated urban wastewater system

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Abstract

In order to comply with the Water Framework Directive's requirement to reveal the major pressures and impacts on the receiving water at river basin level, the merits of a methodology that combines substance flow analysis and mass balances were evaluated with the aid of a case study. The river basin analysis consisted of the analysis of all individual municipal sewer catchments constituting the basin on a yearly time scale, and included the description of the main sewers and waste water treatment plants and their performance in environmental and economical terms. A wide set of indicators was evaluated.

Uncertainties and information gaps arising from the study are described. The choice of the geographic scale seems a key factor in the evaluation.

The case study indicates that such an evaluation is of great value for decision-makers in the perspective of the Water Framework Directive implementation, to highlight situations of weak or strong performance and to pinpoint information gaps requiring further research in order to take more informed decisions, to identify the main pressures on the environment and to plan more cost-effective measures.

Keywords: Benchmarking; Economics; Indicators; Integrated urban wastewater management

1. Introduction

With the introduction of the Water Framework Directive (WFD) (EC, 2000), a crucial change has occurred in river basin management, from emission-based regulations to a "combined approach", consisting of a combination of limits to be applied to pollution emissions, with quality standards to be set in the receiving water. Such an approach makes more degrees of freedom available for basin management; therefore allowing better allocation of economic resources in pollution abatement. In order to be able to prioritise interventions, an overview of the system behaviour has to be produced by means of a comprehensive systems analysis, which should reveal the major pressures and impacts on the receiving water. This analysis is explicitly required by the WFD.

The aim of this work was to develop a methodology allowing a thorough and wide-focused systems analysis of the integrated urban wastewater system (catchment area, sewer, wastewater treatment plant and river). Despite the fact that the urban environments are not always regarded as the major sources of pollution (especially in developed countries), they still represent a powerful, flexible and responsive "control handle" in river basin management.

The outcome of the study will ultimately serve as a basis for the development of a decision-support aid that gives

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Abbreviations: BBI, Belgian biotic index; BOD_5, biochemical oxygen demand after 5 d; COD, chemical oxygen demand; CSO, combined sewer overflow; DPF, discharge pollution fee; DWF, dry weather flow; EER, equivalent energy requirement; KjN, Kjeldhal nitrogen; OCP, oxygen consumption potential; PE, population equivalent; PIO, Prati index for oxygen; RTC, real time control; SFA, substance flow analysis; SS, suspended solids; TN, total nitrogen; TP, total phosphorus; VMM, Vlaamse Milieu Maatschappij (Flemish Environment Agency); WFD, Water Framework Directive; WWTP, wastewater treatment plant

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assistance to the cost-effective development of urban wastewater systems for WFD compliance. The research work reported in this paper was carried out within the scope of the EU project CD4WC (www.cd4wc.org) which is supported by the European Commission under the 5th Framework Programme.

The analysis was carried out on conventional "end of pipe" urban drainage and sanitation solutions, i.e. extensive sewer networks with centralised treatment plants. In industrialised countries these approaches are more and more criticised, and new strategies and concepts are developed (Larsen and Gujer, 1997). On the other hand, centralised systems are still the best option in many cases and—most importantly—they already exist; therefore they require constant efforts in terms of maintenance and performance optimisation.

Among the wide suite of tools available to perform a systems analysis (Finnveden and Moberg, 2001; Balkema et al., 2002) substance flow analysis (SFA) combined with mass balances proved to be appropriate tools to highlight pressures on the environment, i.e. on the receiving water, and to pinpoint information gaps (Belevi, 2002; Jeppsson and Hellström, 2002). The evaluation of a list of indicators helped to characterise the behaviour of sewers and wastewater treatment plants (WWTPs) in environmental and economic terms (Matos et al., 2003); therefore to prioritise areas of intervention in a decision-making context. It allows us to recognise the information gaps in the system owing to the typical methods of data collection and monitoring of the urban catchment, so that we can gather the most useful missing information to be able to take more informed decisions.

The aim of the illustrative case study performed on the Nete river basin was to give an example of systems analysis in a basin with fairly good river water quality, and also to take advantage of the fact that this basin is the one with the largest water quality data set available in Flanders, Belgium. The systems analysis is formed by the analysis of all municipal sewer catchments constituting the basin on a yearly time scale, and includes the description of the main sewers (pump lines) and WWTPs and their performance in environmental and economical terms.

This paper deals with the evaluation of indicators and of information gaps as decision-support to priorities interventions and data collection, illustrated by a case study, while SFA and mass balances are described and discussed by Benedetti et al. (2006).

2. Methodology

2.1. Adopted indicators

The substances analysed in the study were water, BOD_5, COD, total nitrogen (TN), total phosphorus (TP) and Zn. Water was selected since the analysis of its flows can reveal problems such as in- and exfiltration, WWTP overload and hydraulic stress to WWTP, sewers and receiving water body; BOD_5 and COD are indicators of organic pollution leading to oxygen depletion and CO_2 emission; TN and TP reveal the eutrophication potential in the receiving water; Zn is the most detectable heavy metal (therefore measurements are fairly reliable) and is representative of toxic contamination.

The following list describes the major indicators adopted in this study. Note that costs and energy consumptions are the lumped values for WWTPs and sewers, except when stated otherwise. The indicators are calculated on a yearly basis.

(a) *Loads of pollutants entering WWTPs per inhabitant connected* ($g\,d^{-1}\,inh^{-1}$)*, per drained area* ($g\,d^{-1}\,m^{-2}$) *and per population density* ($g\,d^{-1}\,inh^{-1}\,m^{2}$): they provide an indication of the presence of industrial discharges in sewer catchments and on other structural characteristics, like type of urbanisation, presence of local treatment devices (e.g. septic tanks), etc.

(b) *COD- and TN-based population equivalent (PE) load* ($g\,d^{-1}\,PE^{-1}$)*; comparison with inhabitants connected, design PE and percentage of industrial flow*: TN should be favoured as a basis to calculate PE load because it is more conservative than COD in the sewer system. Comparing these parameters can reveal cases of plant overload or underload, or excessive industrial connections.

(c) *WWTP removal efficiencies of pollutants (% of incoming load)*: they express the capacity of WWTPs to prevent pollutants to enter the water body from the sewer system. Still, pollutants are not actually removed, but their path is altered so that they can be disposed of with less harm to the environment (e.g., nutrients contained in waste sludge can be used as fertilizers).

(d) *Total, operational and variable cost, also expressed per unit of (equivalent) total pollutants mass removed* ($€\,kg^{-1}$): it indicates the economic efficiency of the wastewater treatment. In this study, total costs include all accounted costs, operational costs are total costs without capital costs and variable costs are operational costs without personnel costs. Capital costs are the actual depreciation cost accounted by Aquafin for 2002. Costs are normalised by the equivalent mass removed and are calculated by weighting several pollutants differently. The equivalent mass is obtained by summing the pollutant masses removed, each multiplied by a weight, with two different sets of weights (see Table 1):
   (1) the first set is derived from the Flemish legislation for industrial discharge pollution fees (hereafter indicated as DPF) and
   (2) the second is the oxygen consumption potential (OCP) (Balmér, 2000).

(e) *Costs per PE load* ($€\,PE^{-1}$): they express the economic efficiency of wastewater systems as a function of population and industry served. It is a typical benchmarking indicator when data are clustered for PE load

Table 1
Cost weights for pollutants

	BOD	COD	SS	KjN	NO_3	TN	TP
Weight (DPF)	2	1	2	0	0	20	100
Weight (OCP)	1	0	0	18	4	0	100

DPF refers to the discharge pollution fee calculation (Copp et al., 2002), while OCP refers to the oxygen consumption potential calculation (Balmér, 2000).

classes of WWTPs (Bode and Lemmel, 2001). Note that costs here are only for the treatment plant, excluding the costs for the sewer system to make the comparison possible with other studies. For this indicator, capital costs have not been assumed to be the annual depreciation accounted by Aquafin as for indicator (d), but have been calculated from actual construction cost, assuming a depreciation period of 30 years for civil works and of 15 years for electro-mechanical equipment, and a yearly discount rate of 6%.

(f) *Energy consumption per volume of treated wastewater* ($kWh\,m^{-3}$): it indicates the energetic efficiency of treatments. The energy consumed (due to aeration, to wastewater pumping and to sludge treatment) is considered to be closely linked to the amount of wastewater treated, given the assumption that pollutant concentrations do not vary significantly between plants with mostly municipal influent.

(g) *WWTP plant footprint compared to wastewater treated* ($m^2\,m^{-3}$): it represents the efficiency of surface occupation of WWTPs, specific for the volume of treated wastewater. In densely urbanised areas, the plant footprint can be a critical factor for process selection. This can be an issue also in open land, where larger processes use agricultural space and ultimately destroy natural habitat.

(h) *WWTP effluent concentration for pollutants* ($g\,m^{-3}$): it is an emission-based indicator; it is compared with legislative limits.

(i) *Infiltration water entering the sewer systems (% of DWF)*: mainly a function of the sewer network age and materials. Infiltration negatively affects treatment performance by dilution and overloading. It can also reveal the presence of possible exfiltration, and be a cause of sanitary risks (groundwater contamination).

(j) *Stormwater discharged in the receiving water (% of DWF)*: it is a direct pollutants discharge in the receiving water body from combined sewers and surface run-off, entailing hydraulic stress as well. It is commonly addressed as combined sewer overflow (CSO).

(k) *Ratio of pollutants measured on pollutants discharged in the receiving water*: it is a measure of the self-purification capacity of the river. Low values indicate high capacity, high values indicate low capacity. This indicator is calculated for each substance as the pollutant load at the closing section of the considered river stretch (concentration multiplied by the flow measured at the closing section of the basin) divided by the estimated pollutant loads of all emissions along the river. For the calculation of pollutant loads discharged into the river, refer to Benedetti et al. (2006).

(l) *Water quality indexes*: Prati index for oxygen (PIO)—based on the ratio of the concentration of dissolved oxygen and its saturation concentration (Prati et al., 1971)—and Belgian biotic index (BBI)—based on species counting (De Pauw and Vanhooren, 1983). They have up till now been used in Flanders to report on the physico-chemical and biological (ecological) status of the surface waters, respectively. Assuming that most of the point sources of pollution are properly treated, the PIO gives an indication of the remaining oxygen depleting pollution due to non-point sources like unconnected households and agriculture, and the BBI reveals situations where the ecosystem is still suffering from either the presence of toxic substances or untreated discharges, or problems with the morphology of the river course. The values used in this study have been provided by VMM, the Flemish Environmental Agency.

2.2. Materials and methods

The Nete river basin (1673 km^2, 595,823 inhabitants) is located in the eastern part of Flanders (Belgium). The basin was chosen for systems analysis since it is the basin with the largest data set available in Flanders, due to specific studies regularly performed by VMM (2001). The topography of the basin is definitively flat. The basin is characterised by the presence of intensive agriculture and farming, and scattered urbanisation with some small towns.

The Nete basin comprises the Kleine Nete, the Grote Nete and their tributaries which, after merging, form the Beneden-Nete. The Nete itself is a tributary of the Schelde.

The basin includes 29 sewer catchments. The wastewater system (WWTPs and main connectors of sewer networks) is operated by Aquafin, which was founded by the Flemish Government in 1990 as the licence holder for the wastewater transport and treatment infrastructure in Flanders. The smaller collectors of the sewer networks, from the households to the main connectors, are managed by the municipalities.

2.3. Data collection and processing

All calculations were made on a yearly basis. The year for which the analysis was performed was 2002, which was a wet year in Flanders but did not lead to any flooding or malfunctioning of technical infrastructures.

Aquafin provided the data concerning the sewer catchments in all 29 municipalities discharging in the Nete basin. Each municipality has a WWTP to which the sewer system conveys the wastewater collected.

Table 2
Production of substances per inhabitant per day (VMM, 2001)

Water	COD	BOD	TN	TP	Zn
$112\,\mathrm{L\,inh^{-1}\,d^{-1}}$	$94\,\mathrm{g\,inh^{-1}\,d^{-1}}$	$44\,\mathrm{g\,inh^{-1}\,d^{-1}}$	$10\,\mathrm{g\,inh^{-1}\,d^{-1}}$	$1.7\,\mathrm{g\,inh^{-1}\,d^{-1}}$	$30.7\,\mathrm{mg\,inh^{-1}\,d^{-1}}$

Aquafin provided extensive data sets on all WWTPs in the Nete basin. They are all in the range of small to medium plant size (5 WWTPs <2000 PE, 4 WWTPs $<10{,}000$ PE and 20 WWTPs $<100{,}000$ PE). Several types of WWTP technologies are present. Most of them are oxidation ditches, but there are also some activated sludge systems, trickling filters and—for small plants—constructed wetlands. Almost all systems are low loaded.

Data on industrial discharges have been obtained from VMM, and include all monitored industries in the Nete basin. It is important to note that data are available only for the monitored major industries (larger than a minimum size); no data are available for medium and small industries, and for some not monitored major industries.

VMM has also provided data regarding households present in each municipality and the fraction of them being connected to the sewers. These data are from year 2001, but are considered valid also for year 2002, since is was assumed that no significant changes occurred in the residents' distribution in the Nete basin, and no additional sewer connections were introduced in the basin that year. *Per capita* pollutants production from households are in Table 2.

Measured water flow rates in the system were available for the WWTPs influents (daily) and for the effluents of monitored industries (periodically). Water consumption from households (see Table 2) was estimated from the number of inhabitants and by assigning *per capita* water use (VMM, 2001).

A fraction of the rainfall, function of the impervious area in the basin, was routed through the sewer system (stormwater), and the remaining rainfall was considered to end up directly in the receiving water body or to drain into the water table or to evaporate. The impervious area connected to the sewer system was estimated to be $26.26\,\mathrm{km}^2$, resulting from analysis of available maps of the municipalities; this corresponds to 24% of the connected urban areas.

Infiltration was calculated by subtracting water flow rates from households and industries from the dry weather flow (DWF) entering the WWTP. The DWF for each day of the year was calculated as the minimum of the daily inflows within a range of 10 d before and 10 d after that day (in total 21 d), and it expresses the flow without rainwater, with the assumption that at least 1 d of 21 is a dry day (Jardin, 2003).

The water flow discharged directly into the receiving water body (CSO) was calculated as the total stormwater entering the sewer network minus the amount of stormwater treated in the WWTPs. The flow of treated stormwater is the total water flow entering the WWTPs minus the DWF (Jardin, 2003).

Concerning the river Nete, VMM provided values of the PIO and the BBI for the year 2002 at 377 measurement locations and of basic water quality parameters, with an average of six measurements per location per year. The yearly pollutant loads to the receiving water have been estimated from households and industry as for indicator (a), and from agriculture also for TN and TP by means of modelling results provided by VMM (Benedetti et al., 2006). The water flowing in the Nete during 2002 was available from a measurement station at the river closing section.

3. Results and discussion

3.1. Values of indicators

This section discusses the obtained values and results for the indicators outlined in Section 2.1:

(a) *Loads of pollutants entering WWTPs per inhabitant connected, per drained area and per population density*: Fig. 1 shows COD, BOD_5 TN, TP and Zn average loads to the plants and their standard deviations, expressed in grams (milligrams for Zn) per inhabitant per day. Averages and standard deviations are weighted on the inhabitants connected to the plant. From this chart, it can be seen that loads have a rather small variance in the basin. Such small variance—also for indicator (c)—is due to the very similar conditions and performances of the biggest plants. The low load values could be due to biodegradation in the sewer and to pre-treatment devices (such as septic tanks) at household level. High(er) values could be an indicator of a larger industrial wastewater contribution. Note that the average loads are all higher than the values estimated by VMM for households for the whole of Flanders (Table 2). This could be due to the specific additional contribution of agricultural discharges ending up in the sewer system in this part of Flanders.

(b) *COD- and TN-based PE load; comparison of inhabitants connected, design PE and percentage of industrial flow*: in Fig. 2, the design PE of WWTPs (on the basis of the value $54\,\mathrm{gBOD_5\,inh^{-1}\,d^{-1}}$ used by Aquafin) is compared to the actual number of inhabitants connected to the WWTPs and to the load actually entering the WWTPs on a TN basis ($10\,\mathrm{gTN\,inh^{-1}\,d^{-1}}$), which is less subject to conversion processes in the sewer system than COD. From this chart, it emerges that the

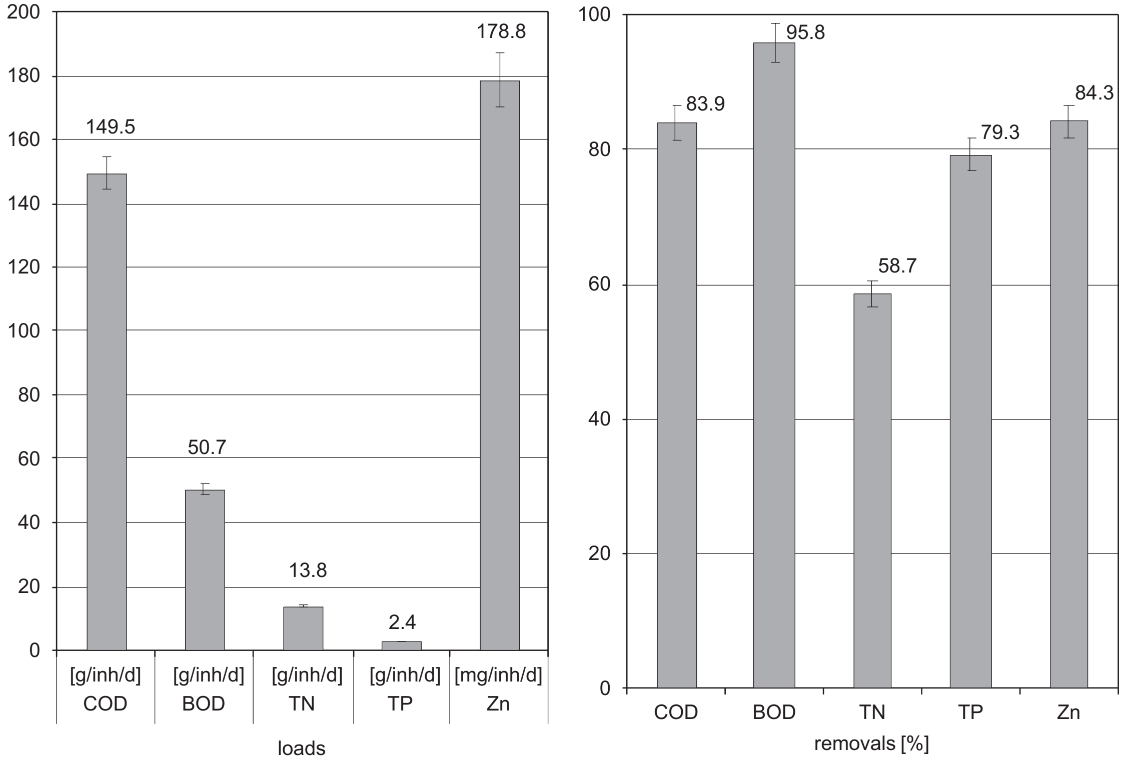

Fig. 1. COD, BOD, TN, TP and Zn average loads (left) and removals (right) of WWTPs with standard deviations; averages and standard deviations are weighted on the inhabitants connected to the plant.

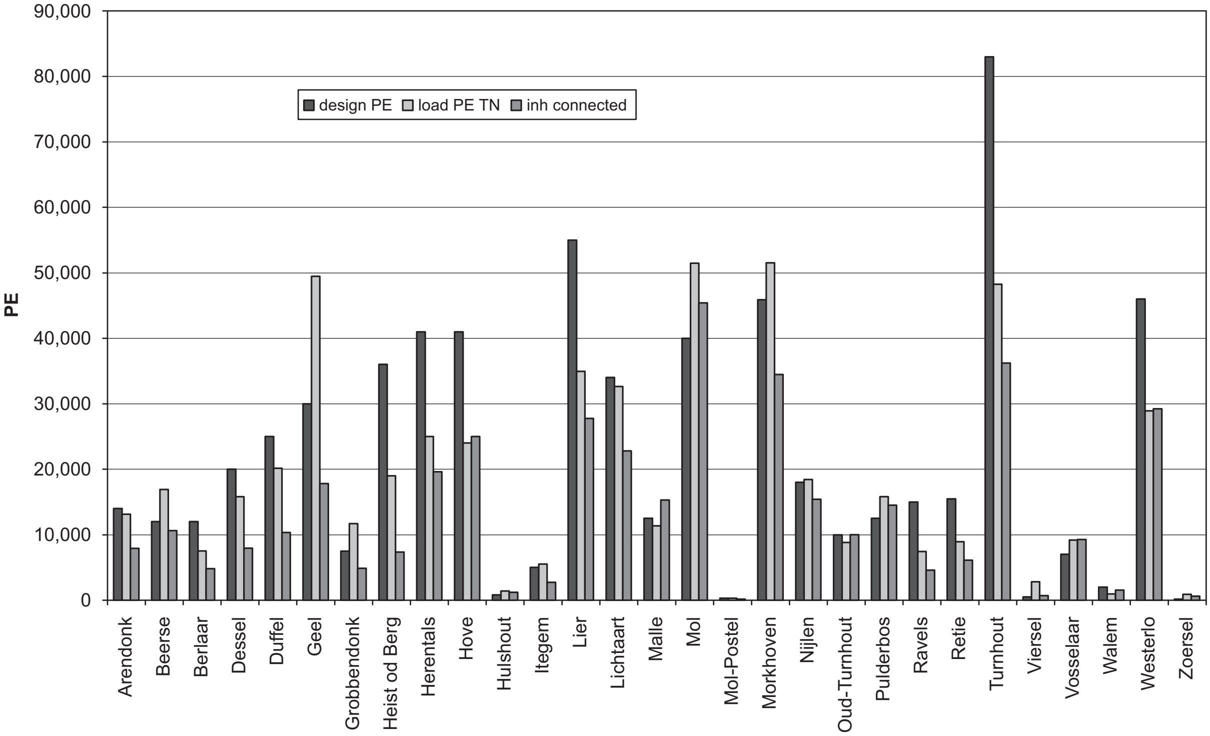

Fig. 2. Design PE (on BOD basis), load PE (on TN basis) and actual inhabitants.

majority of the studied WWTPs are underloaded, so that more households and/or industries can be connected to them.

(c) *WWTP pollutant removal efficiencies*: in 2002, WWTPs with design capacity <10,000 PE were not required to remove nutrients according to Flemish legislation (in 2006 this is changed), but most of them accomplish this task (with low loaded biological processes) since for this region the costs arising from sludge treatment and disposal are higher than the costs for aeration of long sludge age activated sludge. Fig. 1 shows COD, BOD_5 TN, TP and Zn average removals in the plants and their standard deviations, expressed in percentage. Averages and standard deviations are weighted on the inhabitants connected to the plant. COD and BOD_5 removal are larger than the TN removal, indicating that COD removal is present in all systems, while TN removal is not required in WWTPs smaller than 10,000 PE. Also TP removal is rather high, due to very good removal in all of the bigger plants and to the presence of phosphorous removal in most of the plants smaller than 10,000 PE.

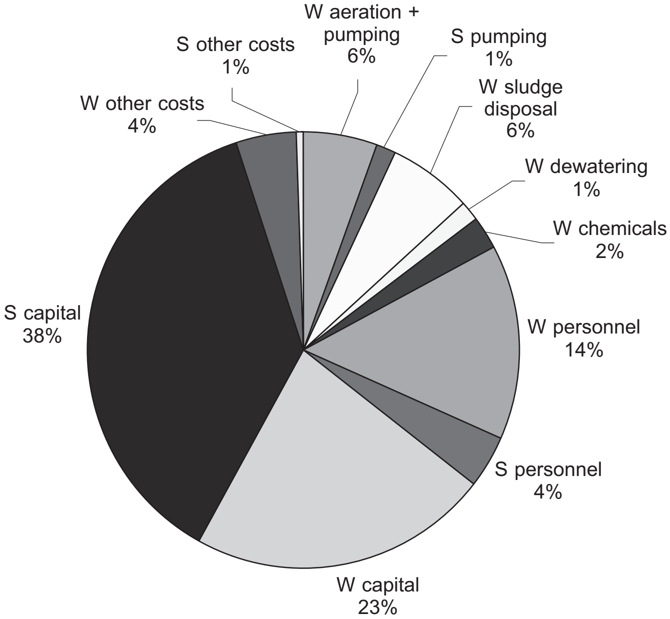

Fig. 3. Percentages of total costs for cost categories in sewers (S) and WWTPs (W).

(d) *Total, operational and variable costs, also expressed per unit of (equivalent) total pollutant mass removed*: as Fig. 3 shows, capital costs are prevailing, since most of the wastewater systems have been built or renovated fairly recently, after the creation of Aquafin in 1990 by the Flemish government. Fig. 4 presents the comparison for all catchments (sewer system plus treatment plant) of variable costs in €$\,kg^{-1}$ removed (the DPF and OCP). An element that clearly emerges from the chart is that the two weighting sets of DPF and OCP give quite similar values for most of the plants, with slightly larger values corresponding to the OCP. Large differences appear only for very small plants, e.g., for Mol-Postel (design capacity 270 PE) the combination of the absence of TP removal in the plant and a high weight attributed to TP removal in the OCP calculation, leads to a very high costs/OCP value for that plant.

(e) *Costs per PE load*: concerning the costs per PE (see Fig. 5), as expected, for very small plants (<2000 PE) costs per PE are higher, especially for capital and staff expenditures, but no clear difference emerges when

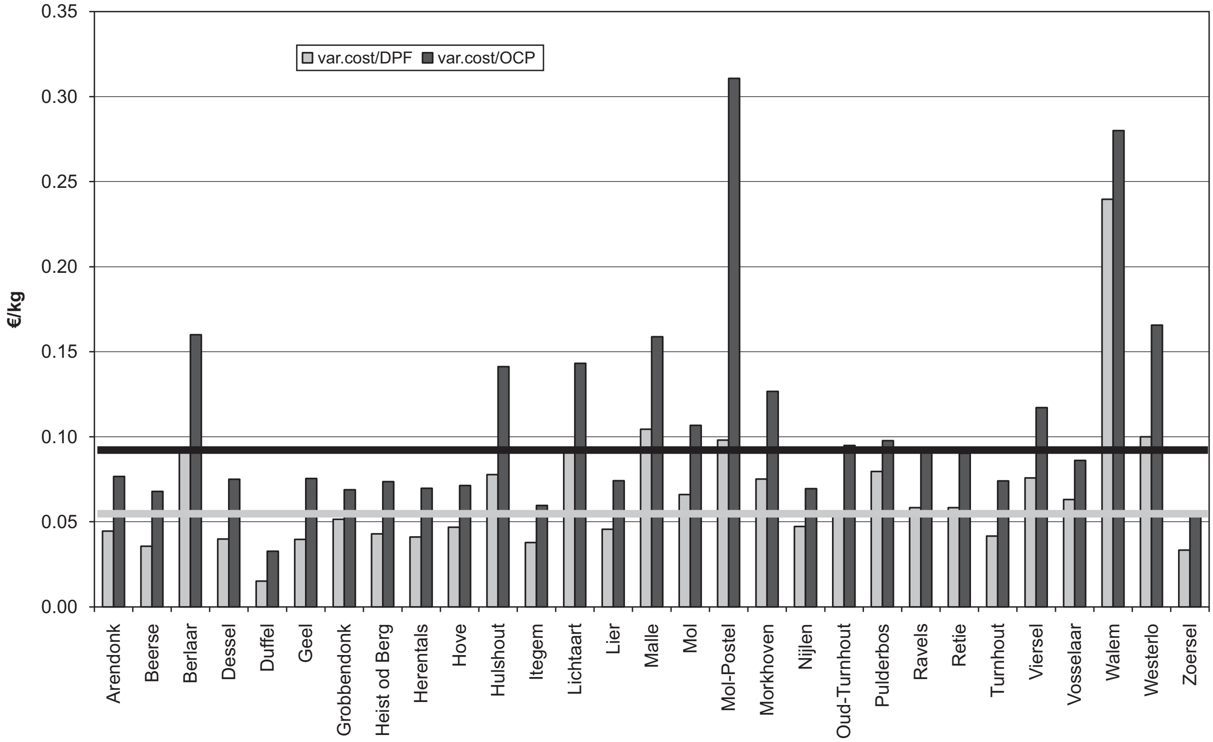

Fig. 4. Variable costs specific to equivalent pollutant mass removed; horizontal lines show average values.

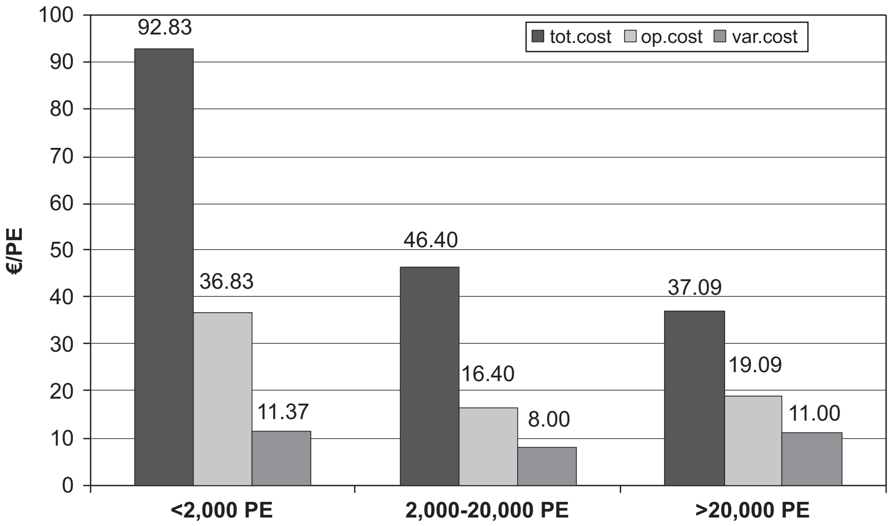

Fig. 5. Costs in € PE^{-1} $year^{-1}$ on the base of 10 gTN inh^{-1} d^{-1} for three classes of WWTPs.

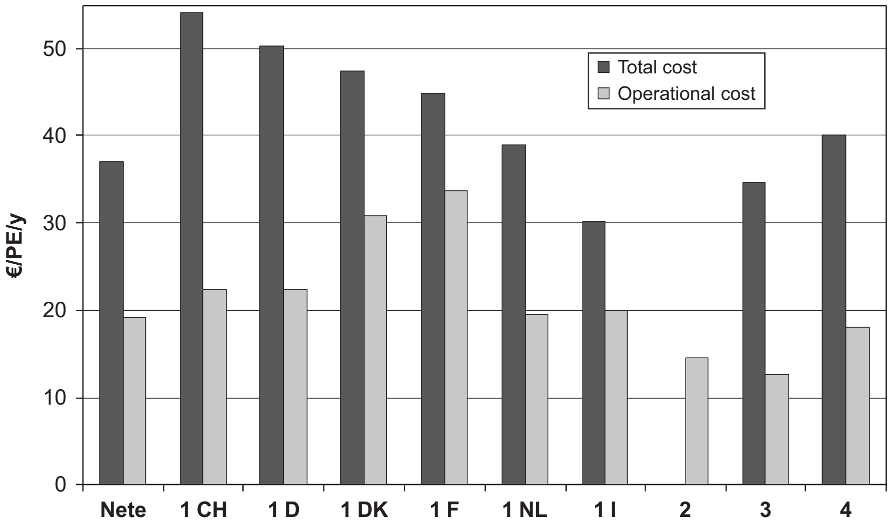

Fig. 6. Total and operational costs for the Nete basin (plants >20,000 PE) and for similar studies: 1 (Bode and Grünebaum, 2000), 2 (Balmér, 2000), 3 (Lindtner et al., 2004) and 4 (Stemplewski et al., 2001).

comparing the other two classes. This is probably due to the fact that all plants are anyway rather small, not exceeding 80,000 PE in terms of design load. The values are comparable to similar studies (Fig. 6).

(f) *Energy consumption per volume of treated wastewater*: Table 3 shows average energy consumption efficiencies specific to volume of treated wastewater with standard deviations. Average and standard deviation are weighted on the volume of wastewater treated by the plant. Lower values are associated to trickling filters and reed-beds, while higher values are found for low loaded oxidation ditches, reflecting the fact that most of the energy is consumed by the aeration process.

Table 3
Average energy consumption efficiency and footprint specific to volume of treated wastewater and infiltration as fraction of base flow, with standard deviations; averages are weighted on the plants treated wastewater volume

	Energy ($kWh\,m^{-3}$)	Footprint ($m^2\,PE^{-1}$)	Infiltration (%)
Average	0.32	0.95	44
S.D.	0.10	0.77	35

(g) *WWTP plant footprint compared to wastewater treated* (see Table 3; average value with standard deviation): the average is weighted on the volume of wastewater treated by the plant. The very high values corresponding to three small-scale plants (reed-beds and lagoons, which are therefore often unsuitable for urban areas) have not been included since they are one order of magnitude larger than all the other values.

(h) *WWTP effluent concentration for pollutants*: all plants comply with Flemish legislation on discharge concentrations.

(i) *Infiltration water entering the sewer systems*: infiltration (see Table 3; average value with standard deviation) is calculated as explained in Section 2.3. The average is weighted on the volume of wastewater treated by the plant. Except for a few cases, most sewer catchments show values relatively close to the average, which is in the expected range of values for the sewer network conditions and topography, and from the estimations of operators. Negative and very high values can be explained by the scarce reliability of imperviousness data for some catchments; also the small scale of some sewer catchments influences the calculations, since inaccurate data have a larger impact on the consequent calculations. The additional pumping costs associated with infiltration are estimated to be approximately €300,000 for year 2002.

(j) *Stormwater discharged in the receiving water*: the water flow discharged directly into the receiving water body (CSOs; see Fig. 7) is calculated as described in Section 2.3. Values are showing a large variance but the average value of 4% of the stormwater entering the system is well within the range of percentages found in literature (Schlütter and Mark, 2003). The explanation of negative and high values is analogous to the one given for infiltration entering the sewer systems. An additional source of miscalculation is due to a combination of high receiving water levels and a lack of flap valves.

(k) *Ratio of pollutants measured on pollutants discharged in the receiving water*: the ratios were calculated for COD, BOD_5, TN, TP and Zn; see Table 4. The values show good self-purification capacity of the river Nete, for which BOD_5 is the major indicator, while COD is of course not all degradable in a river system. Concerning TP and Zn, the values higher than 1 might indicate an underestimation of the discharges in the river; possibly from agriculture for TP, since the loads estimated to come from that source are the most uncertain, being derived not from measurements but from modelling performed by VMM (2001) using as inputs estimated data (manure application); for Zn the cause might be that not all industry effluents are monitored.

(l) *Water quality indexes*: from Fig. 8 (PIO), it appears that oxygen levels are quite high in most headwaters except in the northern and southern areas of the basin (densely populated, and with more unconnected households), and decrease downstream without reaching the worst quality class but in some intermediate stretches. Fig. 9 (BBI) shows a generally good situation, with exceptions in the north of the basin and in the most downstream area, where the untreated pollutants accumulate and have more effect.

Table 4
Ratio of pollutants measured at the closing section on the sum of all pollutants discharged in the receiving water

	COD	BOD	TN	TP	Zn
Load in river (ton year^{-1})	6309	729	2337	452	15.3
Emitted load (ton year^{-1})	11524	3487	2866	252	8.3
Ratio	0.55	0.21	0.82	1.80	1.86

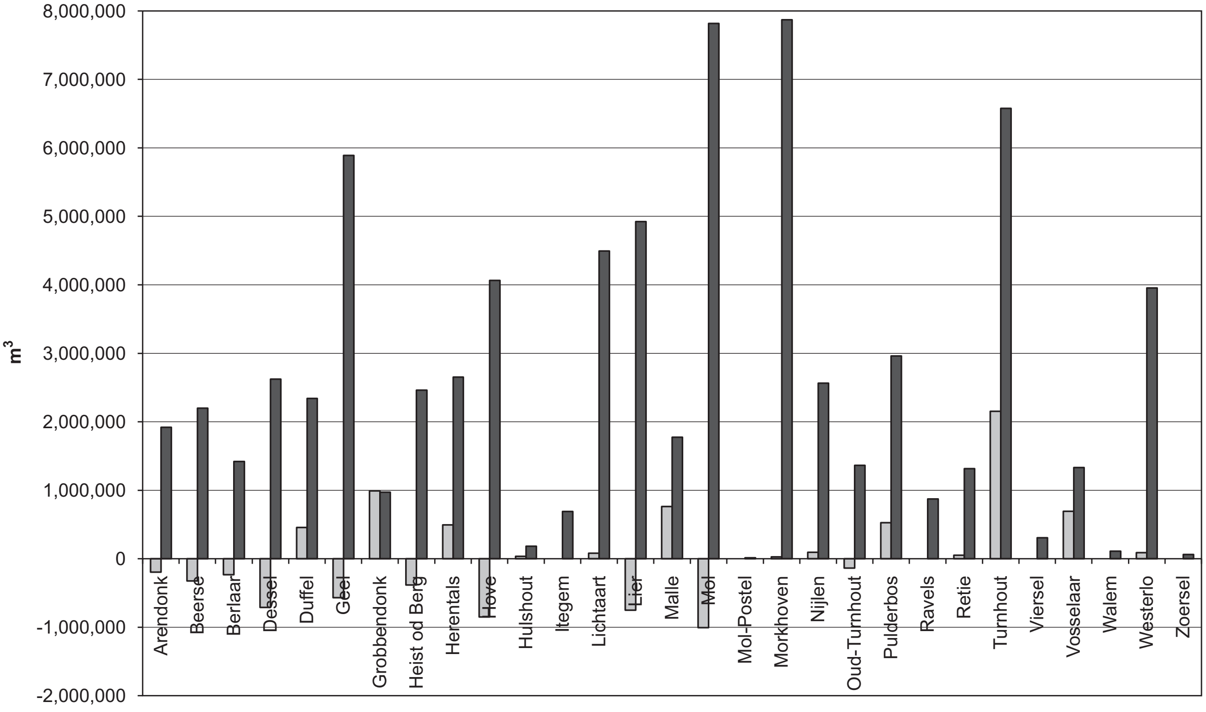

Fig. 7. Estimated CSOs (light grey) compared to WWTP inflows (dark grey).

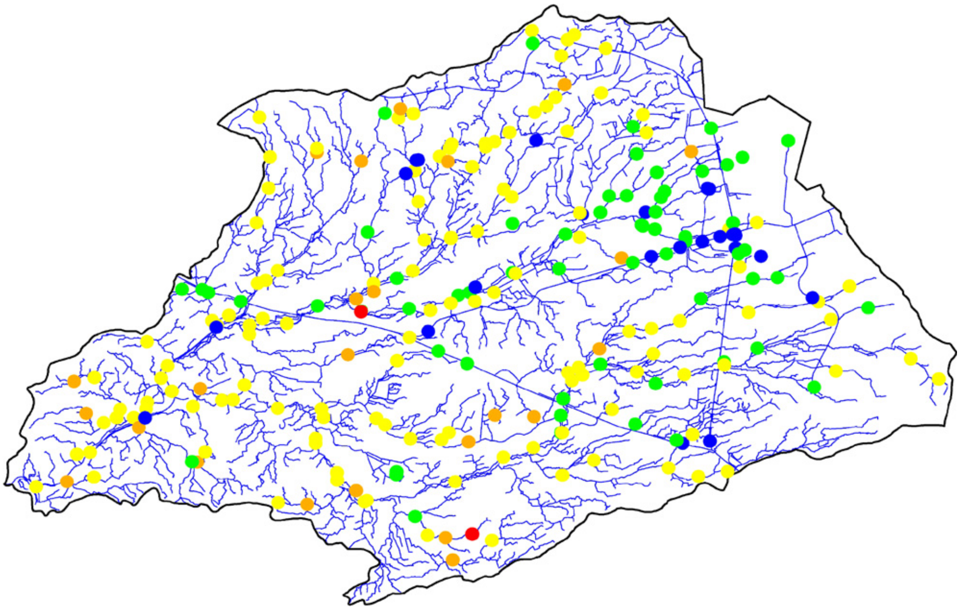

Fig. 8. Prati index for oxygen (PIO) in the Nete basin in 2002; the index values are divided in five classes with increasing water quality: red, orange, yellow, green and blue;flow from right to left.

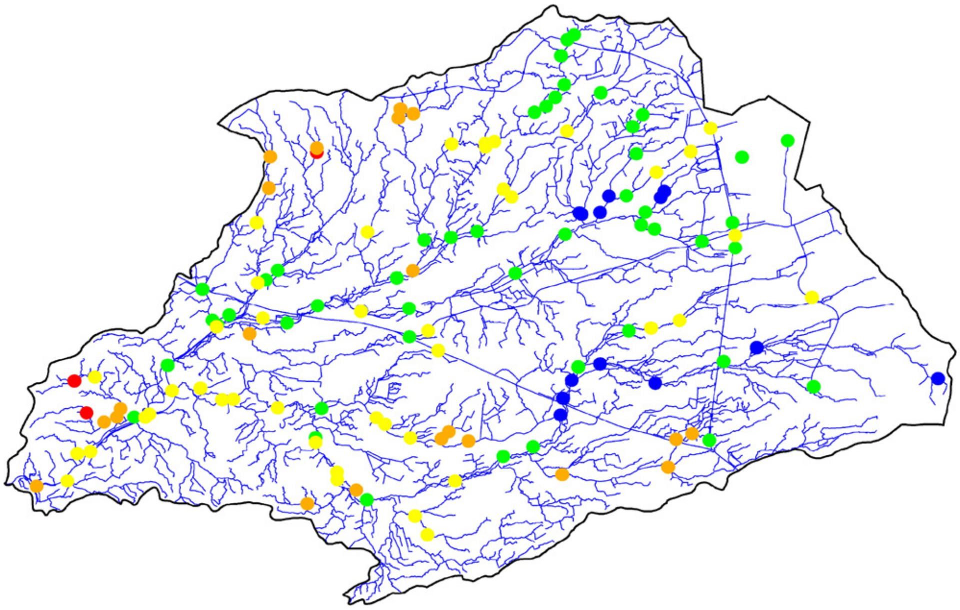

Fig. 9. Belgian biotic index (BBI) in the Nete basin in 2002; the index values are divided in five classes with increasing water quality: red, orange, yellow, green and blue;flow from right to left.

Also very important to draw conclusions on the results obtained with indicators (k) and (l), is the analysis of pressures on the receiving water (Benedetti et al., 2006). From that analysis, Fig. 10 shows as an example the relative contributions to the discharges into the river Nete concerning BOD and TN. For BOD, the chart confirms the impression that organic pollution originates from untreated households discharges, while for TN the large contribution of agriculture to the pollution load result is evident. However, since reducing emissions from the agricultural sector seems to be a difficult problem to tackle, the largest and feasible improvements would be achieved by reducing emissions from WWTPs and by connecting households to the wastewater collection and treatment system. Then, the next step in the decision-making process would be to look at the detailed results of the performance indicators for the 29 catchments, and the ones with larger improvement potential should be chosen first for remediation.

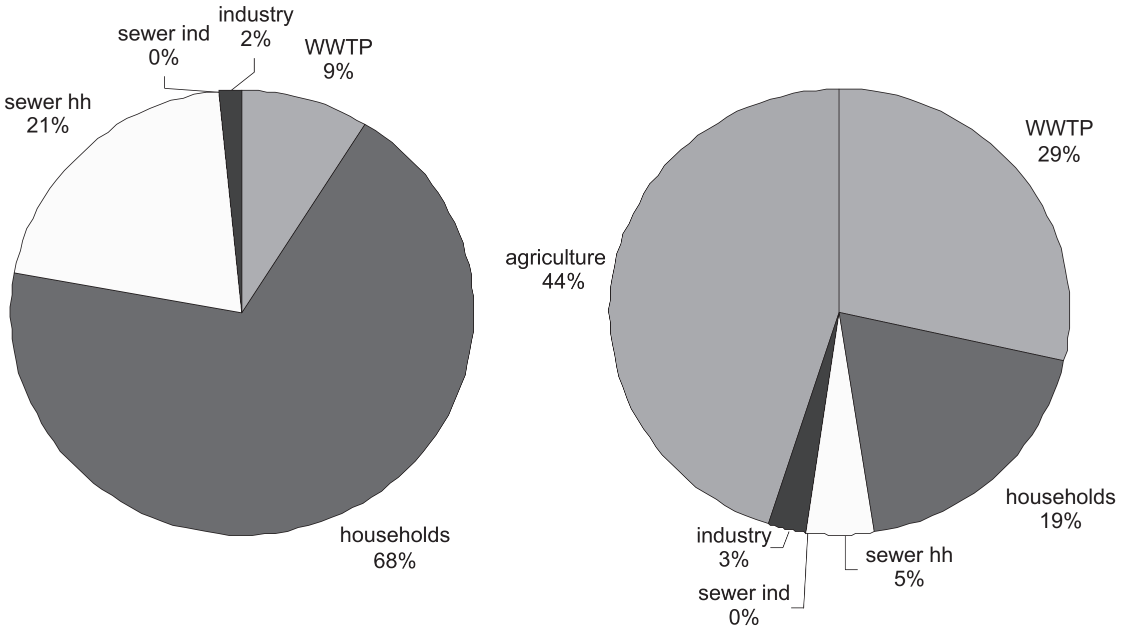

Fig. 10. Relative pressures on the river Nete for BOD (left) and TN (right); "sewer hh" means sewer discharge coming from households and "sewer ind" from industry; agriculture is not included for BOD because of lack of data.

3.2. Uncertainties and information gaps

Several uncertainties and information gaps have to be taken into account in this kind of studies. The most significant are the following:

- Some data come from estimations and other from measurements, making integration and comparison of data difficult; for example, the quantities entering the sewer system are estimated while its effluent is measured.
- Data for this study all correspond to the year 2002, except for households, for which data were available only from year 2001. The assumption has been made that no significant changes in the number of residents occurred from 2001 to 2002.
- The numbers of connected inhabitants are inconsistent: there are differences in the data provided by Aquafin and VMM.
- Small industries are not monitored since only major industries are obliged to self-monitor regularly and are on top of that occasionally monitored by VMM. In this study, only major industries were considered.
- Septic tanks are very common in the Nete basin; they are present at approximately 80% of the households connected to the sewer system due to historical reasons. Such treatment devices remove on average 35% of BOD_5 by biodegradation, 20% of TP by adsorption and settling and 50% of COD by both mechanisms; they are periodically emptied by trucks which bring the septic material to WWTPs with spare treatment capacity; in case the emptying frequency is not sufficient, the tanks overflow causing groundwater contamination and further reduction of load to the sewer system.
- Septic material delivered to the WWTPs was not included in calculations for loads and removals since no data were available for it.
- It was assumed that no transformations or removal occur to pollutants in the sewer network during transport from the source (households, industries) to the WWTP.
- Rainfall data were not available locally for the 29 sewer catchments, so the data available from 11 stations were averaged and used uniformly over the whole basin.
- Impervious areas were not always known with sufficient precision. Therefore, all calculations with respect to surface runoff are rather unreliable.
- CSO loads were not measured but roughly estimated; the main sources of error are: imprecise impervious area, presence of connected open ditches, high water level in the receiving water body leading to reverse flow into the sewers, infiltration.

3.3. The geographic scale

Values of some indicators at sewer catchment scale are showing a large variability but the average values are within the range of values found in literature. It reveals an important aspect of this kind of studies, which is the geographic scale chosen. For large regions like a complete river basin, results are likely to fall in the narrow range of results found in similar studies, since several different contributions compensate each other, producing a value typical for a certain kind of large area. However, with small areas like sewer catchments of small WWTPs, local factors and uncertainties play a major role and very different results appear in seemingly similar areas.

4. Conclusions

The evaluation of performance indicators proved to be a useful tool in the decision-making process needed to fulfil the WFD's requirement by revealing, in a quantitative way, which are the major pressures and impacts and which wastewater systems deserve more attention (showing larger improvement potential) in a river basin. This broad analysis helped also pinpointing information gaps and uncertainties.

The average economic and environmental situation in the studied basin is within the upper range of performance compared with figures reported in the literature as well as to other Flemish urban catchments.

The study on the Nete river basin indicates that the major factor of operational inefficiency of the urban wastewater collection and treatment systems is the infiltration of water entering the sewer network. Infiltration water led to considerable additional treatment and pumping costs in winter, along with environmental risks related to exfiltration (therefore groundwater contamination) in summer. The sewerage networks—as they have often historically grown—have mostly a high drainage component. Whether or not possible rehabilitation processes are deemed to be effective depends on site-specific conditions such as the status of pre-existing infrastructure, institutional arrangements about planning and financing of the urban water cycle and the mindset of the involved parties.

Concerning the receiving water quality, the analysis of specific indexes and of the exerted pressures, allows to indicate the connection of untreated households as the first action to be taken to improve the health of the river, followed by WWTP upgrade.

The case study revealed that the geographic scale chosen is of significant importance in this kind of studies. For large regions several different contributions compensate each other, producing an average value typical for a system with similar properties. But for smaller areas, local factors and uncertainties play a major role, leading to large variations in the indicator values.

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