

Assessing the European wastewater reclamation and reuse potential — a scenario analysis

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Abstract

A model-based estimation of the wastewater reclamation and reuse potential in a European context is presented, and the effects of different water management scenarios on the appraisal are quantified. The impact of climate change on water availability and variation in the demand pattern and water use of considered countries is the modifying variable in these scenarios. The simulation demonstrates that there is a significant potential for an increased utilisation of reclaimed wastewater in many European countries, specifically in the Mediterranean region. Aspects related to the factors that will definitely drive or slow down the development are addressed.

Keywords: Integrated water management; Potential estimation; Wastewater reclamation and reuse; Scenario analysis; Water availability

1. Introduction

Wastewater reuse has developed from a basic method of disposing of wastewater without any treatment to an often highly engineered technique of wastewater upgrading and water resources augmentation in water-scarce regions throughout the world. Due to limited water resources,

typically water-stressed countries in dry climates like Australia, Israel and the State of California, have developed wastewater reuse strategies and programmes acknowledging the beneficial role wastewater reuse can play in integrated water management [1–3].

The water stress situation in Europe is illustrated in Fig. 1, revealing that most countries exhibit a water stress index (a country's ratio of water abstraction to total renewable freshwater

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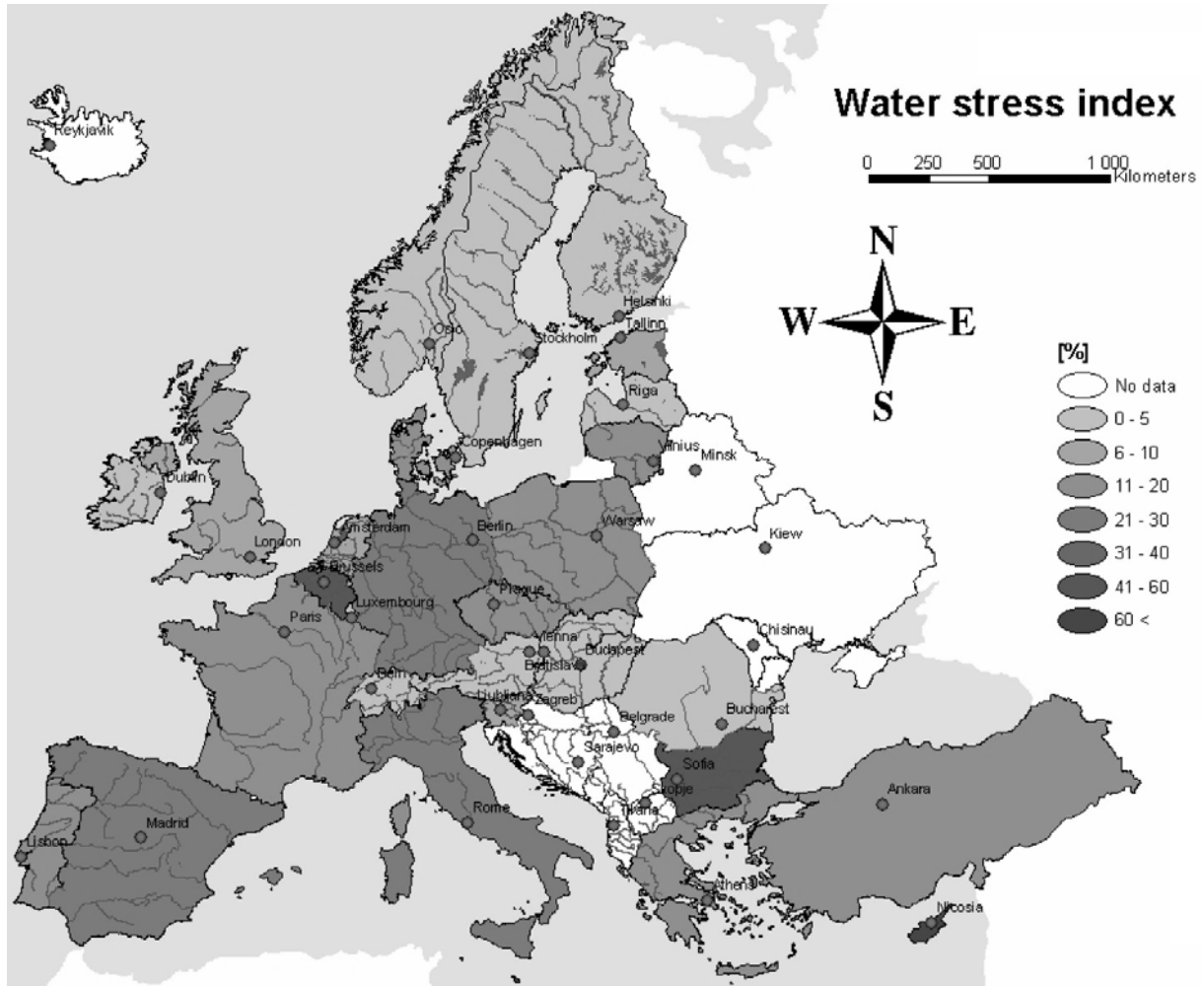


Fig. 1. Water stress index for European countries in 2000 (map provided by [4]).

resources) of less than 20%. Italy, Germany and Spain range between 20% and 30%, whereas Belgium, Bulgaria, Malta and Cyprus exceed 40%. The population of the countries of these two categories makes up approximately 200 million people.

Parallel to increasing severity and frequency of droughts experienced in the early 1990s and in summer 2003, sustainable use of water resources gains more and more importance. In the water policy framework this issue has been incorpora-

ted into the Water Framework Directive (WFD), 2000/60/EC. Enacting the WFD, the EU established an environmental policy which aims at achieve a good status of surface water and groundwater in terms of quality and quantity. This will promote sustainable water resource use and might favour wastewater reclamation and reuse as a viable option. However, on the European level, there are no legislative regulations concerning wastewater reuse so far, apart from the Urban Wastewater Treatment Directive

(91/271/EEC) which advises to reuse wastewater “whenever appropriate”.

Thus the installation of wastewater reuse schemes across Europe has been carried out under country specific national or even regional guidance. Additionally, wastewater reuse potential estimates presented in the literature often exclusively cover particular regions or countries and are presented without any reference to quantification methods applied to derive the appraisal [5,6].

The basic aim of this paper is to present an approach to assess quantitatively the potential of municipal wastewater reclamation and reuse in Europe, taking into account possible changes of today’s circumstances and their impact on the projected reuse potential.

2. Model development

The estimation of water reuse potential in Europe is based on a mathematical representation of that share of water demand and supply which can be covered by reclaimed wastewater. (A more detailed explanation of the model development was presented at the IWA Conference in Marrakech [7].)

The model is based on a straightforward mass balance approach describing the volumetric flow of reused wastewater Q in a particular spatial or temporal context at an equilibrium point of supply and use of reclaimed wastewater. The basic model equation for the assumption of reuse in different sectors is structured as follows:

$$E \cdot \eta = U \cdot \varphi = \sum U_i \cdot \varphi_i = Q$$

$$\Rightarrow Q = \frac{1}{2} \cdot (E \cdot \eta + \sum U_i \cdot \varphi_i) \quad (1)$$

where E is the effluent of wastewater treatment plants [Mm^3/a], U the total water demand [Mm^3/a], U_i the use of water in a specific sector i ,

[Mm^3/a], Q the volumetric flow of reused wastewater [Mm^3/a], η the fraction of wastewater reclaimed (reclamation factor), φ the fraction of total demand covered by reclaimed water (reuse factor) and φ_i the fraction of demand covered by reclaimed water in a sector i .

2.1. Determination of variables

To calculate a change in the total wastewater reuse volume during a time interval, the current wastewater treatment capacity E , the fraction reclaimed (η) and reused (φ) and the sectoral water demand (U) have to be known. Data on sectoral water use and treated effluents were extracted from the EUROSTAT database, the FAO AQUASTAT database and various national statistics. Information on wastewater reclamation and reuse (Q) is based on a literature survey and the compilation of installations conducted by Bixio et al. [8].

Based on these data, the current values for both wastewater reclamation and the reuse factor for a particular country were calculated. As water stress is regarded as a main driving mechanism behind wastewater reclamation and reuse, a correlation between the above-mentioned factors and a country’s water use practice was investigated. In order to emphasise the different influences of sectoral water uses, each was weighted according to its consumptive character, thus deriving the term of consumptive water use intensity (A') according to the following equation:

$$A' = \frac{U_{\text{AGR}} \cdot 0.77 + U_{\text{PWS}} \cdot 0.18 + U_{\text{IND}} \cdot 0.14 + U_{\text{ELE}} \cdot 0.14}{\text{Total renewable freshwater resources}}$$

where A' is the consumptive water use intensity, U_{AGR} the water abstraction for agricultural use [Mm^3/a], U_{PWS} the water abstraction for public water supply [Mm^3/a], U_{IND} the water abstraction

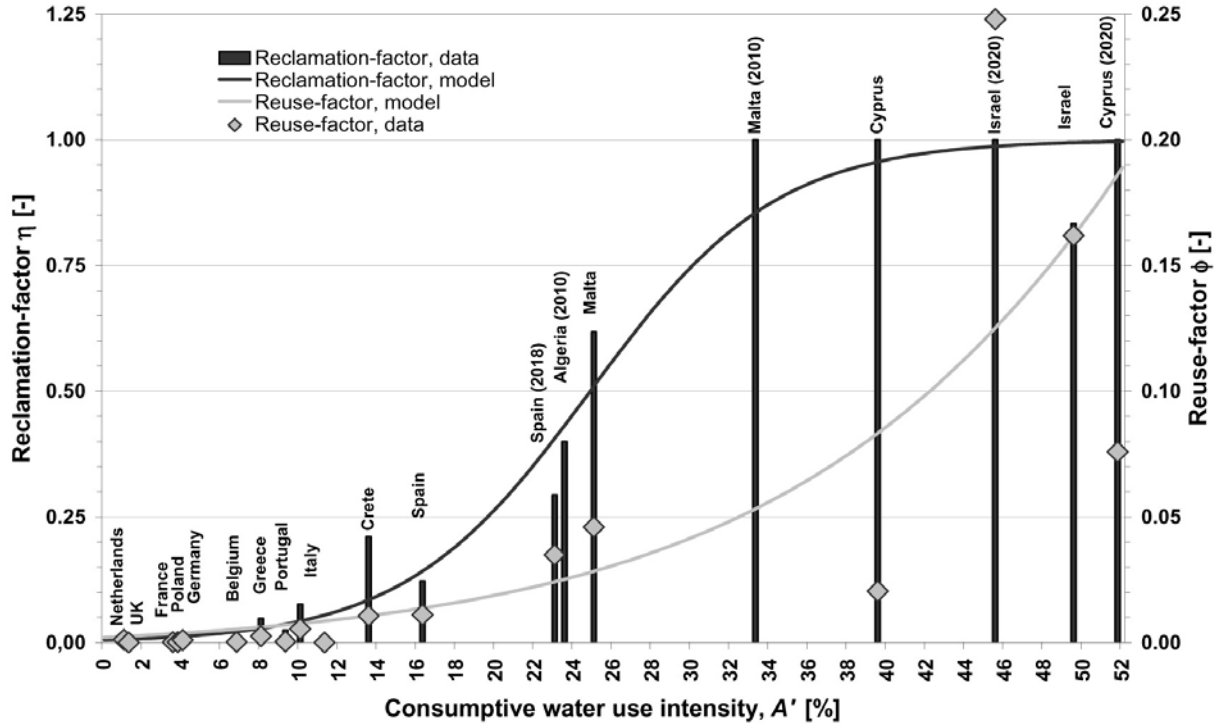


Fig. 2. Correlation of reclamation and reuse factors and consumptive water use intensity.

for industrial uses [Mm^3/a], and U_{ELE} the water abstraction for electricity generation [Mm^3/a].

The sectoral conversion factors were adopted from Lehner et al. [9]. Eventually, a correlation between consumptive water use intensity and both factors was established and mathematically modelled by an empirical function, which proved to be most appropriate in representing the type of observed relationship (cf. Fig. 2).

2.2. Scenario description

The established model implies that any deterioration of water availability or increase in water demand will enforce a change of the consumptive water use intensity that on itself modifies both the wastewater reclamation and reuse factor; hence, the reused wastewater flow Q . In order to depict the impact of decreasing water availability and increasing water demand,

different scenarios were tested. The assumptions for each scenario are summarised in Table 1.

First, the possible decline of water availability due to climate change was appraised referring to the results of the EuroWasser model by Lehner et al. [10]. This model forecasted the impact of climate change on water availability in Europe for the 2020s and 2070s. In accordance with their calculations, some river basins will have to cope with heavily reduced water availability. Decreases of more than 10% are projected for some continental countries (Poland, Hungary) and southeastern countries (Bulgaria, Romania, parts of Turkey), whereas most southern European countries will suffer from reductions of 25% and more. The First European Climate Assessment [11] came to similar conclusions, predicting a reduction of the mean annual flow in Portuguese river basins of 10–20%. Hence, the reductions of water availability for the water shortage scenarios

Table 1
Different scenarios and underlying basic conditions for the year 2025

Scenario	I	II	III	IV
Population	UN Population Division, medium variant			
Water availability	Constant (Itaa 1961–1990)		-10%	-25%
Water demand	Changes due to population growth			
	Constant specific water demand			
	Irrigated area and specific water use		Changes due to population growth	
	Invariant		Economic recovery of AC	
Treated wastewater	Assumption of full compliance with UWWTD by 2025			
	General characterisation Conservative		Demand increase	Demand increase + water shortage
	Slight increase of IND and ELE due to minor economic growth		Increased electricity production AC Intensified agricultural IRR	

ELE, water use for electricity production; IRR, irrigation water use; IND, industrial water use; AC, accession countries; Itaa, long-term annual average.

Table 2
Water use intensity for different scenarios [%]

Country	Status 2000	Scenario I	Scenario II	Scenario III	Scenario IV
Cyprus	39.6	51.9	51.9	57.7	69.1
Israel	49.5	45.3	45.4	50.5	60.6
Malta	25.0	25.5	30.2	33.5	40.2
Bulgaria	8.1	14.8	23.8	27.6	33.2
Spain	16.3	16.3	22.9	25.5	30.6
Italy	9.8	9.8	14.7	16.3	19.5
Turkey	11.2	11.4	11.6	12.9	15.5
Portugal	9.1	9.2	10.5	11.6	14.0
Greece	8.1	8.0	10.1	11.2	13.4
Belgium	6.7	6.1	6.1	7.5	9.0
Poland	3.7	3.7	3.7	5.7	6.9
France	3.6	4.6	4.5	5.1	6.1
Denmark	4.5	4.5	4.5	5.0	6.1
Germany	3.9	4.0	4.0	4.5	5.4
Romania	0.8	0.8	2.1	2.3	2.8
UK	1.2	1.3	1.3	1.4	1.7
Netherlands	1.0	1.1	1.1	1.2	1.4
Hungary	1.0	1.0	1.0	1.1	1.3

III and IV were based on assumptions in these orders of magnitude.

Changes in water demand were estimated to the following premises. As, in general, irrigated

agriculture is much more productive than rain-fed cultivation [12], the resumption and enforcement of irrigation in most of the eastern European countries were assumed. In addition, planned

extensions of irrigated land in Spain and Portugal were taken into account [5,13].

An improvement of the electricity supply in the accession countries by increasing demand and economic recovery will demand additional water resources or might at least cause conflicts between competing water uses. The domestic water demand per capita is considered invariant. This causes changes of the public supply sector's water demand according to population growth and connection rates.

The overall resulting changes of consumptive water use intensity for the different scenarios are listed in Table 2. As expected, the scenarios easily cause an increase of the water use intensity for all countries by up to one-third. Cyprus, Spain, Malta, Portugal, Italy and Bulgaria will experience an intensification of water stress by 50–100%, culminating in water use intensities between 14% and 69%. Obviously, the level and

thus the deterioration of water stress varies remarkably among countries. These changes not only have an impact on water stress but also the number of affected people in Europe.

3. Results

The current status of wastewater reuse in some European countries and the projected wastewater reuse potential according to the model calculations and scenario assumptions are both depicted in Fig. 3. The simulation points out that there is a significant potential for an increased utilisation of reclaimed wastewater in many European countries, specifically in the Mediterranean region.

Spain shows by far the highest projected reuse potential, which is supposed to triple (Scenario II) or even grow six-fold compared to today, reaching a maximum of 2,000 Mm³/y. Similar increases illustrated for Italy, Portugal, Greece and

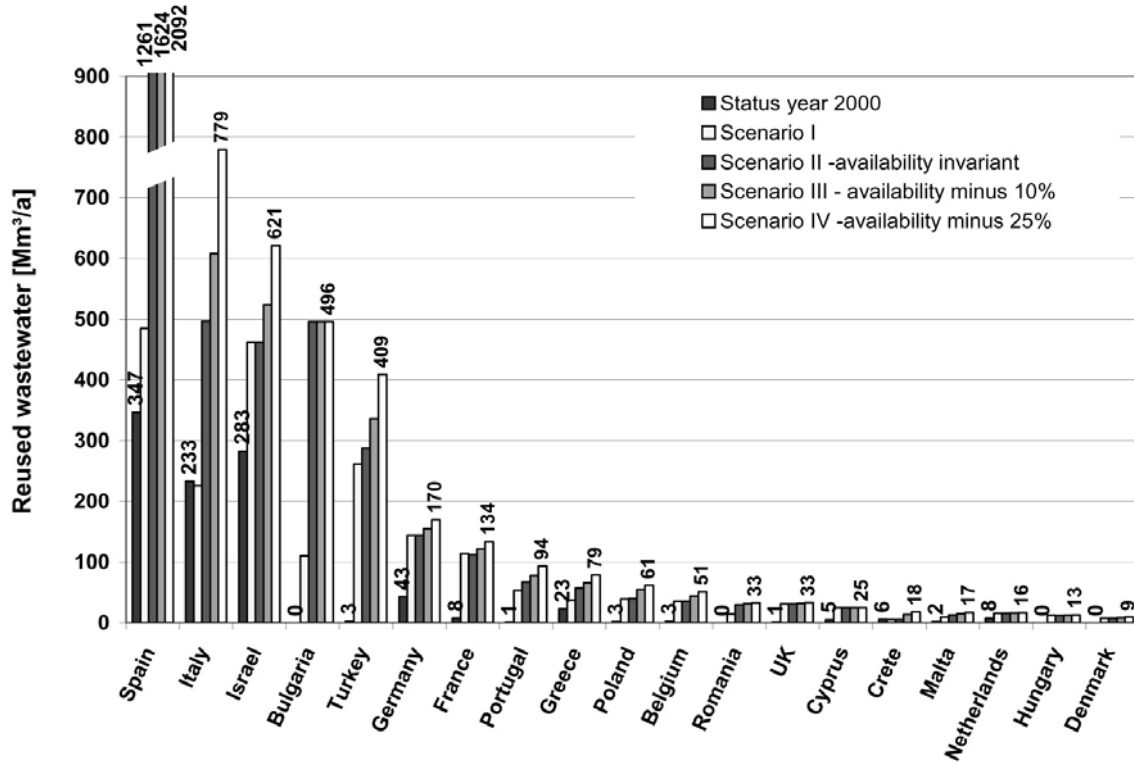


Fig. 3. Estimated wastewater reuse potential under different scenario conditions.

Turkey are primarily caused by a combined effect of high irrigation demand and reduced water availability. Even countries like Germany, Poland and the UK are supposed to develop their wastewater reuse practices under water shortage conditions.

Not only the total amount of reclaimed water but also its substitution potential with respect to a country's water management varies remarkably among the considered countries. According to the model outcome, the demand coverage rate, i.e., the ratio of reused effluent to the total water abstraction (Q/U), ranges from 17–30% in Israel and Malta and amounts to 3–7% in Cyprus and Spain.

On the whole, the reused wastewater volume would save between 1.0–1.5% of total water abstraction of European countries (including Israel) in the year 2025. This is close to estimations for the US, which project a substitution of 1.5% of total freshwater abstraction by wastewater reuse in the year 2000 [14].

4. Conclusions

The scenarios presented reveal an overly proportionate increase in wastewater reuse potential with declining water availability in most European countries. An average water availability curtailment of 25% on a country level can already result in tremendous wastewater reuse potential increase. Any aggravation of water restrictions might consequently promote the reuse of wastewater. Therefore, these results may only serve as a yardstick. Water shortages might be much more severe than expressed by the long-term annual average, which is just a very rough figure characterising a country's water availability. It does not take into account the uneven spatial and temporal distribution and thus the efforts it might already take to balance demand and supply on a regional level. The coverage of seasonal demand peaks, e.g., for irrigation or public water supply in tourist regions, involves the risk of aquifer over

exploitation [15] if no abstraction restrictions or price incentives are asserted.

In addition, a series of dry years can easily push the average annual rainfall below any long-term average. Recent declines in average precipitation compared to the 1960–1990 lta were reported for several countries [16–18].

Moreover, a reduction of water availability is often caused by inappropriate quality of water resources (brackish groundwater due to saltwater intrusion) as well as by stipulated abstraction or supply restrictions for certain users. Such trends might cause even more severe decreases in water availability than assumed in the scenarios presented here.

Nonetheless, the results do raise — but naturally leave open — the question how to accompany the realisation of this massive potential from a regulatory point of view and how to shape an appropriate framework of incentives and implementation support measures. The potential utilisation shall not contradict the “whenever appropriate” claim of the Urban Wastewater Treatment Directive, thus demanding the determination of appropriateness. To date, appropriateness has often been described primarily with regard to health risk prevention, hence aiming at the establishment of limits for certain substances or even comprehensive risk assessment and management practices.

These aspects are of paramount importance for wastewater potential realisation in applications that could absorb huge volumes of water but are at the same time sensitive to health objections as, for example, groundwater recharge. In other cases, switching from conventional water resources to reclaimed wastewater is primarily hindered by cost arguments. This would demand a re-evaluation of water and finally an economic anticipation of the potential environmental benefits of wastewater reuse.

How to investigate the optimal or simply the most acceptable allocation of reclaimed water will be a crucial element in any wastewater reuse

strategy as each of the options will demand specific use-dependent incentives that might even differ from case to case.

It will be a future task to adjust the model variables, especially the reuse factor, taking into account its sensitivity to influences like regulatory constraints, pricing mechanisms, etc.

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