POWERSTEP

WP5 – Integration towards full plant concept, assessment and market replication

D 5.3: Market analysis and economic impact studies

Deliverable 5.3	***Market analysis and economic impact studies***
Related Work Package:	WP 5
Deliverable lead:	UBA
Author(s):	Nathan Obermaier
Contact for queries	Nathan.obermaier@uba.de
Grant Agreement Number:	n° 641661
Instrument:	Horizon 2020 Framework Programme
Start date of the project:	01.07.2015
Duration of the project:	36 months
Website:	www.powerstep.eu
Abstract	PowerStep technologies reduce electricity consumption and increase the generation of sewage gas, which is used to generate electricity and heat that may be sold to consumers. The European target market of PowerStep is very heterogeneous and a sound analysis on the wastewater treatment plant level has to precede an investment decision in PowerStep technology in order to guarantee the most efficient combination of PowerStep's energy efficient treatment technologies. The market analysis shows, that PowerStep technology could have a significant economic impact on wastewater treatment in Europe by increasing sewage gas production, reducing the electricity demand, increasing the heat production at lower OPEX and similar CAPEX

Dissemination level of this document

X	PU	Public
	PP	Restricted to other programme participants (including the Commission Services)
	RE	Restricted to a group specified by the consortium (including the European Commission Services)
	CO	Confidential, only for members of the consortium (including the European Commission Services)

Versioning and Contribution History

Version	Date	Modified by	Modification reasons
v.01	2018-05-06	Nathan Obermaier (UBA)	1st Draft
	2018-06-11	Ulf Miehe (KWB)	1st Review
v.02	2018-06-13	Nathan Obermaier (UBA)	2nd Draft
	2018-06-15	Christian Loderer (KWB)	2nd Review
v.03	2018-06-18	Nathan Obermaier (UBA)	3rd Draft
	2018-06-19	Christian Loderer (KWB)	Final Version

Table of Content

List of Figures

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

List of Tables

Glossary

CAPEX	Capital Expenditures
COI	Cost of Inaction
EC	European Commission
GHG	Greenhouse Gases
MS	Member State
OPEX	Operational Expenditures
PE	Population Equivalent
WWTP	Wastewater Treatment Plant

Executive Summary

Wastewater treatment in Europe is a diverse field that deals with multiple challenges in different areas. Among those are water shortages in Southern Europe, a lacking infrastructure in Eastern Europe, further demands with respect to advanced treatment technologies in Northern and Western Europe. Not surprisingly, the conditions vary in the Member states (MS). Wastewater related properties like the temperature and the composition influence new technologies just like the predominant form of organization, cost recovery principles and investment cycles in the MS.

PowerStep technologies reduce electricity consumption and increase the generation of sewage gas, which is used to locally generate electricity and heat. Both, electricity and heat have different values in each MS. The European target market of PowerStep is very heterogeneous and a sound analysis on the wastewater treatment plant level has to precede an investment decision in PowerStep technology in order to guarantee the most efficient combination of PowerStep's energy efficient treatment technologies. Two PowerStep configurations, an energy neutral one (PowerStep I) and an energy positive one, which includes the anammox technology (PowerStep II) were compared to the status quo and a benchmark scenario.

With PowerStep II, the sewage gas generation in Europe increases by 166% with the highest potential in France, Italy, and Spain due to their currently low generation of sewage gas. When the sewage gas is combusted to generate electricity, PowerStep II also increases the net electricity production to 4 TWh of electricity generated instead of 12 TWh of electricity consumed by plants. Just like the sewage gas production, the biggest potentials exist in France, Italy, and Spain. Additional heat accounts for 2 TWh, an interesting perspective for Northern Europe.

With respect to operational expenditures (OPEX), PowerStep II reduces the wastewater treatment costs by 2 Billion Euros annually, which is almost 20%. MS with high electricity prices like Germany and Italy have comparably higher OPEX savings than MS with low electricity prices. Reducing OPEX is one of the major benefits of PowerStep and increasing costs are a common problem, MS share.

The reduction of GHG emissions is another very important benefit with respect to climate change and the associated avoided costs. PowerStep II reduces GHG by almost 50% based on the current European electricity mix. However, this largely depends on the differences between MS. In France, nuclear power has a large share in the country's electricity mix and PowerStep increases GHG emission. The opposite is true for Poland with its large share of fossil fuels, the GHG emission reduction of PowerStep reaches around 70%.

This effect is illustrated in the cost of inaction (COI) study, the last part of this analysis. In general uncertainty is a key element of COI studies and this is also true for the COI of PowerStep technologies. The cases presented in the market analysis had to be simplified in various ways in order to decrease the complexity of the subsequent COI analysis.

In addition to the market potential analysis, the COI study also concludes that PowerStep technology could have a significant impact on wastewater treatment in

Europe by increasing sewage gas production, reducing the electricity demand, increasing the heat production at lower OPEX and similar CAPEX.

1. Introduction

PowerStep technology reduces the electricity demand and increases the sewage gas generation leading to an energy efficient wastewater treatment. This energy efficiency is one of the unique selling points PowerStep has and an assessment of the market potential is the next logical step to identify possible focus areas and to further specify the products PowerStep could provide in order to guarantee a successful diffusion and the transition from research and large scale demonstration into markets.

The market potential of PowerStep technologies is affected by national and geographical characteristics like water or energy related issues, the general status of wastewater treatment in the country and operator specific properties like the dominant form of organization. Part One identifies and describes these properties and puts a special focus on the comparability between different regions, e.g. Northern Europe and Southern Europe. All regions are dealing with specific challenges that might influence the possible adaption of PowerStep technology like water shortage in Southern Europe and further requirements on wastewater treatment in Northern Europe.

Even though an investment in PowerStep technology needs an assessment on the WWTP plant, the analysis of PowerStep’s impact on the European wastewater treatment market is necessary. Decision makers on both the European and the national level need information about changes induced by PowerStep and how PowerStep helps to reach set goals e.g. an energy efficient infrastructure.

Therefore, Part Two of this report analyses the impact of two PowerStep scenarios compared to the status quo and a benchmark scenario and quantifies additional sewage gas generation, the net electricity demand, heat generation, operational expenditures, capital expenditures, and GHG emission savings. Both PowerStep scenarios use data provided by the life cycle analysis performed in D 5.5.

Part Three deals explicitly with the calculated GHG emission savings of PowerStep and the expected development in the future. A cost of inaction study compares investment costs for PowerStep technology with avoided costs related to GHG emission savings. With an electricity mix that strives towards being 100% renewable, the possible GHG emission savings of PowerStep decrease. However, the substitution of other energy resources like natural gas enables PowerStep to show its full potential with respect to cost efficient climate change mitigation.

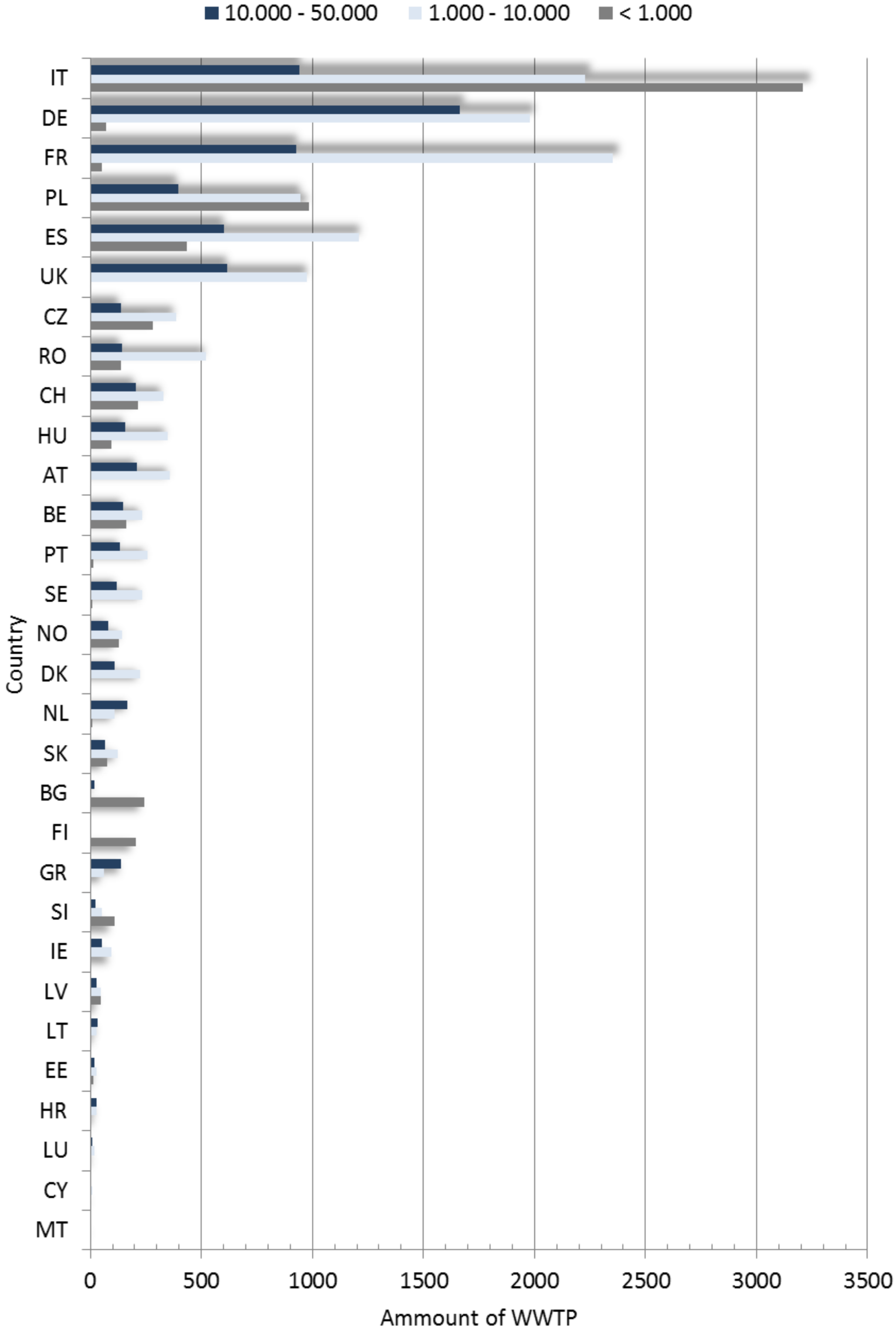
With Part One describing the market situation in general, Part Two assessing the impact of PowerStep technology and Part Three analysing the cost of inaction, this report provides a basic assessment of PowerStep’s impact on today’s and future markets and should help decision makers to recognize the improvements energy efficient wastewater treatment technology like PowerStep could deliver.

2. Part One: Assessment of Existing Market Conditions in Europe

Wastewater treatment in Europe differs from member state to member state and specific characteristics are responsible for much of the previous system development. This chapter deals with the status quo of European wastewater treatment, both with respect to water as well as energy issues. The next section starts with detailed information on European wastewater treatment plants in the different MS, the amount, their size and the corresponding load.

2.1. Amount of WWTP per size class in each EC country

Figure 1 and



The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Figure 2 show the amount of WWTP listed in the Urban Wastewater Treatment directive report that MS must submit biannually to the European Commission. Figure 1 shows the WWTP with more than 50.000 connected PE (

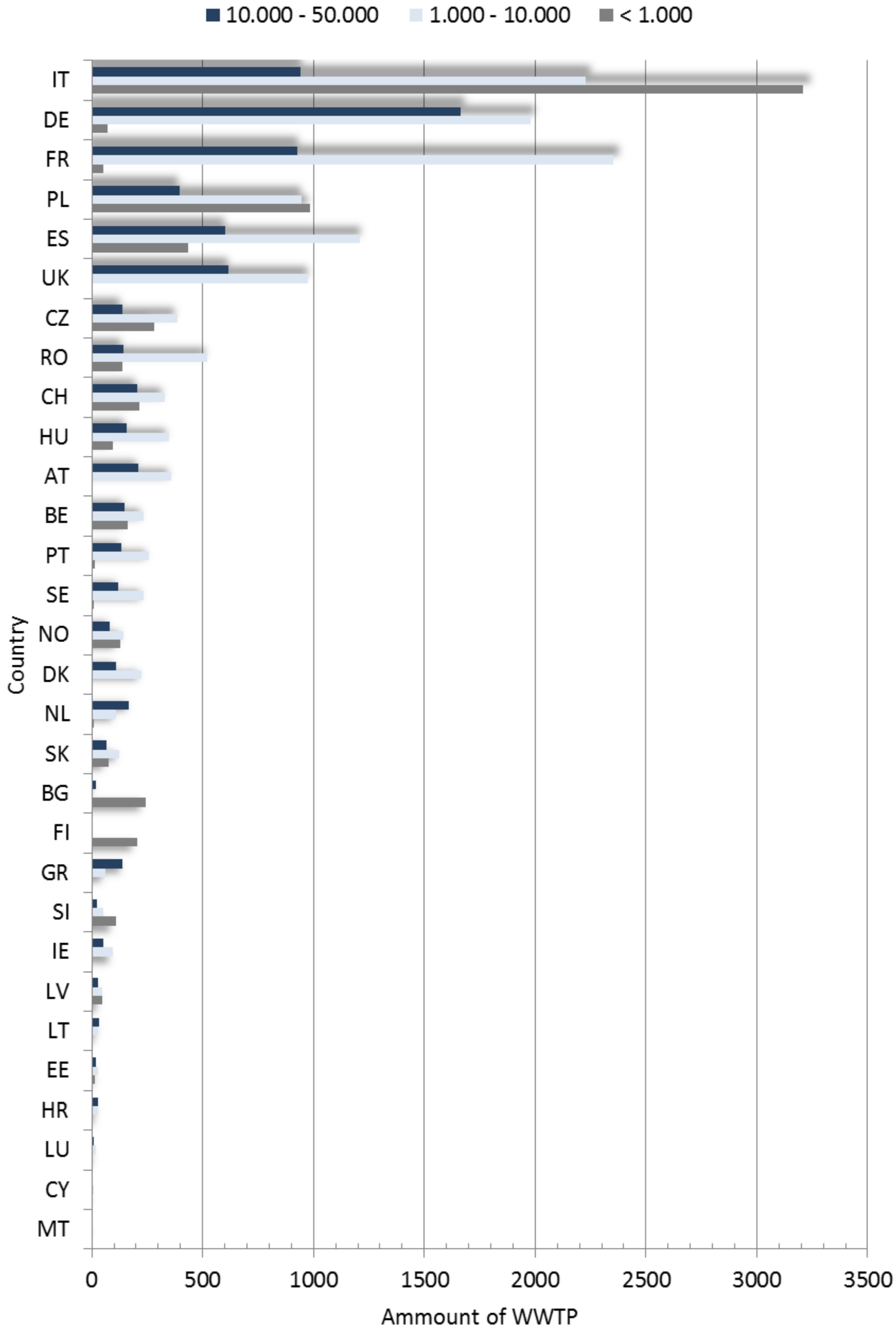


Figure 2 continues with the WWTP having less than 50.000). Interestingly, Germany, Italy and Spain account for 87 of the biggest WWTP in Europe, just as much as all other European states combined (including Norway and Switzerland).

In the second largest size category, Germany, Italy, Spain and France account for more WWTP than all other European countries combined. This also shows that even though PowerStep is a European project, the focus area with respect to certain size classes is on few countries.

The second chapter of this report will focus on the advantages of PowerStep technology with regard to different size classes. The combination of both the advantages and the amount of WWTP will yield a first estimate of the existing adoption potential.

The amount of WWTPs with less than 1.000 connected PE is rather irrelevant and on top of that, MS do have to report if WWTPs have more than 2.000 connected PE leading to a high amount of uncertainty within that size.

We recommend that due to the high amount of uncertainty and the low potential (due to techno economic factors described later in this report), WWTPs with less than 10.000 connected PE will play no major role for the market analysis.

Figure 3 shows the amount of WWTP of the countries, that are, due to the existing WWTP infrastructure, the most relevant for PowerStep. Hence, the market analysis should focus on Germany, Italy, France, Spain, the United Kingdom, and Poland.

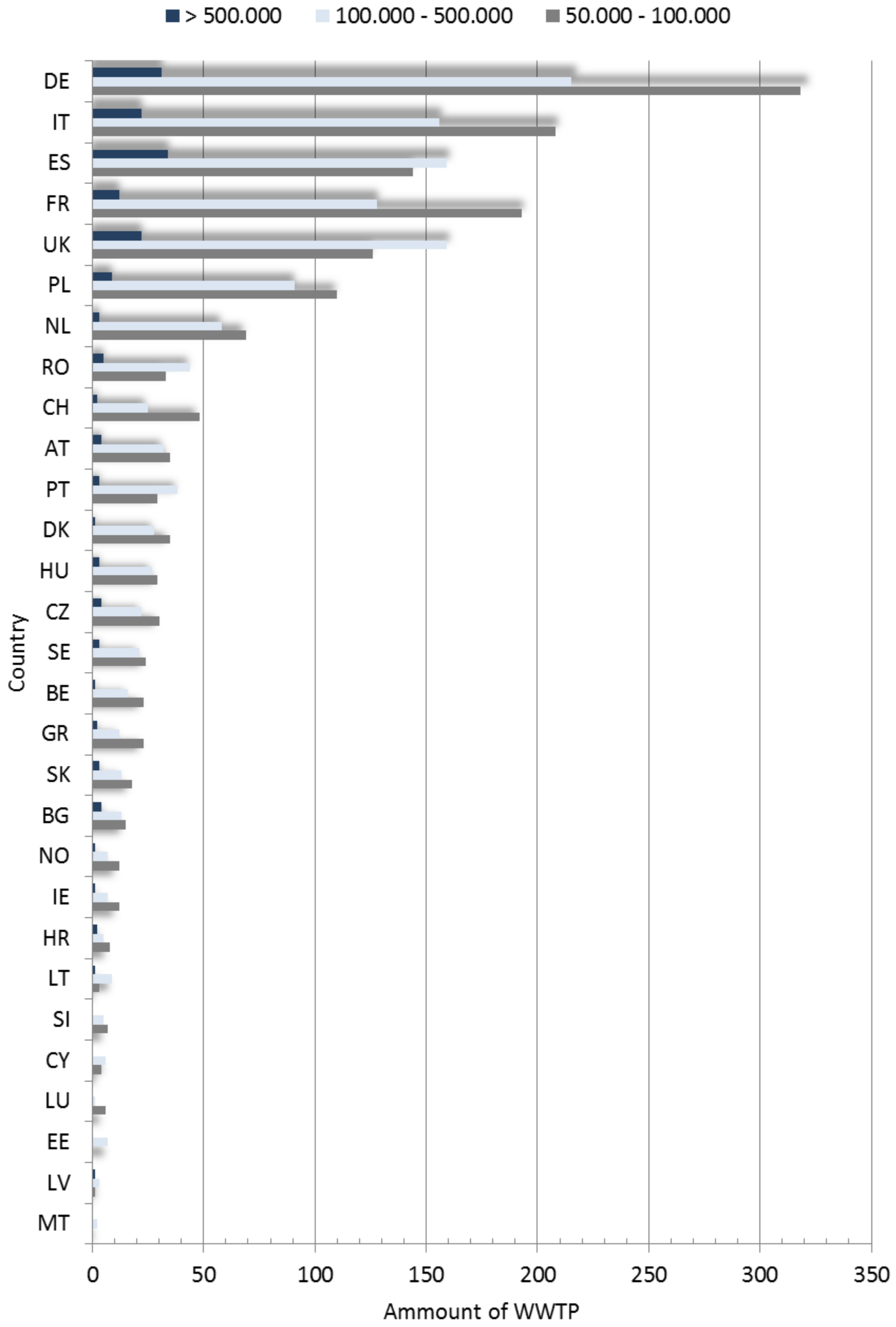


Figure 1: Amount of WWTP within different size classes in selected European countries

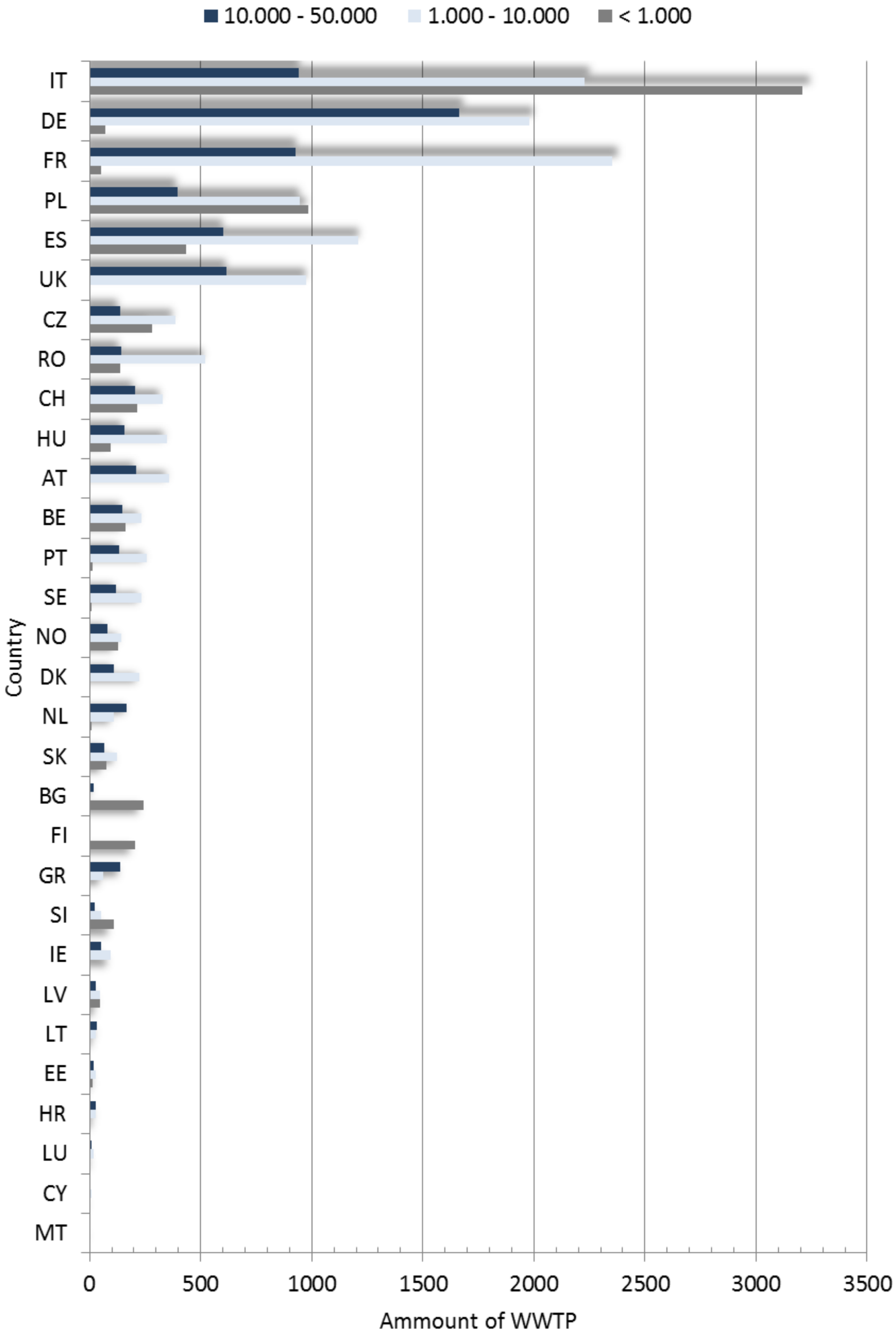


Figure 2: Amount of WWTP within different sizes classes in selected European countries, continued

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

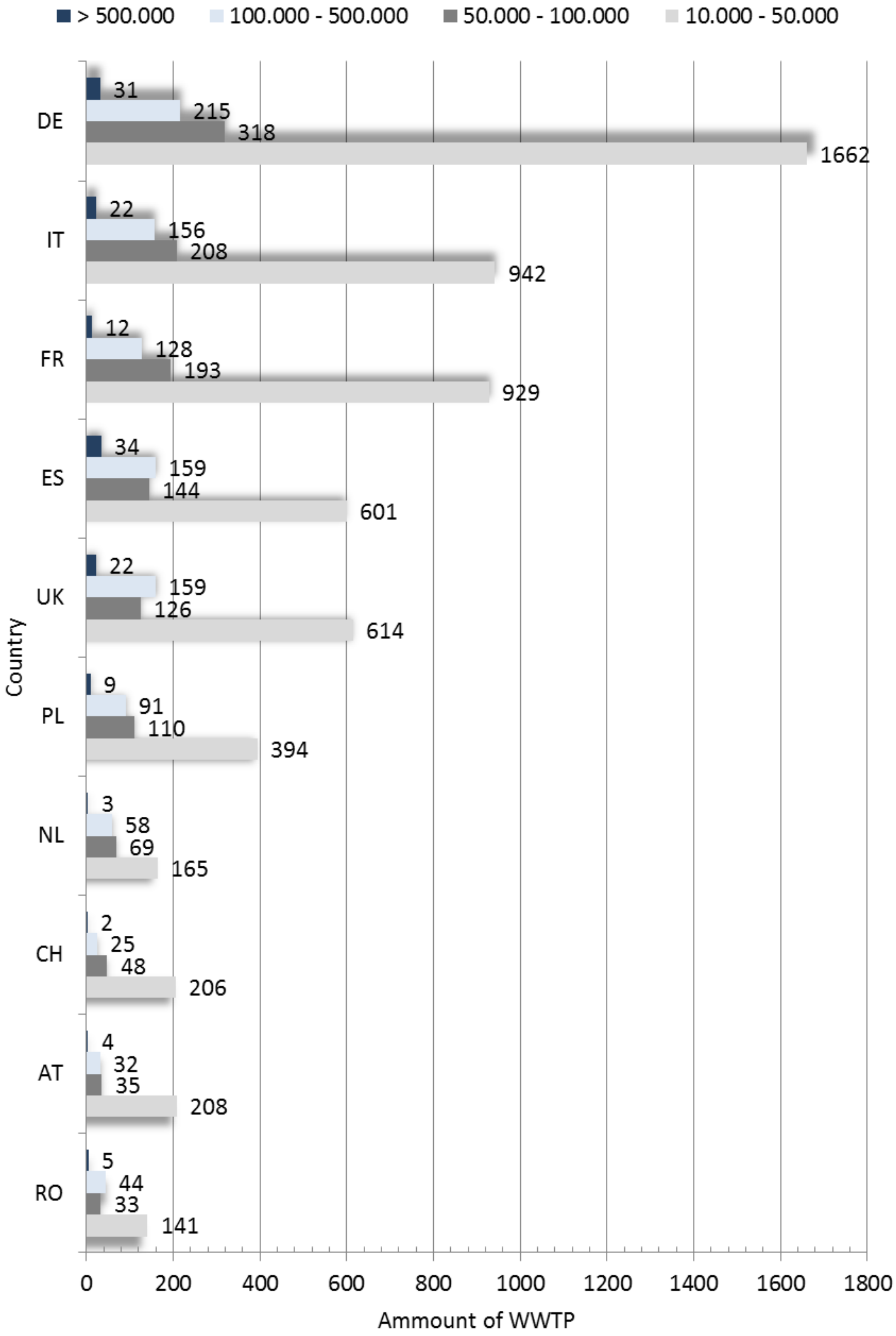


Figure 3: Top ten countries with the maximum amount of WWTP in the most relevant size classes for PowerStep

2.2. Actual Load Entering WWTPs in Europe

Not only the amount of WWTPs matters – the actual load of PE entering European wastewater treatment plants also affects the possible market potential of PowerStep technology. Figure 4 shows the actual load of wastewater entering the WWTPs for each country. Of course, the actual load correlates with the amount of WWTP shown in Figure 3. Germany, France, the United Kingdom, Italy, Spain, and Poland treat most of the European wastewater (75%). In addition, Figure 4 shows that WWTPs with more than 10.000 connected PE treat most of the wastewater.

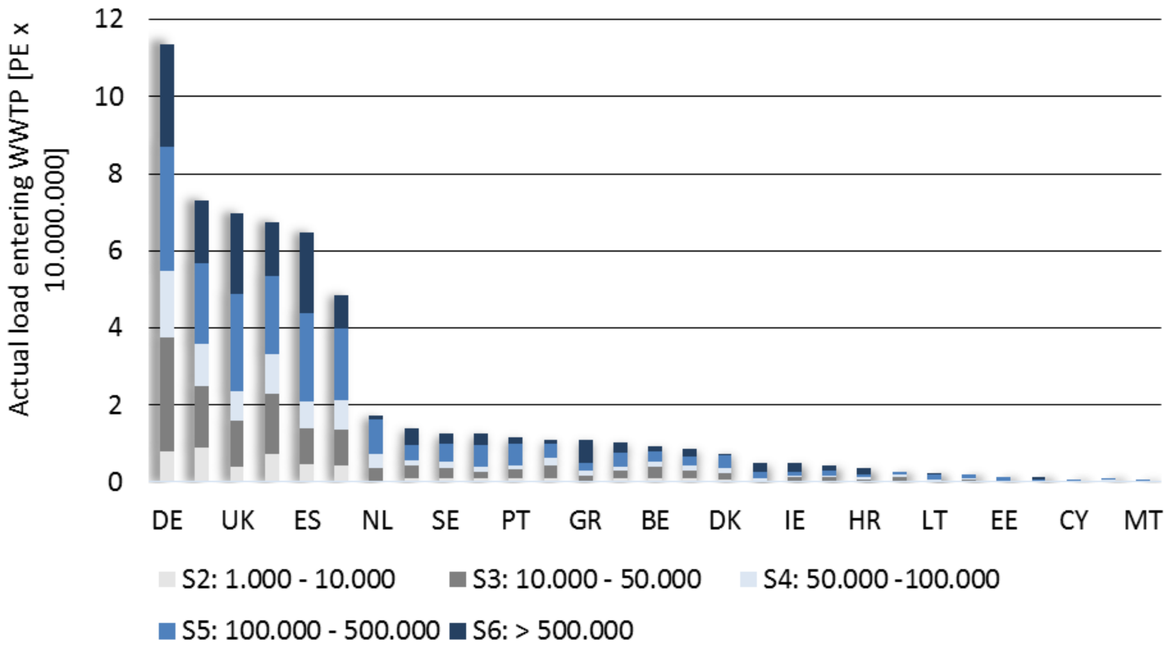


Figure 4: Actual load of wastewater entering WWTP (in PE, capacity data used for SE and HR because no actual load data is available)

Finally, Figure 5 links the load entering the WWTP and the size classes. The findings correlate with available country specific information (e.g. Germany). Large WWTPs treat a large share of the discharge, even though there are significantly more smaller and medium sized WWTPs. As Figure 5 shows, 66% of the total discharge enters WWTPs with more than 100.000 connected PE and. However, these WWTPs represent 10% of the total amount of WWTPs.

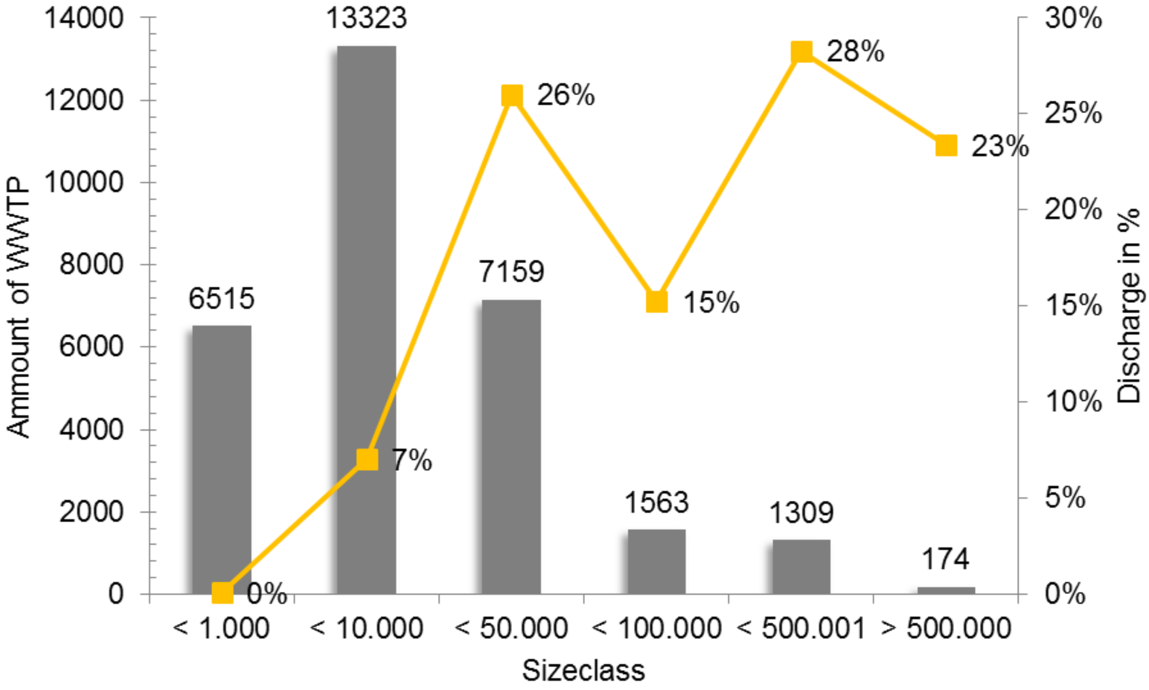


Figure 5: Discharge percentage treated in different size classes according to the Urban Wastewater Treatment Directive (UWWT) database

2.3. Inhabitants connected to WWTP services

Eurostat itself claims, that with respect to the connection rate, that "[…] countries have been grouped to show the relative contribution on a larger statistical basis and to overcome the incomplete nature of the data."[1] This clustering process will also play a major role in the following section of the market analysis. In addition, Eurostat only includes countries with coherent data sets for all the different times yielding the clusters shown in Table 1.

Table 1: Cluster creation within the Eurostat wastewater treatment status and connection assessment (according to Eurostat meta data[2])

Northern Cluster	Eastern Cluster
Sweden	Poland
Norway	Latvia
Finland	Estonia
Iceland	Hungary
Central Cluster	Lithuania
Germany	Slovakia
Denmark	Slovenia
England & Wales	Czech Republic
Austria	**Southern Cluster**
Switzerland	France
The Netherlands	Spain
Scotland	Portugal
Luxembourg	Greece
Ireland	Cyprus
	Malta
	South Eastern Cluster
	Bulgaria
	Romania
	Turkey

---

[1] https://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment

[2] taken from https://www.eea.europa.eu/data-and-maps/figures/changes-in-wastewater-treatment-in-regions-of-europe-between-1990-and-2#tab-european-data

Therefore, Figure 6 shows grouped datasets with different clusters for Northern, Central, Southern, Eastern and Southeastern Europe and the respective connection to sewage services at five different date clusters. In each cluster, the situation is improving and the amount of connected inhabitants kept rising, so did the treatment quality. In general, the amount of people connected to WWT services is highest in central Europe while southern Europe has seen the biggest improvements since 1995. With respect to wastewater treatment, the share of wastewater treated with a tertiary treatment is highest in northern Europe and lowest in southeastern Europe. Hence, the retrofitting of plants in northern Europe is quite unlikely, so is the construction of new plants. In southeastern Europe on the other hand, a lot of plants need an upgrade and the percentage of population connected to WWTP service is still quite low.

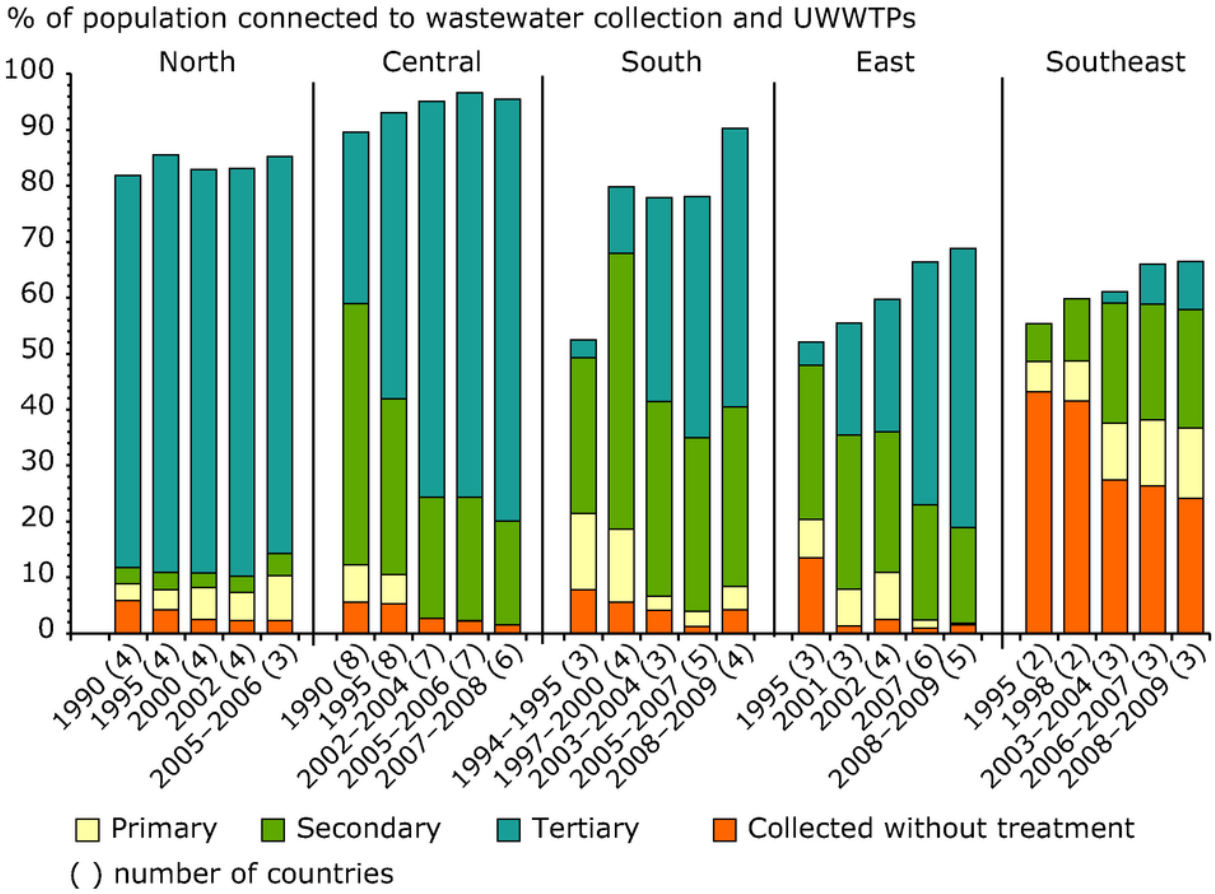


Figure 6: WWTP connection rate and wastewater treatment in Europe according to the EEA (taken from https://www.eea.europa.eu/data-and-maps/indicators/urban-waste-water-treatment/urban-waste-water-treatment-assessment-3)

2.4. Cluster Creation

The cluster creation process applied in the connection rate analysis is a helpful tool if data is missing or data quality issues occur. In combination with the load and connected PE analysis in the previous sections, the following clusters further define the market potential of PowerStep.

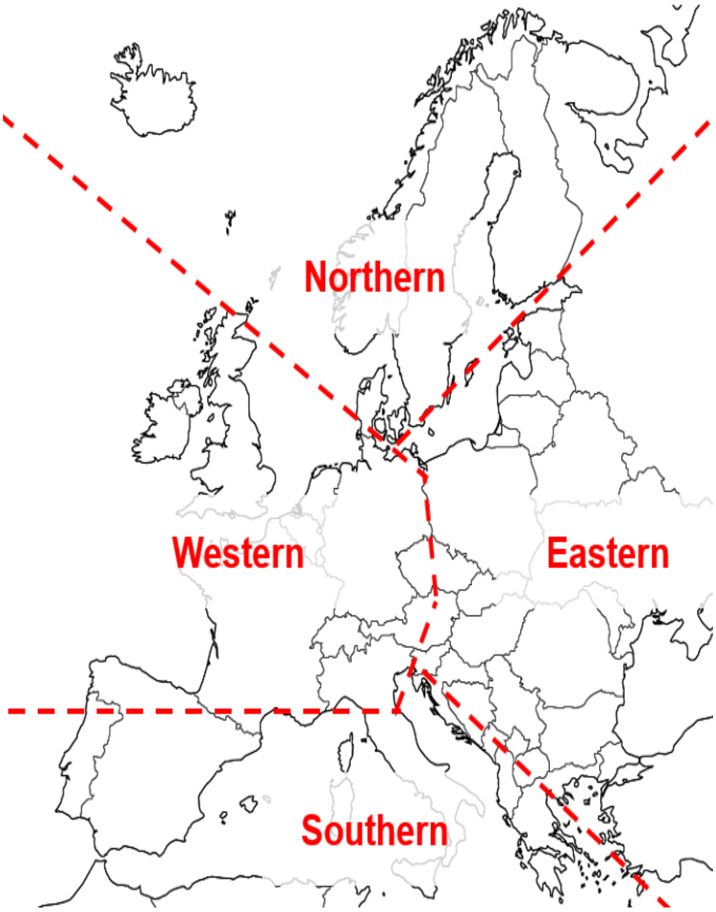


Figure 7: General subdivision of Europe with respect to cluster creation for the PowerStep market analysis (MS are part of one cluster only, e.g. Austria of the western cluster)

Table 2 shows the results of the cluster creation process. The table includes the assignment of countries to a specific cluster, as well as the six most relevant countries described in the previous sections (yellow background). Only the northern cluster does not include a country that is highly relevant due to its size and therefore, Denmark will serve as a representative for this section. In contrast to Eurostat, this report works with three clusters only, splitting the south Eastern cluster and reassigning few countries to other clusters.

Table 2: Country assignment to different clusters

Northern Cluster	Eastern Cluster
Denmark	Poland
Sweden	Latvia
Norway	Bulgaria
Finland	Estonia
Iceland	Hungary

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Western Cluster	Lithuania
Germany	Slovakia
France	Romania
United Kingdom	Czech Republic
Austria	**Southern Cluster**
Switzerland	Italy
The Netherlands	Spain
Belgium	Portugal
Luxembourg	Greece
Ireland	Croatia
	Slovenia
	Cyprus
	Malta

The following sections describe the main idea of the clustering process, which is to bundle countries with similar challenges and strategies. This might be inaccurate with respect to detailed national strategies, but the overall picture should be valid.

2.4.1. The North (Denmark, Sweden, Norway, Finland, Iceland)

In general, the wastewater treatment technology applied is rather advanced. Due to that, the demand for retrofitting existing WWTPs or the construction of new WWTP is rather low. Tertiary treatment is common, so is the anaerobic digestion yielding biogas. The further use of biogas does not solely center on electricity generation, selling the biogas to existing grids or using it in the transport sector is also common.

2.4.2. The West (Germany, France, UK, Austria, Switzerland, The Netherlands, Belgium, Luxembourg, Ireland)

Wastewater treatment in the western cluster is quite similar to northern Europe, however, treatment is a bit less advanced but the connection rate is higher (also compare with Figure 6). This leads to a retrofitting demand slightly higher than the one of northern Europe. The use of biogas coming from anaerobic digestion focuses on generating electricity, other uses of the gas are uncommon.

2.4.3. The East (Poland, Latvia, Bulgaria, Estonia, Hungary, Lithuania, Slovakia, Romania, Czech Republic)

In contrast to western and northern Europe, WWTPs in Eastern Europe have a rather high demand for retrofitting and the further potential with respect to the connection rate will lead to several greenfield plants in the next couple of years. Apart from few lighthouse projects, anaerobic digestion plays only a minor role and the potential for additional reactors is high.

2.4.4. The South (Italy, Spain, Portugal, Greece, Croatia, Slovenia, Cyprus, Malta)

Southern Europe has less potential for greenfield and upgrading WWTPs than eastern Europe, but still the treatment quality is less good than in northern or central Europe. In southern Europe, water reuse is the most important issue with respect to water policy and innovative solutions that foster the use of the energetic content (biogas production) only have a minor importance.

2.5. Water Related Issues

In addition to the factors described in the sections above, other site or wastewater specific factors define the possibility of a successful implementation of PowerStep technology. A short description and their impact on the implementation follow in the next sections.

2.5.1. Wastewater Temperature

Southern Europe has a Mediterranean climate with hot summers and relatively mild winters leading to a wastewater with up to 25 degrees centigrade in summer (Hvitved-Jacobsen, Vollertsen et al. 2013). Northern, central and eastern European countries on the other hand face quite cold winters with wastewater temperatures reaching temperatures lower than 10 degrees centigrade. These effects have to be considered as they determine which technologies fulfill the demanded PowerStep properties. Unfortunately, wastewater temperatures are very site dependent as they rely on multiple criteria. Hence, assuming certain values for countries does not make much sense and general remarks about a possible implementation of PowerStep technology should not include wastewater temperatures.

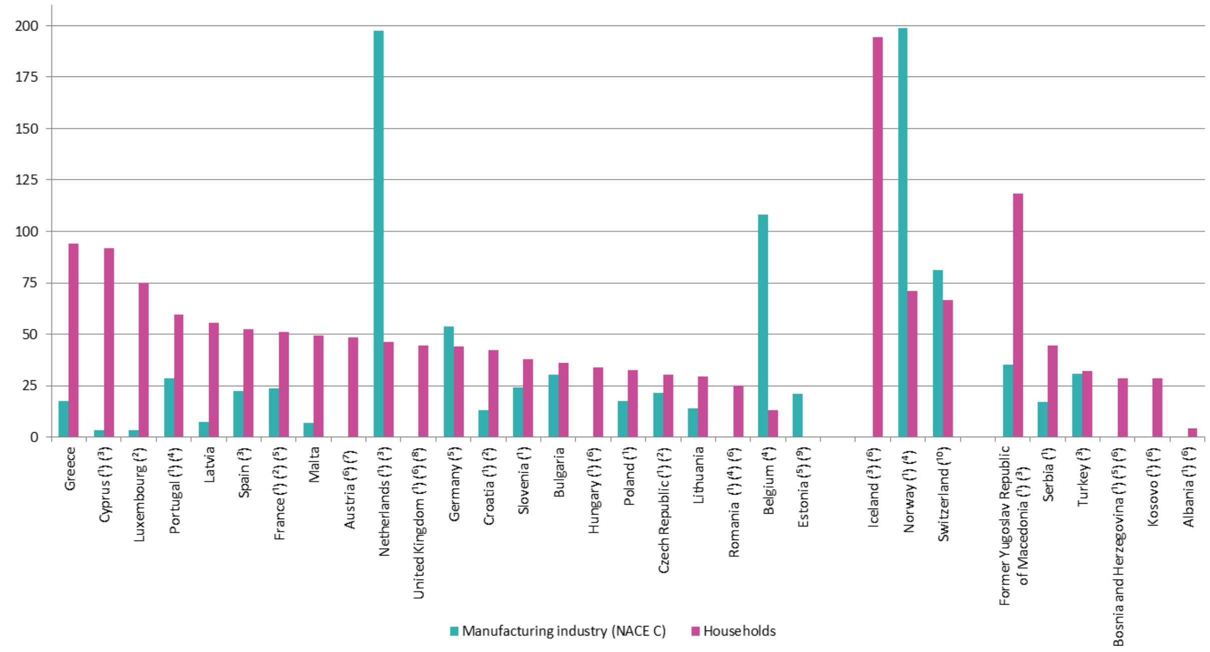
2.5.2. Wastewater Composition

The composition of the treated wastewater defines the mass flows that reach the wastewater treatment plant. Simplified, a high amount of carbon (based on the volume) in the wastewater benefits the PowerStep technology of micro sieving and hence the subsequent energy generation. Instead of focusing on the technological issues of micro sieves, basic remarks on the wastewater composition follow. Neither the EC's data provider, Eurostat, has direct information on overall wastewater composition in various European MS nor the UWWT Directive database. In addition, a literature scan using the publication databases Elsevier and Scopus revealed no publications dealing with this issue. However, using other information might provide some hints on wastewater composition within the EU.

Figure 8 shows the water consumption of households and the manufacturing industry in European states (household consumption includes public supply only, hence the actual number might be higher). In order to present an even bigger picture, Figure 8 does not exclude states that are currently no members of the European Union. Most of the states' water consumption ranges from 25 m^3/a to 50 m^3/a with a few exceptions (e.g.

Iceland, Former Yugoslav Republic of Macedonia consuming significantly more and Albania, Belgium consuming significantly less). The general assumption that a higher water consumption leads to wastewater with less carbon per m³ might be true regarding the exceptions, but cannot explain differences between e.g. Austria and Malta with a quite similar water consumption. With respect to wastewater composition, water consumption is not the only factor that matters. The sewage network (e.g. infiltration water), industry discharge and the water use (e.g. irrigation etc.) largely determine the load arriving at the wastewater treatment plant adding even more uncertainty.

Overall, a direct correlation between water consumption and wastewater composition is hard to establish, regarding MS with relatively similar water consumption and a relatively similar wastewater discharge system, it should not differ too much. On the municipal scale, the differences between wastewater compositions are enormous due to all the different site-specific issues mentioned above. The analysis of the wastewater composition yields the same results as the wastewater temperature analysis: site-specific data is required to draw conclusions about the possible implementation of PowerStep technologies.



Note: Denmark, Ireland, Italy, Slovakia, Sweden, Finland: no data available

(1) households: only public water supply
(2) NACE C: only self and other supply
(3) 2014
(4) 2009
(5) 2013
(6) NACE C: not available
(7) 2010
(8) 2011
(9) households: not available
(10) 2012

Figure 8: Water consumption of private households and the manufacturing industry in m³ per year. (Eurostat data from 2015)

2.6. Operator Related Issues

The implementation of PowerStep technology is dependent on operators preferring this technology over other possible treatment technologies. Basic properties like the form of organization and cost recovery heavily influence a possible successful implementation.

2.6.1. Form of Organization

The form of organization largely influences investment and the freedom of action of WWTP operators. Lieberherr and Truffer (2015) found out, that especially with respect to legal liabilities, economic perspectives and sustainability targets, the form of organization is one of the key criteria. In addition to the wastewater temperature and the wastewater composition, the form of organization is usually site specific with the tendency that smaller WWTPs have less economic and legal freedom and larger WWTPs have additional room. Hence, general recommendations for PowerStep are hard to assess.

In addition to the site specific form of organizations, there are predominant forms of organizations in the MS mostly differentiating between private and public operators. Figure 9 shows the difference regarding this aspect in European MS. For example, in England and Wales the water sector is completely private while in Ireland, the state owns every plant. In the Netherlands and in Denmark, municipalities are the owners of the WWTPs and in all other countries with available data, both public and private WWTP operators exist. The country specific composition is suggestively displayed with different blue scales in Figure 9.

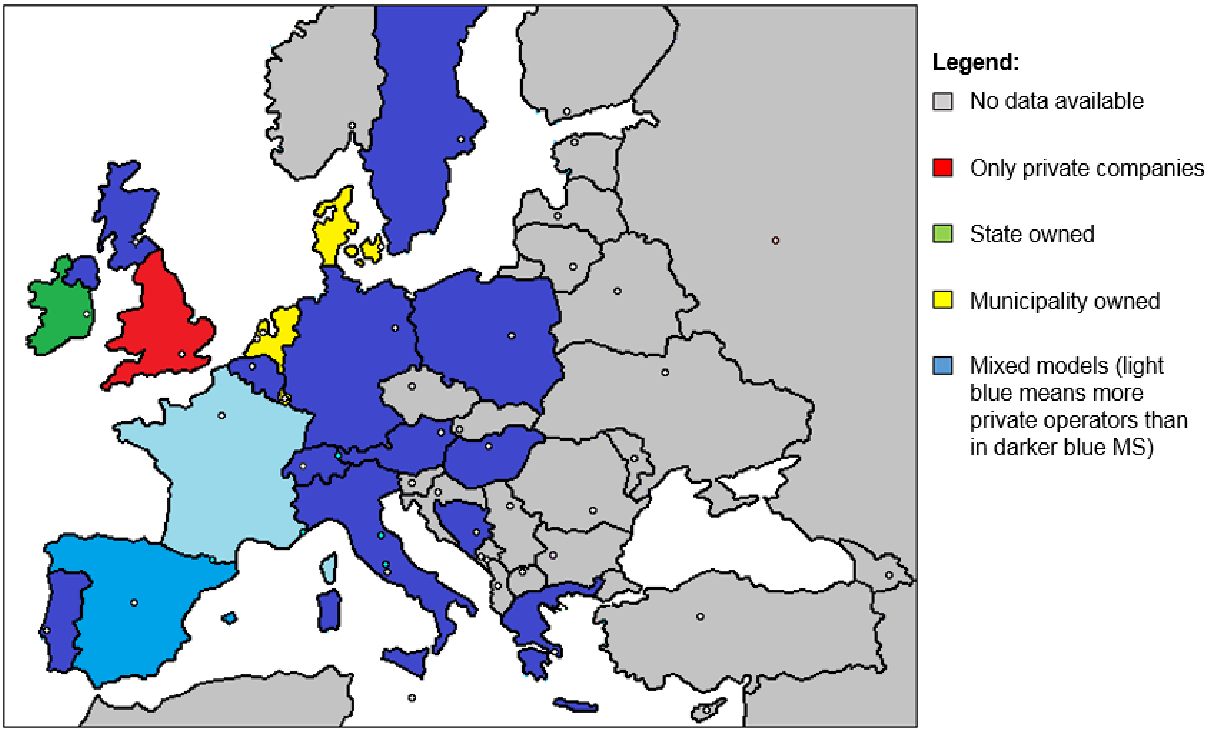


Figure 9: Different form of organisations in European MS

In addition to legal and economic freedom, the form of organization also influences the type of cost recovery of the plant operators.

2.6.2. **Cost Recovery**

The aspect of cost recovery is pivotal for the implementation of PowerStep technologies. Costs for water and wastewater treatment, including maintenance and investments[3] need to be transferred to the consumers in order to guarantee that no uncontrollable investment risks limit the operators' decision to implement innovative technologies.

The European Commission recognized the importance of a stable economic framework for water services and further specified this in Article 9 of the Water Framework Directive[4] , which deals with the recovery of costs for water services including environmental and resources costs.

The inclusion of environmental and resources costs leads to a further discussion about ecosystem functions and how to quantify these hard to measure effects (e.g. Gawel (2014)). The difficulties involving correct price assessments even include the very basic definitions of "cost recovery" and "water services". As the European Commission (2012) states, "the narrow interpretation of the concept of water services by some Member States is hindering progress in implementing cost recovery policies beyond drinking water and sanitation". Hence, every MS and even every WWTP operator handles the cost recovery aspects and the principle of "polluter pays" differently leading to a varying level of actual cost recovery reached.

In the past, Ireland and Hungary had to use certain funding mechanisms to compensate operators of water services because prices were too low. In contrast to Ireland and Hungary, the England and Finland fulfil the principle of cost recovery.

The principle of cost recovery is more or less an indirect proxy for the ability of WWTP operators to invest in innovative technologies. However, as there is basically no documentation about the level of cost recovery on the WWTP scale, the derivation of further general conclusions regarding the financing of PowerStep technology seems impractical.

2.6.3. **Investment Cycles and Annual Investment**

Investment Cycles relate to both, existing infrastructure and past decision. Especially past decisions influence the ability to invest in new, radically different technologies as certain buildings like concrete basins have a useful life of more than 30 years (rather short compared to the useful life of 40 – 100 years of sewers).

Normally, writing off differs from plant component to plant component with e.g. concrete basins being written off within 30 plus years in contrast to sensor and control instruments in usually less than ten years. However, this calculation does not only differ

---

[3] The common implementation strategy for the WFD lists OPEX, CAPEX, administrative costs, taxes and funding, other costs and environmental and resource costs.

[4] Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy

based on components but also on tariff calculation cycles and plant specific calculations.

Other parts of WWTP are continuously subject to reinvest and correlated writing off procedures and identifying the window of opportunity to invest in a new system is rather difficult due to existing sunken costs. Table 3 shows different deprecation periods of various buildings and components of a WWTP. Even within the same treatment step, the deprecation period differs from each other (e.g. machinery in the mechanical treatment).

Table 3: Different deprecation periods based on building types/components, according to a german valuation guideline[5].

Building Type	Usual deprecation period [a]
Wastewater pumps	08 - 10
Mechanical treatment (machinery)	08 - 10
Other pumps	08 - 12
Mechanical treatment (other machinery)	10 - 12
Biological treatment (machinery)	10 - 15
Electrical components	10 - 15
Sludge treatment (digester machinery)	10 - 15
Sludge treatment (machinery sludge dewatering)	10 - 15
Biological treatment (machinery secondary sedimentation)	12 - 15
Mechanical treatment (machinery primary settlers)	12 - 15
Sludge treatment (pre thickeners)	12 - 15
Biological treatment (machinery aeration)	12 - 16
Wastewater pumps (screw pumps)	15 - 20
Pressure pipe (leachate)	15 - 20
Biological treatment (trickling filter)	20 - 25
Sludge treatment (biogas storage, biogas machinery)	20 - 25
Pressure pipe (wastewater)	30 - 40
Sludge treatment (Gravitational thickeners)	30 - 40
Sewers	40 - 60
Other buildings made out of concrete and steel	60 - 100

The annual investment of WWTP operators depends on the ongoing investment cycles and on current investment and of course differs from WWTP to WWTP. However, there

---

[5] MBl. LSA Nr. 22/2006 vom 2. 6. 2006

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

are annual investments that do not fluctuate as much and give an approximation of the necessary investment.

In order to approximate the reinvestment, data from Oelmann, Roters et al. (2017) serves as a baseline. The replacement value of Germany's wastewater infrastructure lies roughly between 500 and 690 Billion Euros. Furthermore, Oelmann, Roters et al. (2017) set an average lifetime of 80 years (mainly related to the sewer network) leading to a mandatory (to keep the replacement value) annual investment of 6.3 Billion Euros to 8.3 Billion Euros. Compared to the actual investment presented in Figure 10, Germany simply does not invest enough money to maintain the value of its wastewater infrastructure.

The wastewater infrastructure includes both the sewer network as well as the WWTP. 70% of the investment costs are for repairs and other measures regarding the sewer network (Oelmann, Roters et al. 2017), leaving 30% for WWTP and other wastewater related buildings. This leads to a necessary annual investment in WWTP of 1.9 Billion Euros – 2.5 Billion Euros and an actual annual investment ranging from 1 Billion Euro – 2 Billion Euro.

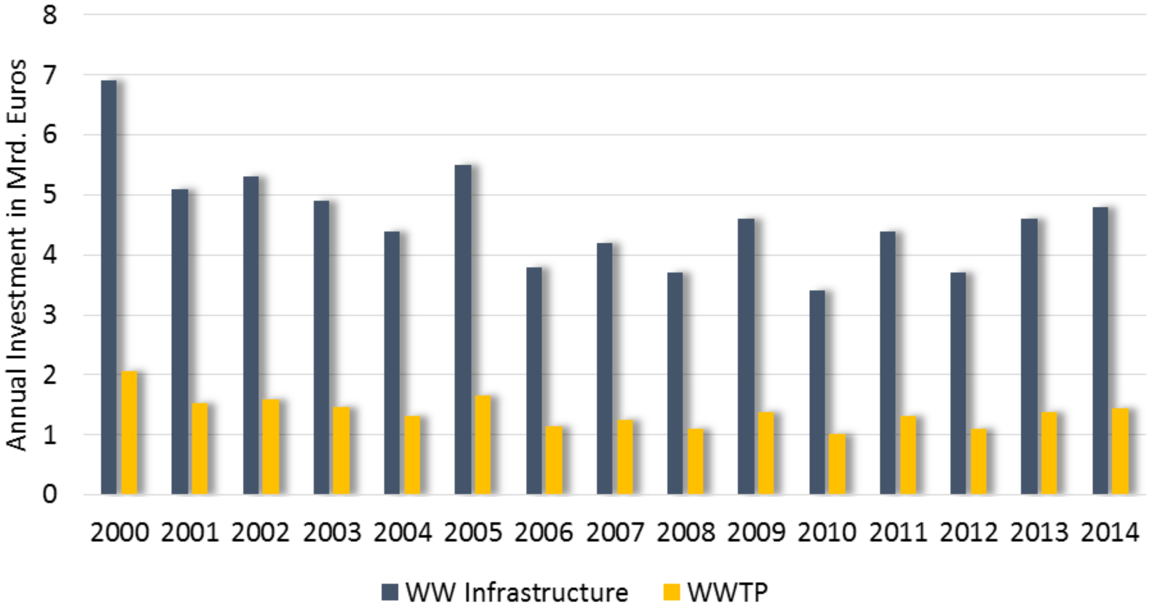


Figure 10: Annual investment in wastewater infrastructure in Billion Euros in Germany based on Oelmann, Roters et al. (2017)

In order to calculate the annual investment in WWTP in Europe, the German investment is based on the actual load entering German WWTPs and then multiplied by the actual load of the other MS. Table 4 shows the lower and upper annual investment bound based on the actual load entering WWTPs. The total annual investment, based on Germany's values lies between 5.2 Billion Euro and 10.4 Billion Euro. The six states with the highest actual load (DE, FR, UK, IT, ES, PL) contribute 73% of the annual investment.

Table 4: Lower and upper annual investment bound and the respective share of MS

MS Code	Actual Load	Lower Investment Bound	Upper Investment Bound	Share

MS Code	Actual Load	Lower Investment Bound	Upper Investment Bound	Share
DE	113662413	1.000.000.000	2.000.000.000	19%
FR	72951238	641.823.766	1.283.647.533	12%
UK	69842993	614.477.479	1.228.954.958	12%
IT	67367288	592.696.268	1.185.392.536	11%
ES	64609372	568.432.169	1.136.864.339	11%
PL	48630957	427.854.343	855.708.685	8%
NL	17406208	153.139.526	306.279.051	3%
AT	13933366	122.585.520	245.171.040	2%
SE	12695343	111.693.414	223.386.829	2%
RO	12641483	111.219.555	222.439.110	2%
PT	11624227	102.269.754	204.539.508	2%
CH	11102655	97.680.972	195.361.944	2%
GR	10943514	96.280.852	192.561.705	2%
HU	10154932	89.342.921	178.685.842	2%
BE	9204100	80.977.517	161.955.034	2%
CZ	8667577	76.257.197	152.514.394	1%
DK	7398895	65.095.354	130.190.708	1%
BG	5033890	44.288.080	88.576.159	1%
IE	5006677	44.048.660	88.097.320	1%
SK	4230144	37.216.736	74.433.472	1%
HR	3765335	33.127.354	66.254.708	1%
NO	2767164	24.345.462	48.690.925	0%
LT	2478843	21.808.819	43.617.638	0%
SI	1825116	16.057.340	32.114.680	0%
EE	1374730	12.094.851	24.189.703	0%
LV	1240698	10.915.640	21.831.280	0%
CY	815336	7.173.312	14.346.625	0%
LU	651728	5.733.892	11.467.784	0%
MT	525735	4.625.408	9.250.815	0%
Total	**592551957**	**5.213.262.163**	**10.426.524.325**	**100%**

2.7. Energy Related Issues

Energy management on the WWTP depends on several different country specific factors like the energy prices, the gas prices, and the role of renewables within the countries. In addition, the next sections also deal with the current situation of energy production from sewage sludge and first and foremost with the energy demand and generation of WWTP in general. First, the focus will lay on electricity and second on heat.

2.7.1. **Electricity Demand of WWTPs**

Measuring and analyzing the energy demand of WWTPs is a challenging task. Various factors influence the total amount of electricity that powers pumps and the WWTP itself. Local characteristics like the amount of infiltration water, the water consumption and the climate influence the energy demand significantly. In addition, the WWTP location, size and the necessary treatment, (this may be due to indirect dischargers and different receiving waters) provide numerous variables that change the energy demand of WWTP.

In Germany, the German Association for Water, Wastewater and Waste (DWA) assessed the energy demand in their annual benchmarking to be 30,5 kWh/PE/a for a large WWTP (more than 100.000 connected PE) (DWA 2015). This includes state of the art wastewater treatment including the removal of nutrients like phosphate and nitrogen. Smaller WWTP require significantly more energy. Due to its complete fulfillment of the UWWT Directive requirements, German WWTPs are a useful approximation of electricity demand of state of the art WWTPs in Europe. This helps assessing the existing market potential in Europe.

Figure 11 shows the specific electricity demand in kWh/PE/a of different WWTP size classes in Germany on the abscissa. The ordinate shows the percentage of WWTPs that have a certain electricity demand (e.g. 20% of the GK1[6] WWTPs have an electricity demand of 30 kWh/PE/a or lower.

---

[6] The WWTP size classes classify as follows: GK1: <1.000 PE, GK2: 1.000 PE - 5.000 PE, GK3: 5.001 PE - 10.000 PE, GK4: 10.001 PE - 100.000 PE, GK5: > 100.000 PE

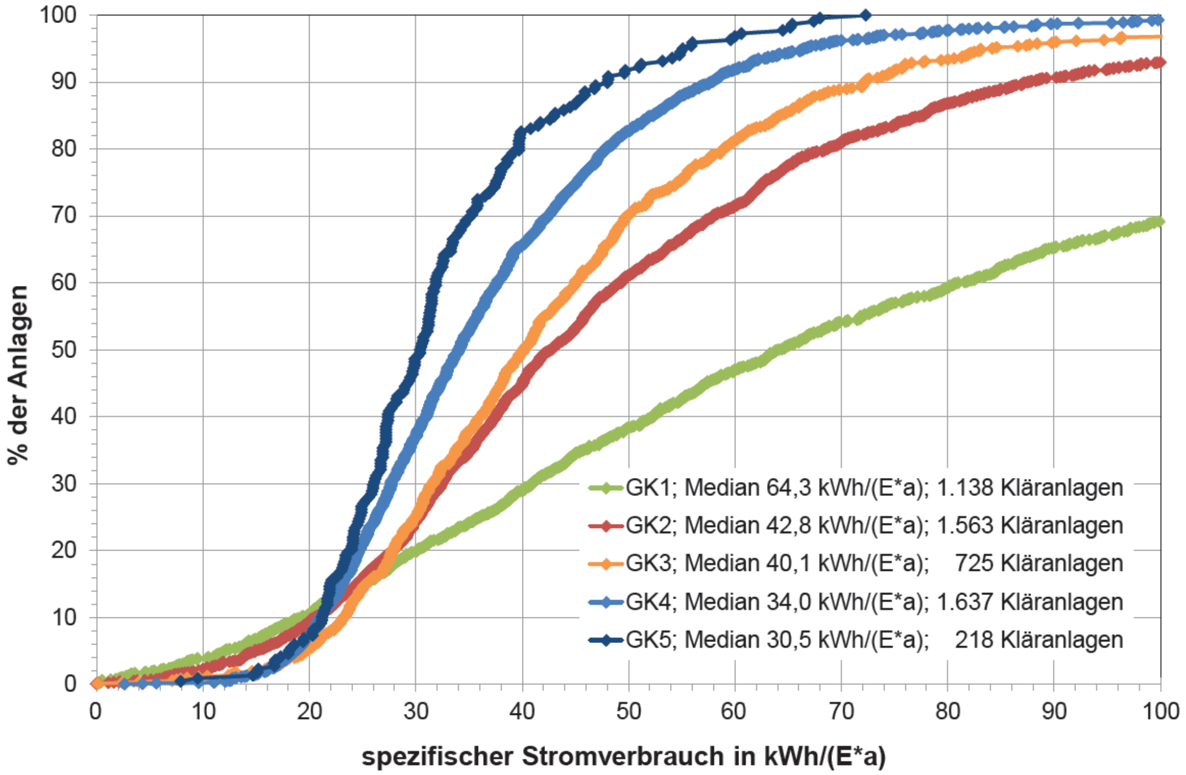


Figure 11: Specific electricity demand in kWh/(PE*a) of different WWTP size classes (GK1 - GK5) in Germany based on the DWA benchmark (Figure taken from DWA (2015))

The German characterization of the size classes differs slightly from the size classes specified in the section: Amount of WWTP per size class in each EC country. However, due to techno – economic limitations, only WWTPs with a size of more than 10k connected PE are relevant for this analysis[7]. Table 5 presents a short overview of the two relevant size classes. GK 4 and GK 5 WWTPs treat 92% of the wastewater in Europe and using the energy demand of the DWA, the weighted average energy calculates as:

$$Demand_{elec} = \frac{100}{92} \times \left(0{,}41 \times 34 \frac{kWh}{PE \times a} + 0{,}51 \ \times 30{,}5 \frac{kWh}{PE \times a}\right) = 32{,}06 \ \frac{kWh}{PE \times a}$$

Hence, the average electricity demand of WWTPs that are primary targets for PowerStep technology is 32 kWh/PE/a. WWTPs equipped with anaerobic digesters are also producing electricity. Both, the electricity demand and the electricity production show the potential of PowerStep technology in the European MS.

Table 5: Overview of WWTPs of a certain size class, their annual load and the respective energy demand according to the DWA figures

Size Class	Amount of WWTPs in Europe	Percentage of wastewater treated	Energy demand [kWh/PE/a]

---

[7] The feasible size of 10.000 PE is based on experience with anaerobic digesters in Germany

The project “Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration” (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

GK4 (10k-100k PE	8.722	41%	34,0
GK5 (> 100k PE)	1.483	51%	30,5

2.7.2. Electricity Production of WWTPs

The DWA also presents benchmark figures for electricity generation of WWTPs. First, the variation of the electricity generation seems to be lower than the variation of the electricity demand (based on the steepness of the size class specific curves in Figure 11 and Figure 12). However, WWTPs of the GK 5 size class show less variation than there smaller counterparts leading to the assumption, that a number of measures lead to a rather similar approach regarding the electricity consumption and production on the largest WWTPs. This is probably due to very similar WWTP treatment technology installed on the various plants and thus little room for plant specific adjustments.

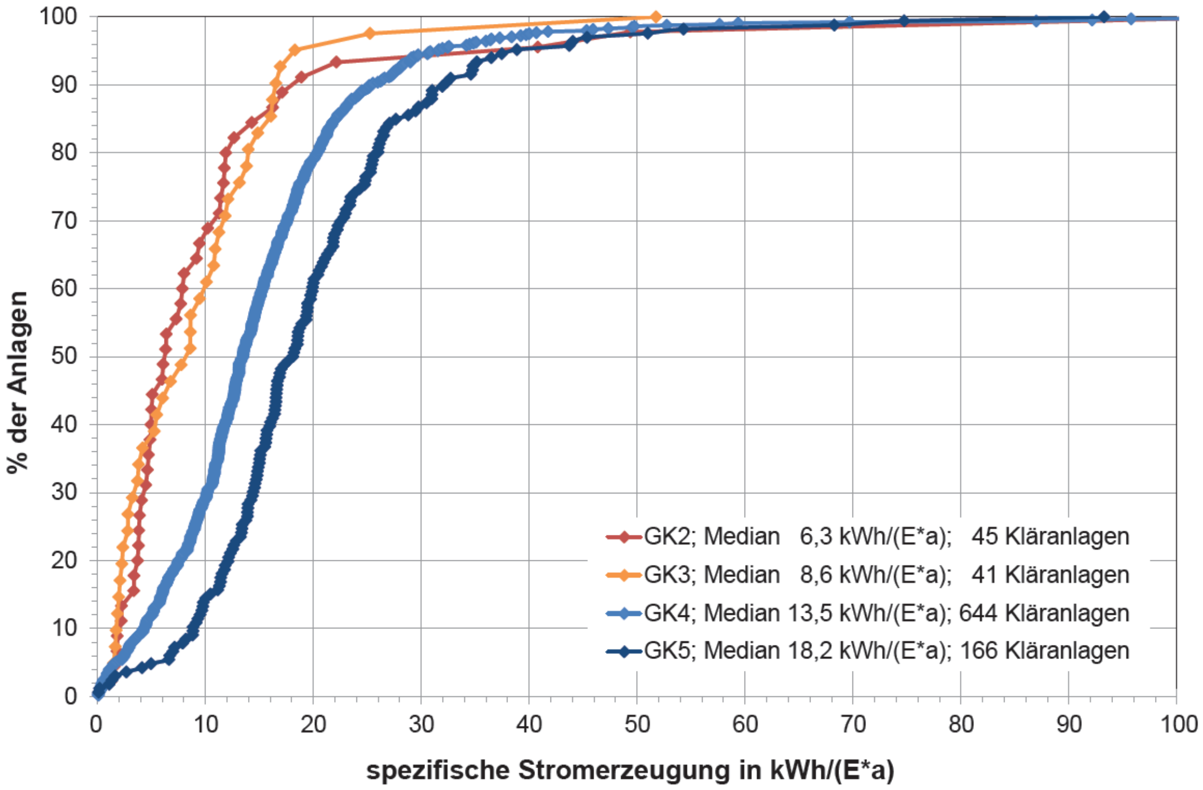


Figure 12: Specific electricity generation in kWh/(PE*a) of different WWTP size classes (GK2 - GK5) in Germany based on the DWA benchmark (Figure taken from DWA (2015))

In addition, Figure 12 represents a significantly smaller amount of WWTP compared to Figure 11 leading to the assumption that there still is an existing potential with respect to electricity generation on plants in Germany. According to Table 6, only 3% of the GK2 WWTPs and 6% of the GK3 WWTPs report generated electricity in contrast to 39% of the GK4 and 76% of the GK5. These findings support the assumption that electricity generation on WWTPs is subject to scaling effects making it significantly more feasible on large WWTPs.

Table 6: Amount of WWTPs in the electricity demand and generation benchmark of DWA.

Size Class	Amount of WWTP in the electricity demand benchmark	Amount of WWTP in the electricity generation benchmark	Ratio
GK2 (1k – 5k PE)	1.563	45	3%
GK3 (5k – 10k PE)	725	41	6%
GK4 (10k- 100k PE	1.637	644	39%
GK5 (> 100k PE)	218	166	76%

Finally, Table 7 compares the electricity demand with the electricity generated on the same plant.

Table 7: Comparison between electricity demand and electricity generation of WWTPs of different size classes within the DWA benchmark.

Size Class	Electricity demand [kWh/PE/a]	Electricity generation [kWh/PE/a]	Ratio
GK2 (1k – 5k PE)	42,8	6,3	15%
GK3 (5k – 10k PE)	40,1	8,6	21%
GK4 (10k- 100k PE	34,0	13,5	40%
GK5 (> 100k PE)	30,5	18,2	60%

Large WWTPs (GK5) already generate around 60% of their on electricity demand. GK4 40%, GK3 21% and GK2 15%. A large variation of the electricity consumption within the GK2 and GK3 WWTPs limits the explanatory power of any further conclusions.

Hence, based on existing figures there is a certain potential for energy efficient wastewater treatment with respect to GK4 and GK5 WWTPs, GK3, GK2 and GK1 WWTPs will do not play pivotal role.

This leads to the subsequent task to assess the potential of PowerStep technology in WWTPs with less than 10.000 connected PE. A significant advantage compared to state of the art technology will alter the electricity demand/generation ratio and lead to a reduced electricity consumption and increased electricity/gas production.

Even though there might be further improvements in smaller WWTPs, the focus is clearly on WWTPs with more than 10.000 PE. First of all, these WWTPs treat most of the wastewater as shown in Table 5 (92% in Europe) and second scale effects become increasingly important.

2.7.3. **Heat Demand of WWTPs**

The DWA benchmarks includes numbers for electricity generation and demand but does not present these numbers for heat. This is mainly due to the fact, that heat is not a scarce source in most WWTPs and it is rarely sold to other consumers. Hence, the heat distribution network and the heat consumption of the digester is directly related to the excess heat of the CHP leaving room for a series of improvements with respect to insulation and circulation[8]. However, due to the close correlation of CHP efficiency and heat demand, this potential of improvements is again quite hard to assess because the WWTPs mainly target heat self-sufficiency and not an optimal on site heat management.

For further calculations, the heat demand and generation of a state of the art WWTP is:

$$Demand_{heat} = \frac{100}{92} \times \left(0{,}41 \times 13{,}5 \frac{kWh}{PE \times a} + 0{,}51 \ \times 18{,}2 \frac{kWh}{PE \times a}\right) = 16{,}11 \ \frac{kWh}{PE \times a}$$

Of course, the demand of 16,11 kWh/PE/a is only an approximation and the possible heat production of WWTP might be a lot more if heat cascade systems are present and insulation and external distribution systems allow operators to sell heat to third parties.

2.7.4. **Energy Prices per Country**

Energy prices (especially electricity) are one of the main operational costs of WWTP. In addition to the high relevance, costs for energy are comparably easy to lower up to certain, site-specific values. Hence, incentives increase with the relative amount, WWTP have to pay for electricity supply. This is also in line with innovation theory and economic factors as one of the biggest driver of change (Tauchmann and Clausen 2004). In addition to electricity, the value of gas defines available options for WWTP and the ration between gas and electricity shows, if a correlation between prices and use of sewage gas as a resource to provide electricity exists.

The following figures and tables provide a detailed overview of the MS specific energy prices. The analysis both includes electricity and gas and determines the possible savings MS could achieve using PowerStep technology. The prices include all taxes and levies assuming the WWTP operators have to pay that price. In several countries, WWTP operators pay significantly less than the prices provided in Table 8 due to special deductions or other benefits. Eurostat also provides the data including a Purchasing Power Standard (PPS), which improves the value of the actual costs greatly[9]. Table 8 shows the same cluster structure as Table 2 and further includes cluster specific standard deviation values for electricity (ELEC) and gas. The low standard deviation values show, that the situation within the clusters is rather similar. In general, gas and electricity prices based on the PPS seem to be rather similar.

---

[8] For example, the WWTP in Oldenburg could reduce their heat demand by more than 500.000 MWh/a de Boer, J., K. Erdmann and O. Fricke (2015). "Ganzheitliche Optimierung der Kläranlage Oldenburg." KA - Korrespondenz Abwasser, Abfall **10**.

[9] The PPS closely correlates to the actual price of Euro/kWh.

Table 8: Adjusted electricity and gas prices in European countries (the data shown in this table and the subsequent charts comes from Eurostat, the EC's data provider)

	Electricity [PPS/kWh]	Gas [PPS/GJ/100]	Ratio between electricity and gas prices	Standard Deviation ELEC	Standard Deviation Gas
Northern Cluster	**0,12**	**0,20**	**0,59**	**0,03**	**0,04**
Denmark	0,16	0,16	1,02		
Sweden	0,10	0,24	0,43		
Norway					
Finland	0,09				
Iceland					
Western Cluster	**0,16**	**0,13**	**1,22**	**0,04**	**0,02**
Germany	0,26	0,14	1,77		
France	0,14	0,14	1,02		
United Kingdom	0,14	0,11	1,26		
Austria	0,14	0,15	0,97		
Switzerland					
The Netherlands	0,20	0,17	1,20		
Belgium	0,17	0,12	1,41		
Luxembourg	0,11	0,09	1,18		
Ireland	0,14	0,15	0,97		
Eastern Cluster	**0,19**	**0,17**	**1,08**	**0,03**	**0,02**
Poland	0,23	0,18	1,26		
Latvia	0,23	0,16	1,48		
Bulgaria	0,20	0,19	1,02		
Estonia	0,14	0,15	0,93		
Hungary	0,19	0,17	1,11		
Lithuania	0,16	0,15	1,04		
Slovakia	0,16	0,17	0,92		
Romania	0,23	0,17	1,36		
Czech Republic	0,16	0,21	0,74		
Southern Cluster	**0,23**	**0,19**	**1,23**	**0,09**	**0,03**
Italy	0,22	0,20	1,13		
Spain	0,16	0,17	0,94		
Portugal	0,27	0,26	1,06		
Greece	0,24	0,19	1,27		
Croatia	0,17	0,15	1,17		
Slovenia	0,16	0,17	0,91		
Cyprus	0,18				

	Electricity [PPS/kWh]	Gas [PPS/GJ/100]	Ratio between electricity and gas prices	Standard Deviation ELEC	Standard Deviation Gas
Malta	0,46				

The ratio in Table 8 describes the relationship between electricity and gas prices. A value closer to 0 means that gas is more expensive in relation to electricity, a higher value means that electricity is more expensive in relation to gas.

Figure 13 shows the electricity prices in the first semester of 2017 in various European countries for entities consuming more than 15.000 kWh/a. WWTPs with an installed capacity of around 450 PE consume that amount of electricity[10]. However, this is just an approximation to the electricity price WWTP operators pay. Negotiations with the local electricity provider lead to changing prices within a country and different tax and levy reductions make it impossible to assess the actual price of electricity. Hence, the price in Table 8 and in the subsequent figures rather shows the value of electricity in European countries (therefore also including taxes and levies).

Malta clearly has the highest electricity prices with 45 PPS/kWh. This is more than four times the amount, people in Finland pay (0,09 PPS/kWh). The European average is 0,18 PPS/kWh. Besides the high electricity prices in Malta, most of the other countries have electricity prices lower than 25 PPS/kWh and in a few countries, people have to pay less than 15 PPS/kWh.

[10] Assuming an electricity consumption of 34 kWh/PE/a, the German benchmark

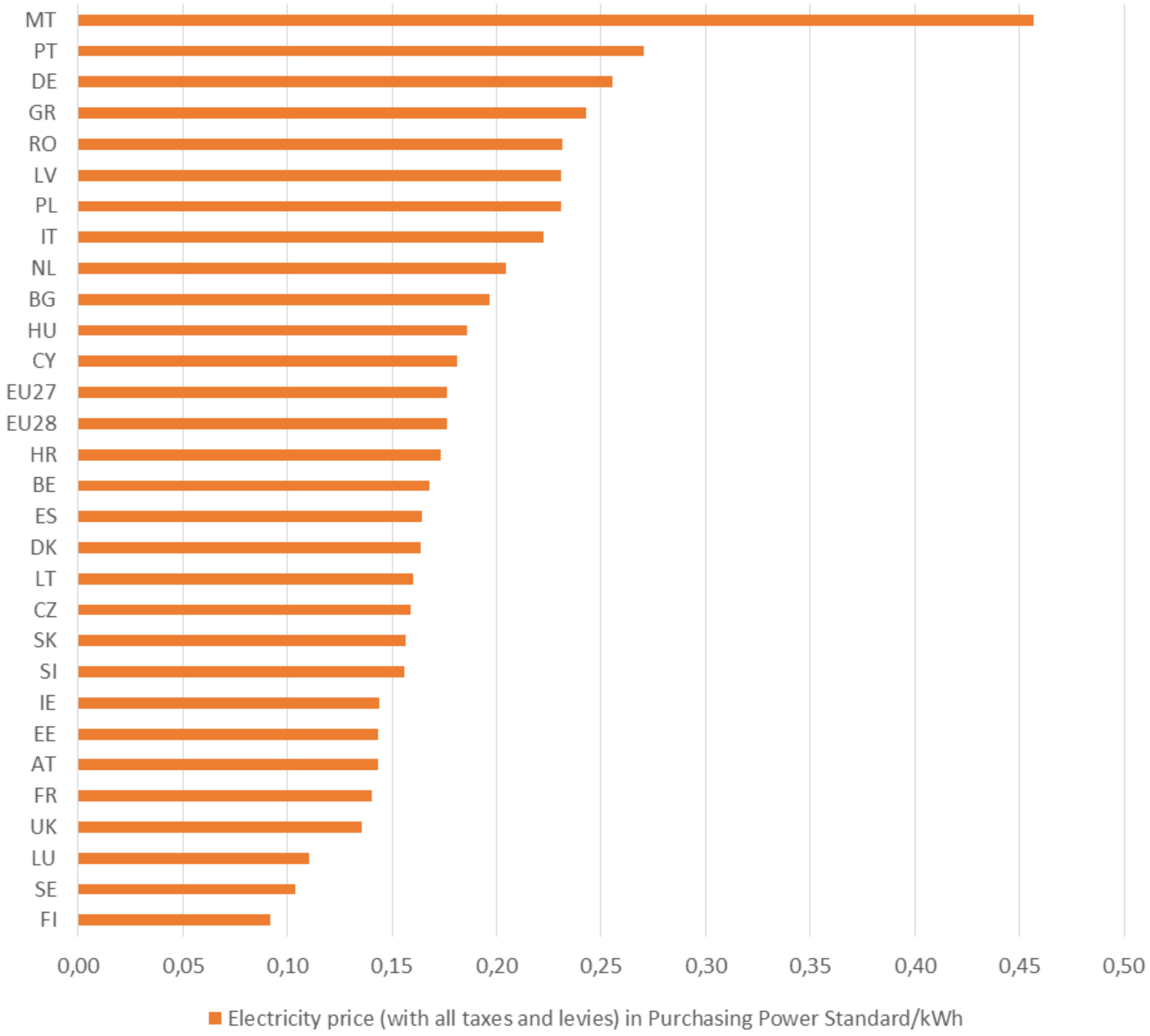


Figure 13: 2017 electricity prices of different European countries based on the PPS

Figure 14 shows the gas prices in the first semester of 2017 for some European countries. Just like the electricity price, the gas price is just a rough approximation of the value of gas in the different countries. Therefore, the consumption (the highest) is >200 GJ.

As the majority of the electricity prices, the distribution of the gas prices is uniform with most of the country specific prices being around 15 PPS/GJ/100. The European average is also at 15 PPS/GJ/100. The gas prices in Portugal and in Sweden are significantly higher than in most other European states leaving different possibilities for the implementation of PowerStep technology.

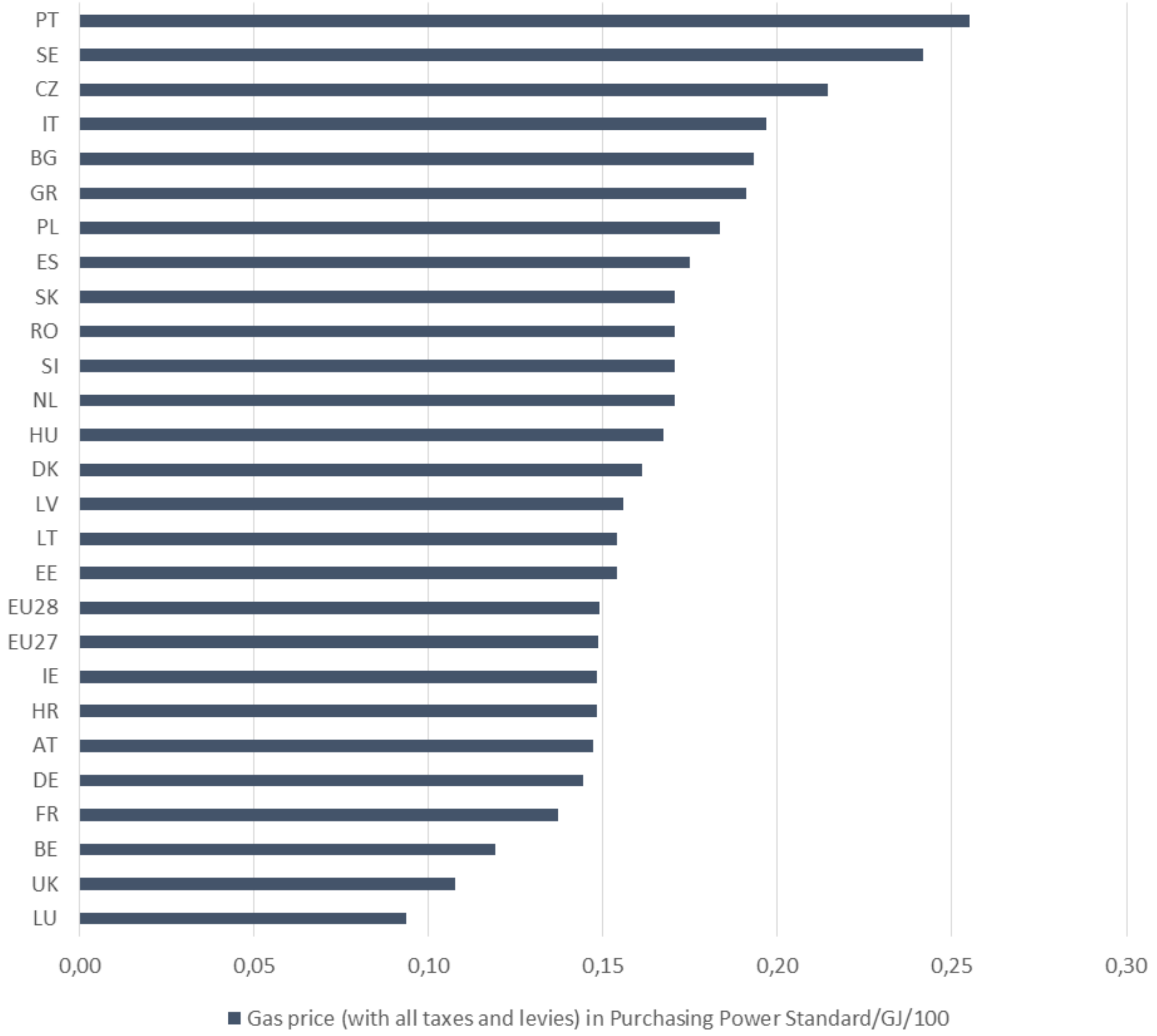


Figure 14: 2017 gas prices of different European countries based on the PPS

Finally, Figure 15 shows the relationship between gas and electricity prices. The ratio calculates as the price of electricity in PPS/kWh divides through the price of gas in PPS/GJ/100. Hence, regarding the energetic value of gas and electricity, gas is cheap compared to electricity. Therefore, the following statements do not cover real values, but the relation between gas and electricity in different countries.

A low value in Figure 15 means that gas has a relatively high value compared to electricity or in other words, that electricity has a relatively low value compared to gas (e.g. in Sweden). A high value, that gas has a low value compared to electricity (e.g. Germany). Again, the distribution is rather uniform and apart from few states like Germany, the Czech Republic or Sweden, most countries have a rather similar ratio between gas and electricity prices. This also means that the chance for a successful implementation of PowerStep technology is rather similar in the countries with a suggested focus on gas in Sweden and a focus on electricity in Germany.

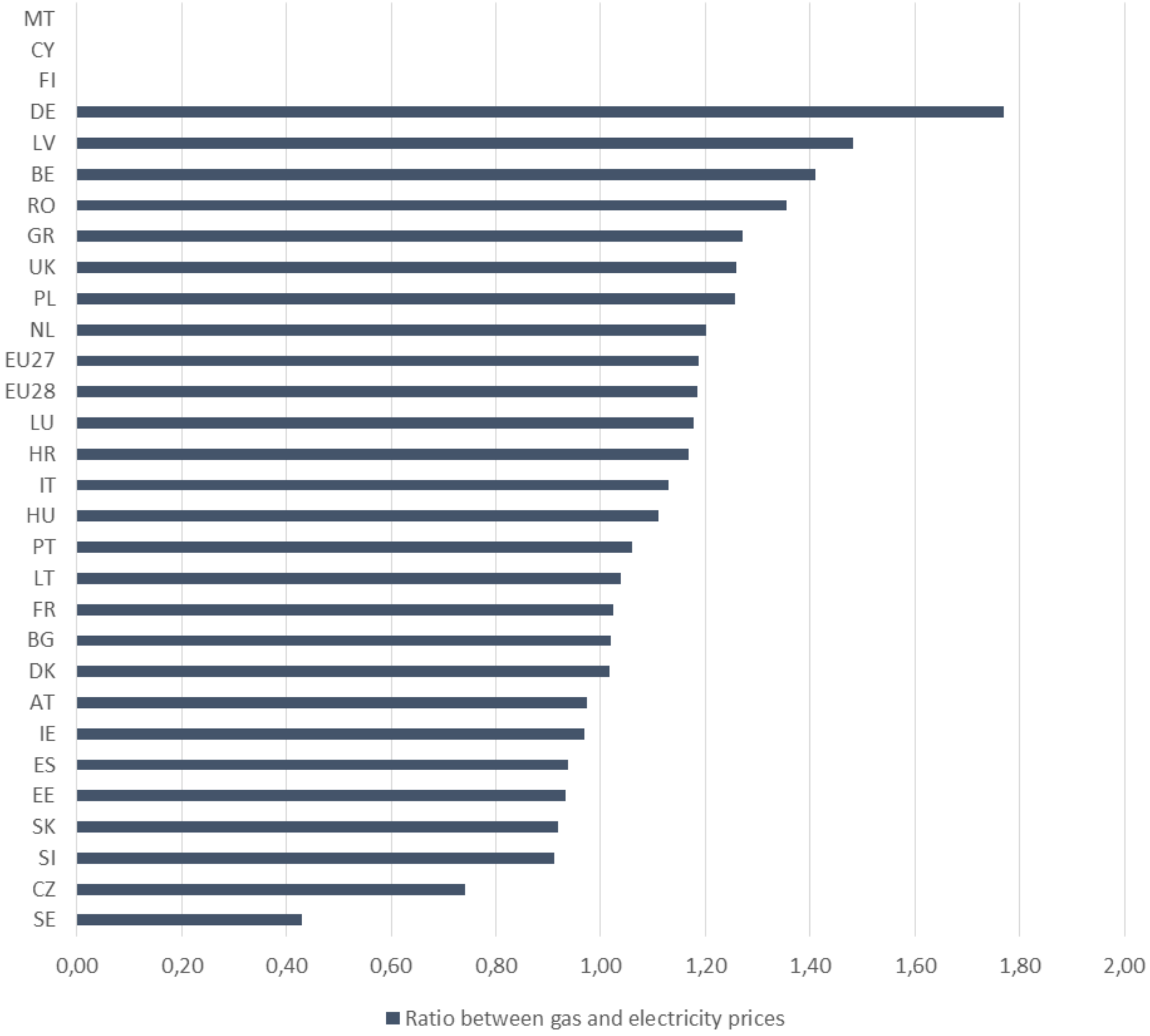


Figure 15: 2017 relationship between gas and electricity prices in European countries based on PPS

Overall, for the majority gas and electricity prices based on PPS are rather similar. Apart from few countries, PowerStep does not have to consider country specific issues, a focus on the site specific criteria is way more important.

2.7.5. **Power Mix per MS**

The power mix in the different MS influences a possible implementation of PowerStep technology and specifies the demand for other possible contributions in the energy sector, like providing balancing power. Figure 16 shows the renewable energy production of the EU28 based on the different sources and Table 9 shows the annual share of renewables in the EU from 2006 till 2015.

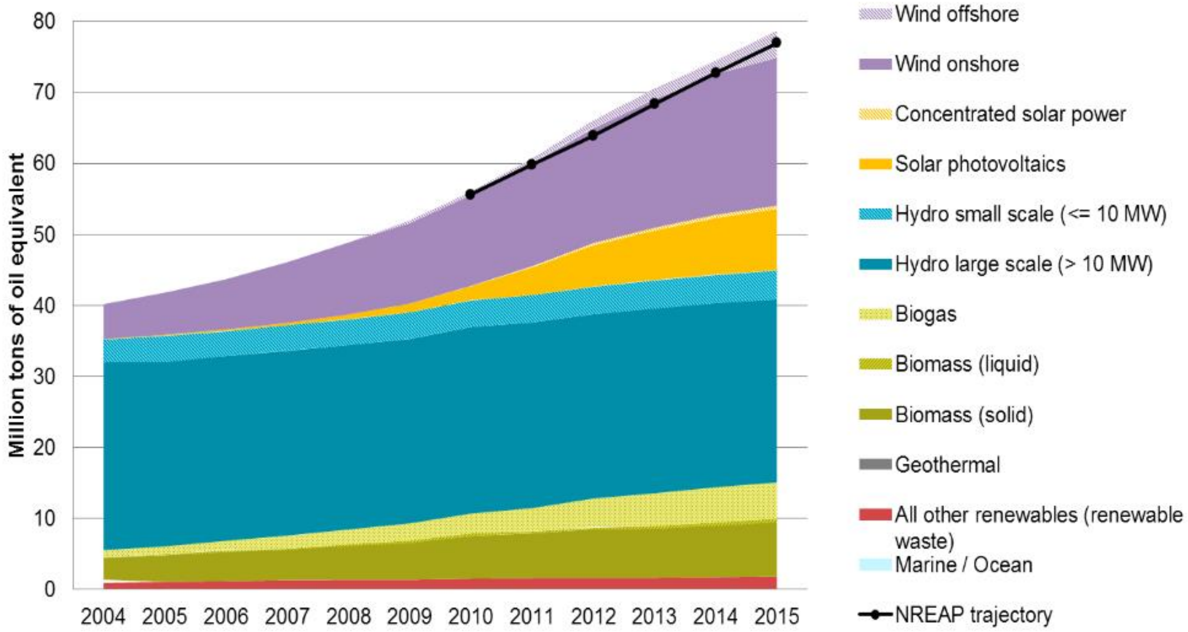


Figure 16: Renewable electricity production of the EU28 based on source taken from the Renewable Energy Progress Report 2017

In general, Figure 16 shows that wind and PV had the biggest increase in recent years. Apart from that, the contribution of biogas and biomass (both liquid and solid) rose constantly from 2004 to 2015, while hydropower (small and large scale) and other renewables remained at the same level or decreased.

Table 9 shows the annual share of renewables in the EU and the development over the last 10 years. The share varies greatly ranging from more than 70% in Austria to just slightly above 4% in Malta. The European average is at almost 29%. The development over time is important to classify actions taken by the MS. For example, Austria, the country with the biggest share of renewable energies increased that share by 8.1 % since 2006 while the overall share rose by 13.4 %. Denmark increased its share of renewable energy by 27.3 %. Combining the information provided by Table 9 and the information of Figure 16, the increase is largely due to rising shares in wind and PV.

Table 9: Annual share of renewable energies in the EU since 2006 in percent and the development (Data from Eurostat nrg_ind_335a)

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Increase
Austria	62.2	64.3	65.3	67.9	65.7	66.0	66.5	68.0	70.1	70.3	8.1
Sweden	51.8	53.2	53.6	58.3	56.0	59.9	60.0	61.8	63.2	65.8	14.0
Portugal	29.3	32.3	34.1	37.6	40.7	45.9	47.6	49.1	52.1	52.6	23.3
Latvia	40.4	38.6	38.7	41.9	42.1	44.7	44.9	48.8	51.1	52.2	11.8
Denmark	24.0	25.0	25.9	28.3	32.7	35.9	38.7	43.1	48.5	51.3	27.3

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Increase
Croatia	35.0	34.0	33.9	35.9	37.6	37.6	38.8	42.1	45.3	45.4	10.4
Romania	28.1	28.1	28.1	30.9	30.4	31.1	33.6	37.5	41.7	43.2	15.1
Spain	20.0	21.7	23.7	27.8	29.8	31.6	33.5	36.7	37.8	36.9	16.9
Italy	15.9	16.0	16.6	18.8	20.1	23.5	27.4	31.3	33.4	33.5	17.6
Slovenia	28.2	27.7	30.0	33.8	32.2	31.0	31.6	33.1	33.9	32.7	4.5
Finland	26.4	25.5	27.3	27.3	27.7	29.4	29.5	30.9	31.4	32.5	6.1
Germany	11.8	13.6	15.1	17.4	18.1	20.9	23.6	25.3	28.2	30.7	18.9
European Union (28 countries)	15.4	16.1	17.0	19.0	19.7	21.7	23.5	25.4	27.5	28.8	13.4
Ireland	8.7	10.4	11.2	13.4	14.6	17.4	19.7	21.0	22.9	25.2	16.5
Slovakia	16.6	16.5	17.0	17.8	17.8	19.3	20.1	20.8	22.9	22.7	6.1
United Kingdom	4.5	4.8	5.5	6.7	7.4	8.8	10.7	13.8	17.9	22.4	17.9
Greece	8.9	9.3	9.6	11.0	12.3	13.8	16.4	21.2	21.9	22.1	13.2
Bulgaria	9.3	9.4	10.0	11.3	12.7	12.9	16.1	18.9	18.9	19.1	9.8
France	14.1	14.3	14.4	15.1	14.8	16.3	16.4	16.9	18.3	18.8	4.7
Lithuania	4.0	4.7	4.9	5.9	7.4	9.0	10.9	13.1	13.7	15.5	11.5
Belgium	3.1	3.6	4.6	6.2	7.1	9.1	11.3	12.5	13.4	15.4	12.3
Estonia	1.5	1.5	2.1	6.1	10.4	12.3	15.8	13.0	14.1	15.1	13.6
Czech Re-	4.0	4.6	5.2	6.4	7.5	10.6	11.7	12.8	13.9	14.1	10.1

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Increase
public											
Poland	3.0	3.5	4.4	5.8	6.6	8.2	10.7	10.7	12.4	13.4	10.4
Nether erlands	6.5	6.0	7.5	9.1	9.6	9.8	10.4	10.0	10.0	11.1	4.6
Cyprus	0.0	0.1	0.3	0.6	1.4	3.4	4.9	6.6	7.4	8.4	8.4
Hungary	3.5	4.2	5.3	7.0	7.1	6.4	6.1	6.6	7.3	7.3	3.8
Luxem embourg	3.2	3.3	3.6	4.1	3.8	4.1	4.6	5.3	5.9	6.2	3.0
Malta	0.0	0.0	0.0	0.0	0.0	0.5	1.1	1.6	3.3	4.2	4.2

In addition to the overall development of RES, Figure 16 also shows that the development of renewable electricity is within the NREAP trajectories. MS do not have to accelerate their efforts to increase the share of renewable energy in the electricity sector. However, the question arises if MS focused primarily on low hanging fruits and future progress will require significant contributions of several different RES, like sewage gas. Table 10 shows the annual primary energy production in TJ using sewage sludge gas in the year 2006 and 2015. First, few countries including Germany and the UK contribute the majority (UK and Germany account for 57%) of the total primary energy production. Second, an overall increase of primary energy of 160% based on the year 2006 and 2015 values shows that MS are investing in primary energy from sewage gas.

Table 10: Annual primary energy production (in TJ) of sewage sludge gas in the EU for 2006 and 2015, including the increase in percent and the contribution of MS to the total value. (Data from Eurostat table nrg_109a)

MS / TIME	2006 [TJ]	2015 [TJ]	Increase	Contribution
European Union (28 countries)	35.805	57.432	160%	100%
Euro area (19 countries)	23.462	33.019	141%	57%
Belgium	54	1.009	1869%	2%
Bulgaria	0	79		0%
Czech Republic	1.303	1.675	129%	3%
Denmark	879	914	104%	2%
Germany	14.707	18.933	129%	33%
Estonia	45	64	142%	0%
Ireland	328	334	102%	1%

MS / TIME	2006 [TJ]	2015 [TJ]	Increase	Contribution
Greece	402	664	165%	1%
Spain	2.361	2.949	125%	5%
France	1.852	2.277	123%	4%
Croatia	0	144		0%
Italy	38	2.241	5897%	4%
Cyprus	0	19		0%
Latvia	87	85	98%	0%
Lithuania	62	294	474%	1%
Luxembourg	42	65	155%	0%
Hungary	337	707	210%	1%
Malta	0	0		
Netherlands	2.010	2.316	115%	4%
Austria	631	470	74%	1%
Poland	1.803	4.043	224%	7%
Portugal	44	108	245%	0%
Romania	0	0		
Slovenia	47	101	215%	0%
Slovakia	287	443	154%	1%
Finland	465	647	139%	1%
Sweden	860	3.127	364%	5%
United Kingdom	7.161	13.724	192%	24%

Figure 17 shows the development of primary energy production from sewage gas since 2006. Together, the five MS represent 74% of the total energy production from sewage gas. Besides Spain, which shows significant fluctuations in general, all other MS increased their production in this time span. After 2012 the production in Germany and in the UK rose significantly.

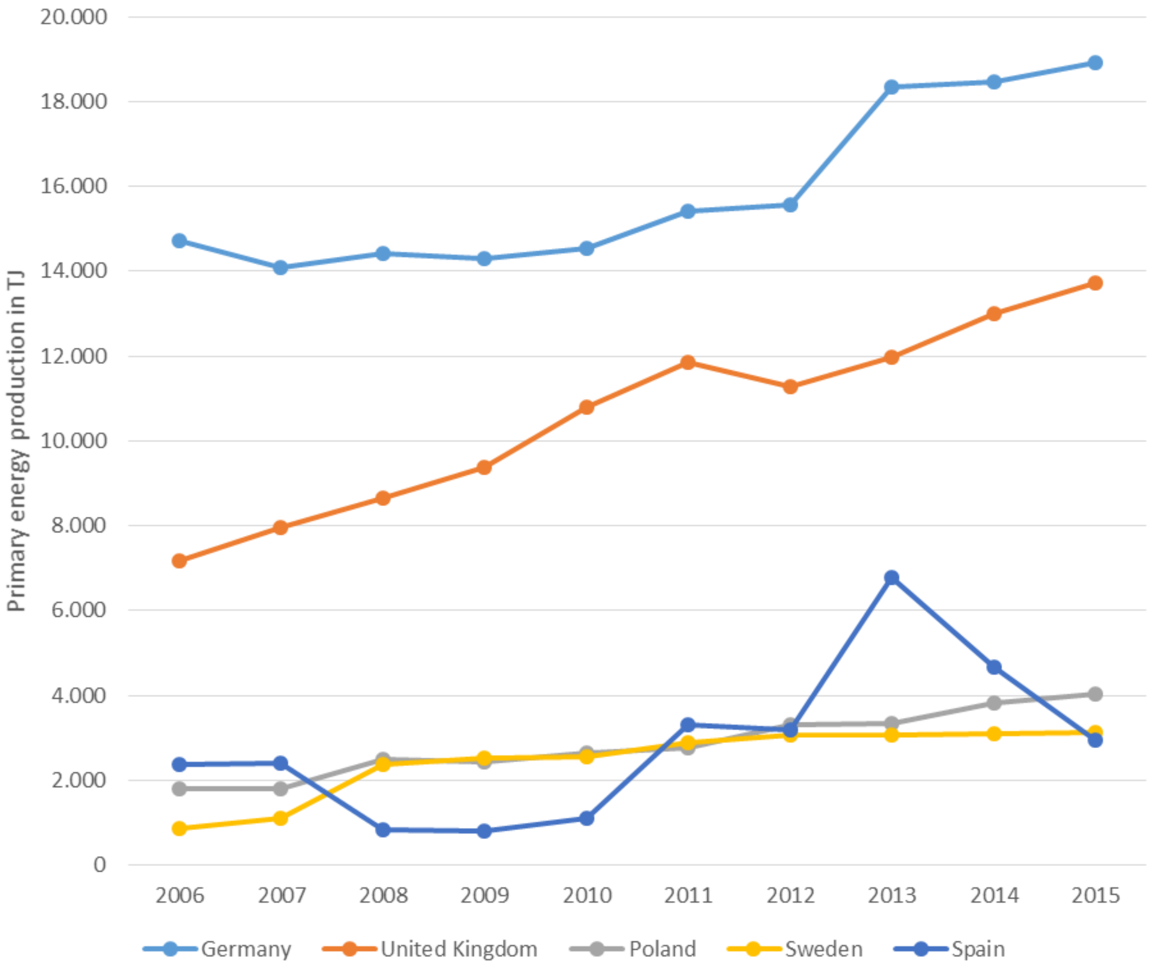


Figure 17: Development of primary energy production out of sewage sludge gas in the five most productive MS

Figure 17 also shows that the amount of inhabitants per MS influence the energy production from sewage sludge gas. Interestingly, France one of the most populous MS does not show up in the top five. Hence, the primary energy production out of sewage sludge gas should be based on a per capita approach to assess the true potential that exists in each MS before setting up a trajectory regarding the impact of PowerStep technology.

Table 11: Share of primary energy from sewage sludge gas per PE based on the actual load according to the UWWT Database

Country	Sewage Sludge Gas Including Industrial Sewage Sludge [TJ]	Share in Europe	Share in Europe per Inhabitant *1.000.000 [MJ]	Standard Deviation	Probability Coefficient
Eastern Cluster			**77,54**	**54,49**	**0,70**
Bulgaria	79	0%	15,59		
Czech Republic	1675	3%	192,85		

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Country	Sewage Sludge Gas Including Industrial Sewage Sludge [TJ]	Share in Europe	Share in Europe per Inhabitant *1.000.000 [MJ]	Standard Deviation	Probability Coefficient
Estonia	64	0%	46,47		
Hungary	707	1%	69,47		
Latvia	85	0%	67,43		
Lithuania	294	1%	118,56		
Poland	4043	7%	83,02		
Romania	0	0%	0,00		
Slovakia	443	1%	104,48		
Northern Cluster			**159,23**	**61,82**	**0,39**
Denmark	914	2%	123,53		
Finland	647	1%	107,96		
Sweden	3127	5%	246,20		
Southern Cluster			**33,12**	**19,96**	**0,60**
Croatia	144	0%	38,24		
Cyprus	19	0%	23,30		
Greece	664	1%	60,68		
Italy	2241	4%	32,81		
Malta	0	0%	0,00		
Portugal	108	0%	9,25		
Slovenia	101	0%	55,20		
Spain	2949	5%	45,46		
Western Cluster			**104,33**	**56,00**	**0,54**
Austria	470	1%	33,73		
Belgium	1009	2%	109,46		
France	2277	4%	31,20		
Germany	18933	33%	166,46		
Ireland	334	1%	64,77		
Luxembourg	65	0%	99,68		
Netherlands	2316	4%	133,06		
United Kingdom	13724	24%	196,32		

Table 11 shows the share of primary energy from sewage sludge gas based on the actual load reported by MS within the UWWT database. This share indicates the progress in primary energy generation from sewage gas as the value ranges from values at around ten to above 200 in Sweden[11]. Hence, Table 11 shows the possible power generation of the existing system. However, Sweden is one of few countries that do not report connected PE in the UWWT report and therefore, calculations in Table 11 use the number of inhabitants. Usually, the amount of connected PE is significantly higher (in Germany round about 140%) which decreases the share of primary energy per PE.

Table 11 reveals that the share of primary energy production from sewage gas differs not only greatly between MS, but also between the selected clusters with the southern cluster averaging 33 MJ, the eastern cluster averaging 78 MJ, the western cluster 104 MJ and the northern cluster 159 MJ. In addition, the standard deviation and the dimensionless probability coefficient that divides the standard deviation by the average show that deviation within clusters is ranging from 0,39 to 0,70 compared to 0,76 for the total dataset.

Table 11 also shows that even though Austria has the highest share of renewable energies (see Table 9) the primary energy production from sewage gas is among the lowest in its cluster. Hence, the importance of renewable energies in general does not automatically lead to a high importance of renewable energy from sewage gas.

3. Part Two: PowerStep's Potential in Europe

PowerStep includes different technologies and connectable modules that present different treatment possibilities. In order to assess the potential of PowerStep, the project includes one work package that compares the above mentioned wastewater treatment technologies with each other and identifies the best solution with respect to net energy efficiency, OPEX, CAPEX, and CO_2-Equivalent. This analysis could use three different WWTP size classes (large, medium and small). However, only large and medium sized WWTP have a major contribution to WWT on a European level and small plants are therefore no part of this analysis (see next section).

The focus of this deliverable is the impact of PowerStep on the European level. Therefore, we used a variety of different data sources including sewage gas data provided by Eurostat and the UWWT directive database to assess the current status quo

In a next step, we upgrade the existing plants to both a benchmark WWTP and a WWTP with PowerStep technology and analyze the resulting improvements.

This approach leads to a holistic view on the European wastewater sector and shows its possibilities and the full potential of upgrading European WWT with respect to energy.

3.1. Methodology of the Market Assessment

This section describes the necessary constraints the subsequent analysis will use. All numbers and figures presented here are estimations of the actual values. WWTP are unique socio-technical systems and properties and system specifics vary significantly.

First, the focus of this analysis is on medium and large WWTP. This dramatically reduces the amount of data that has to be verified and analyzed without compromising the overall value of the assessment. Figure 18 shows that large (>100k connected PE) and medium (10-100k connected PE) treat more than 90% of the European wastewater according to the UWWT (2014) database.

The status quo is referring to the WWTP in the UWWT.

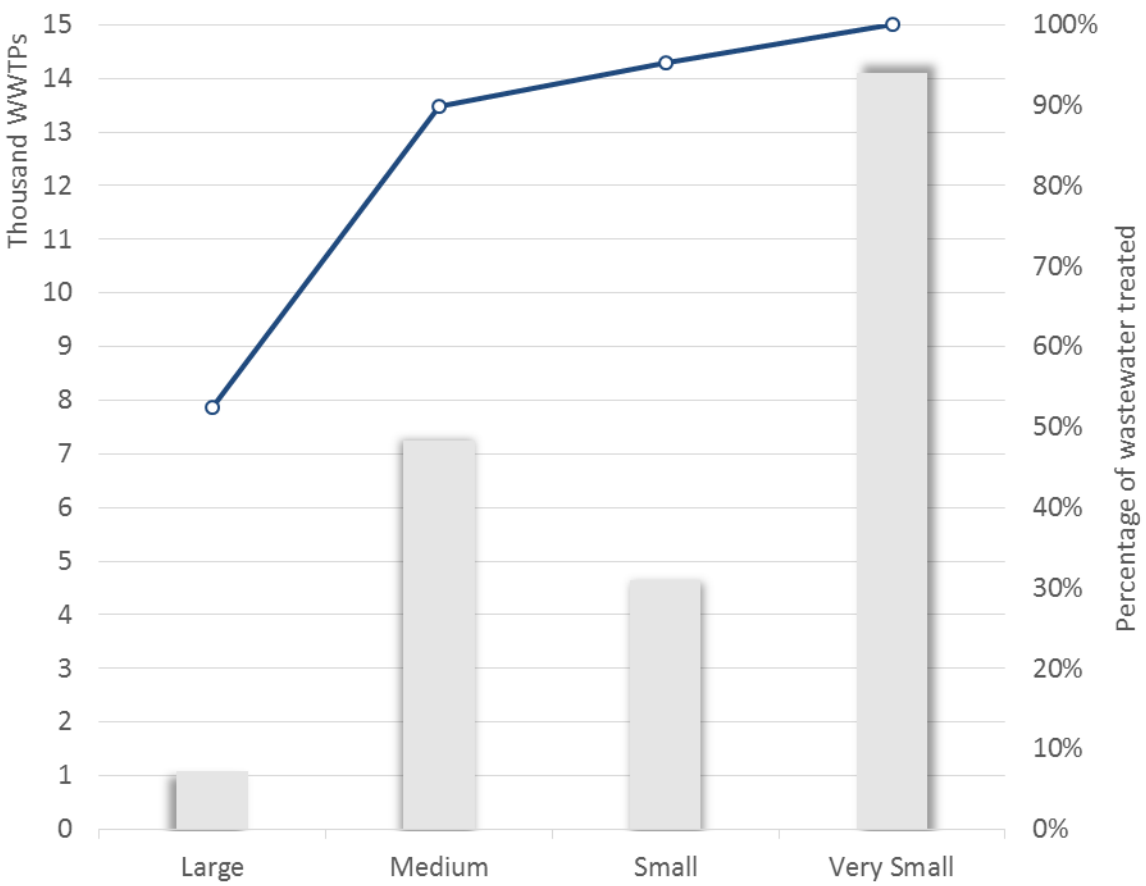


Figure 18: Amount of WWTPs in the respective size class (grey columns, left axis) and the corresponding percentage of treated wastewater of that size class (blue line, right axis), based on the UWWT database

Second, Deliverable 5.5 set up a benchmark plant that serves as an example for state of the art technology. The benchmark WWTP shows the possibilities that are available using current technologies. PowerStep aims at being the next step in energy efficient wastewater and should be more efficient than the benchmark.

In this analysis, PowerStep is reduced to two single technology approaches yielding an energy neutral WWTP and an energy positive WWTP (including the fairly challenging anammox process). These two PowerStep scenarios were elaborated by Deliverable 5.5 and serve as an approximation to actually achievable values (see Deliverable 5.5).

Third, energy consumption data availability is quite poor on the European level and there is also little information about energy production of WWTPs. Available data comes from a German association that gathers energy related data from members (WWTP operators in this case) and reported this data in 2011 and 2015 (DWA (2011), DWA (2015)). Germany is one of the European member states that fulfills the Urban Wastewater Treatment Directive (European Economic Community 1991) and we state that in order to comply with the directive, other European MS need a WWT similar to Germany and hence, with respect to energetic values, also similar to German WWPT. Therefore, we extrapolate WWTP electricity consumption data using the connected PE and the German values for the two size classes medium and large.

For WWTP electricity production, the Eurostat database Primary production - all products - annual data (nrg_109a) provides basic information about sewage gas generation in different MS; however, the sewage gas production also includes additional substrates (e.g. grease separator residues) and industrial sewage sludge (contributing a lot in MS with a lot of pulp and paper production, like Sweden). This means that in most countries, the status quo sewage gas production includes other sewage gas sources that cannot be included when looking at the benchmark and PowerStep scenarios. In some member states (UK and Sweden) the sewage gas production exceeds the benchmark production (without additional substrates) and for that reason has been cut at a level slightly above the benchmark. Using MS specific data also means that differences between large and medium sized plants have to be neglected in certain calculations. For example, the sewage gas production uses PE specific values that are equal for large and medium sized plants however, these numbers differ in the benchmark, PowerStep I and PowerStep II. The status quo is an overestimation of the current situation.

Table 12 provides an overview of data that could be acquired on the MS level and data that had to be extrapolated based on the German WWT or generalized due to missing information or non-sufficient information. Especially the data on electricity consumption of WWTP on a national level is crucial for future assessments and a recommendation would be to start gathering this data on the MS level.

Table 12: Overview of data that could be acquired on the MS level and data that had to be extrapolated or generalized due to missing information.

MS Specific Data	Non-MS Specific Data
Sewage gas production (includes industrial sewage and co-substrates) → Electricity (35% efficiency) → Heat (50% efficiency)	Energy consumption (based on German data) → Electricity → Heat
Electricity costs (for OPEX)	CAPEX
CO2-Equivalent of electricity mix	
Connected PE (on WWTP level)	

Table 13 presents the different data values that have been used in order to assess the impact of PowerStep on a European level for large and medium WWTP including the gas electricity and heat generation, the electricity and heat demand, OPEX, CAPEX, and CO_2-Equivalent calculations.

Table 13: Comparison of benchmark performance standards and PowerStep performance standards based on the OCEAN software and the preceding analysis of Christian Remy and Damien Cazalet.

Criteria	Unit	Large WWTP	Medium WWTP
		>100k PE	10-100k PE
Gas generation			

Criteria	Unit	Large WWTP	Medium WWTP
Status quo	[kWh/pe*a]	MS specific (capped at 45)	
Benchmark	[kWh/pe*a]	41	42
PowerStep I	[kWh/pe*a]	48	60
PowerStep II	[kWh/pe*a]	67	66
Electricity generation			
Status quo	[kWh/pe*a]	MS specific	
Benchmark	[kWh/pe*a]	18	14
PowerStep I	[kWh/pe*a]	21	21
PowerStep II	[kWh/pe*a]	26	22
Electricity demand			
Status quo	[kWh/pe*a]	17 (German values)	18 (German values)
Benchmark	[kWh/pe*a]	17	18
PowerStep I	[kWh/pe*a]	18	19
PowerStep II	[kWh/pe*a]	19	20
Heat generation			
Status quo	[kWh/pe*a]	Set to heat neutrality	
Benchmark	[kWh/pe*a]	18	19
PowerStep I	[kWh/pe*a]	20	21,5
PowerStep II	[kWh/pe*a]	23	23
Heat demand			
Status quo	[kWh/pe*a]	Set to heat neutrality	
Benchmark	[kWh/pe*a]	17	18
PowerStep I	[kWh/pe*a]	18	19
PowerStep II	[kWh/pe*a]	19	20
OPEX			
Status quo	[Euros/pe*a]	MS specific	
Benchmark	[Euros/pe*a]		
PowerStep I	[Euros/pe*a]		
PowerStep II	[Euros/pe*a]		
CAPEX			
Status quo	[Euros/pe*a]	No data available	

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

Criteria	Unit	Large WWTP	Medium WWTP
Benchmark	[Euros/pe*a]	19	27,2
PowerStep I	[Euros/pe*a]	No data available[12]	
PowerStep II	[Euros/pe*a]	20,1	28,7
CO_2-Equivalent			
Status quo	[kg/pe*a]	MS specific	
Benchmark	[kg/pe*a]		
PowerStep I	[kg/pe*a]		
PowerStep II	[kg/pe*a]		

The time frame of the subsequent diagrams is one year.

3.2. Potential Sewage Gas Generation in Europe

Figure 19 shows the sewage gas generation in Europe for the status quo, the benchmark, PowerStep I, and PowerStep II for medium and large sized WWTP. The status quo uses the sewage gas production data provided by Eurostat and caps it at the benchmark level[13], generally overestimating the current production. With today's technology, 13.4 TWh primary energy are produced in Europe. An upgrade to the benchmark in every European MS leads to an increase of sewage gas production of 166% to 22.3 TWh of primary energy. With PowerStep I and PowerStep II, these numbers increase to 28.6 TWh and 35.9 TWh respectively.

Figure 20 differentiates between large and medium sized plants. Even though, large plants represent only a small fraction (<5%) of the total amount of WWTP, they provide the biggest share of sewage gas. Due to the different configuration of the respective PowerStep approaches (see D5.5), the increase between large and medium sized WWTP with respect to PowerStep II varies as well.

---

[12] CAPEX have been estimated for PowerStep II only

[13] Actually, the benchmark electricity level serves as the boundary value the sewage gas production can reach. However, this value (45 kWh/Pe/a) differs from the benchmark sewage gas production value (42 kWh/PE/a for a large plant and 41 kWh/PE/a for a medium sized plant). This difference is quite small and has not been adjusted also accounting for the fact, that data availability on sewage gas production on the plant level is not available on the European level.

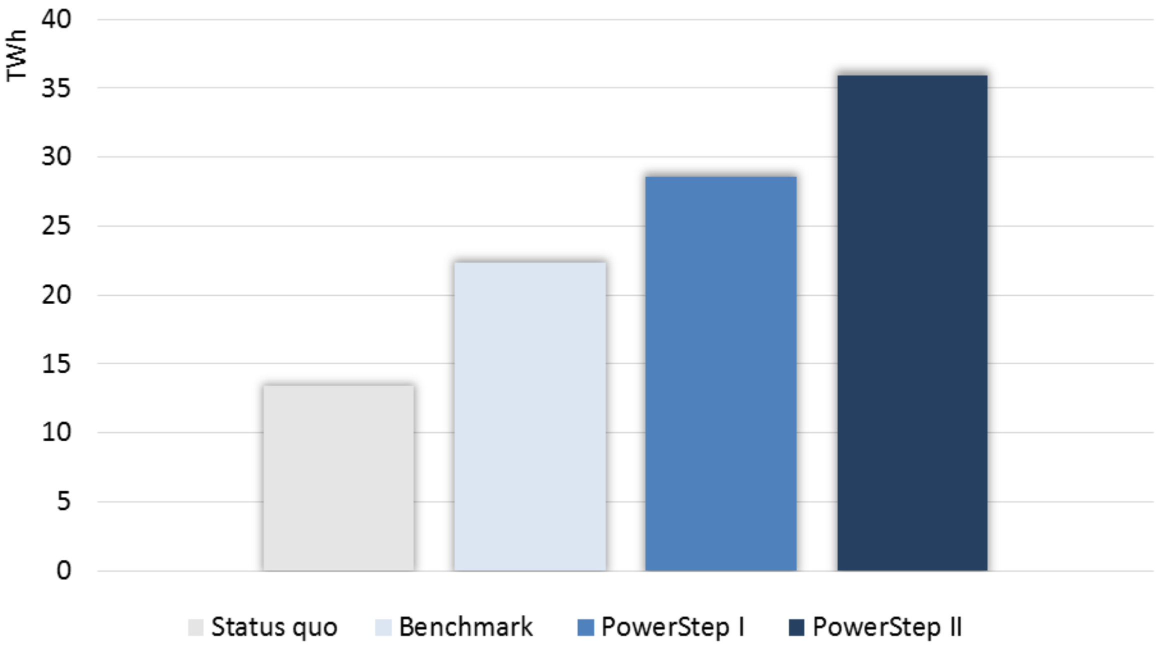


Figure 19: Annual sewage gas generation in Europe for the status quo, the benchmark, PowerStep I, and PowerStep II for medium and large sized WWTP

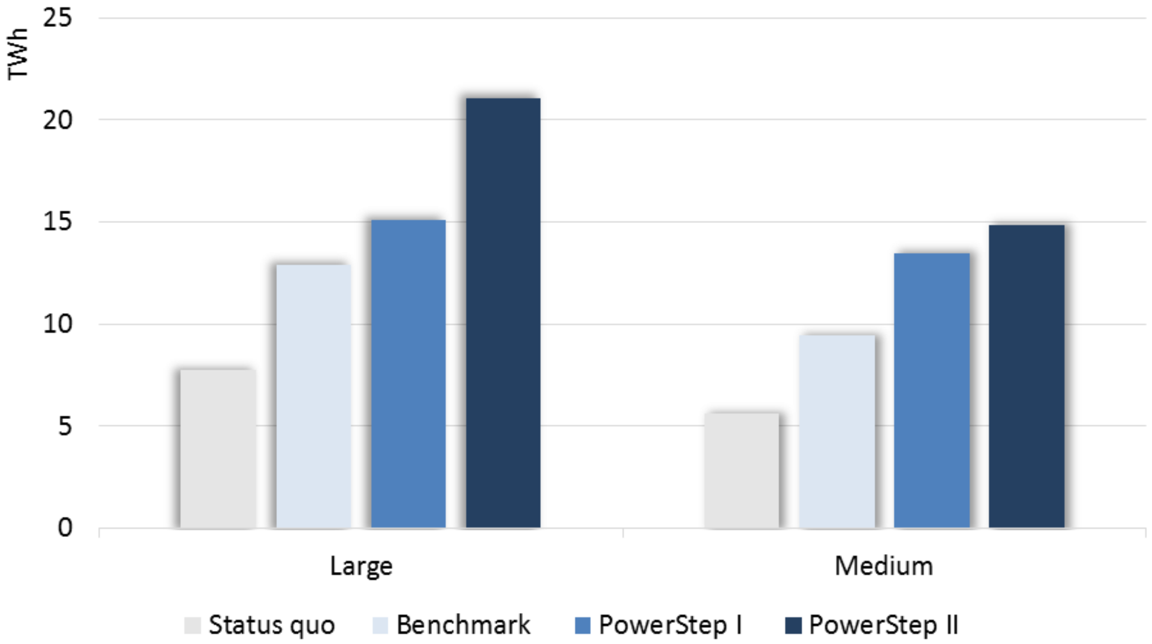


Figure 20: Annual sewage gas generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II

The PowerStep potential differs from MS to MS. Figure 21 shows that in Germany and the UK, a switch from the status quo would result in less TWh of sewage gas generated due to the overestimation (co-substrates and industrial sewage sludge) of the status quo compared with the benchmark. Figure 21 also shows that the overall potential of PowerStep is bigger in France, Spain and Italy than in Germany or the UK because of

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

the small share of sewage gas with respect to the status quo. Table 14 compares the status quo with PowerStep II and shows that the MS France, Italy and Spain have a potential of more than 3 TWh while Germany only reaches 2.2 TWh and the UK only 1.4 TWh. This also means, that with respect to energy related issues on WWTP, Germany and the UK operate at a higher level and improvements result in less gains than in France, Italy or Spain. The same effect occurs when comparing Sweden and Romania that share a quite similar sewage gas generation of PowerStep II, however, the impact in Romania (with barely any sewage gas generation) is three times higher than the impact of PowerStep in Sweden.

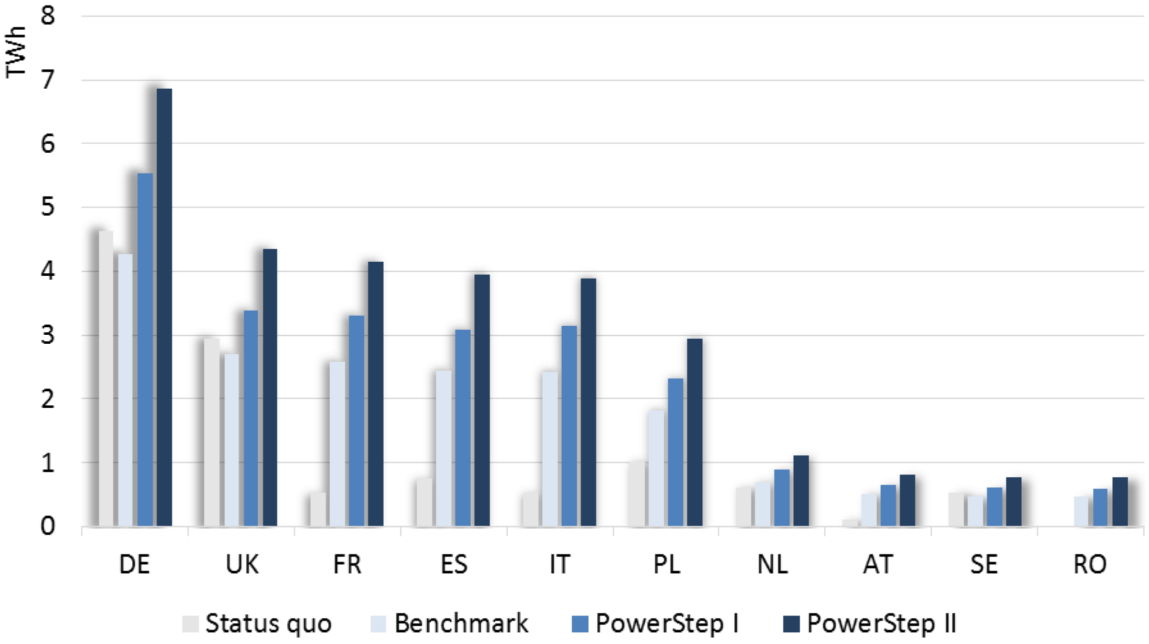


Figure 21: Annual sewage gas generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II with respect to different MS (top 10)

Table 14: Additional annual sewage gas generation with PowerStep technology compared to the status quo (top 10 MS).

Member State	Potential in TWh primary energy
FR	3.61
IT	3.35
ES	3.20
DE	2.22
PL	1.92
UK	1.41
RO	0.77
AT	0.71
NL	0.50
SE	0.25

3.3. Potential of Net Electricity Production in Europe

The generation of sewage gas serves as a proxy for electricity generation on WWTP using a conversion efficiency of 35%, which is a standard value for today's combined heat and power plants.

Data on electricity consumption of WWTP is scarce on the European level. Therefore, electricity consumption data from German WWTP multiplied with the WWTP specific connected PE result in the WWTP specific consumption in Europe. This means, there is a difference between large and medium sized plants but not between MS. Again, due to its fulfillment of the WWTP, Germany's WWT seems as a suitable representative.

Figure 22 shows the net electricity production in Europe comparing the status quo, the benchmark, PowerStep I (energy neutral) and PowerStep II to each other. Currently, WWTP in Europe has a net demand of more than 8 TWh of electricity, which consists of an electricity demand of more than 17 TWh (Figure 26) and an electricity generation of about 5 TWh (Figure 24).

The gap between the status quo and the benchmark is significant. Figure 22 states that around 10 TWh of electricity could be saved if WWTPs are upgraded to meet benchmark requirements. Again, the status quo overestimates the current electricity generation and underestimates the current electricity demand resulting in an even higher benefit by upgrading. An upgrade to PowerStep I would yield an additional 2.5 TWh compared to the benchmark and an upgrade to PowerStep II would lead to a net electricity production in Europe of more than 4 TWh.

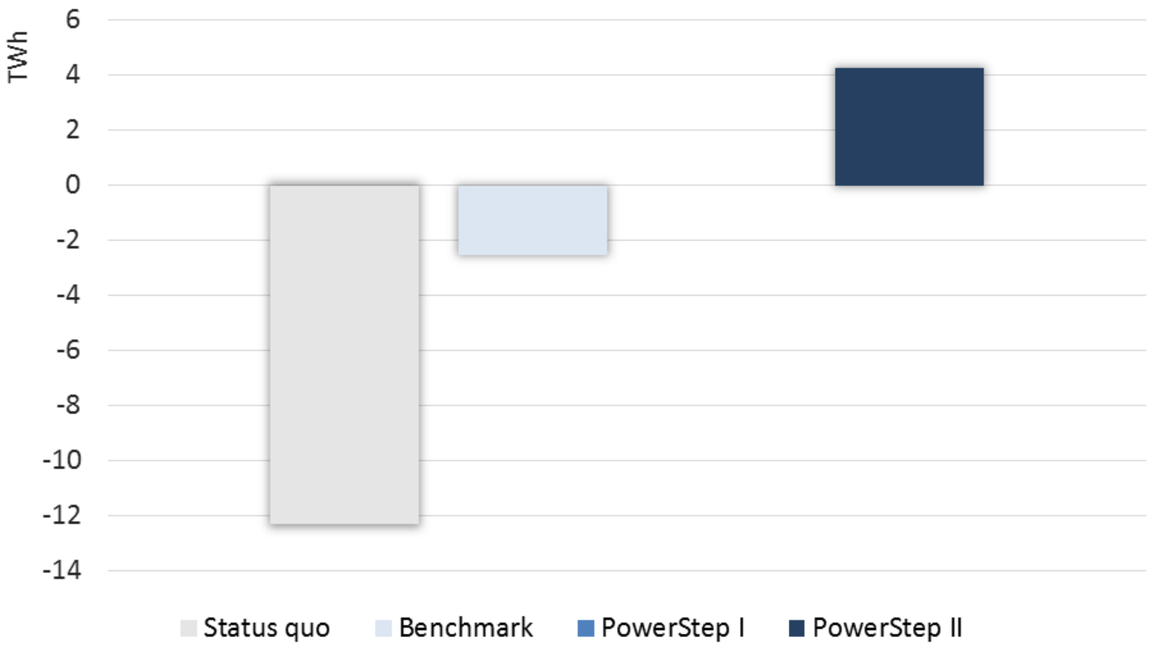


Figure 22: Annual net electricity generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II for medium and large sized WWTP

Figure 23 shows the net electricity generation for European MS. Again, due to their small amount of sewage gas production, the potential in France, Italy and Spain is comparably higher than the potential in the UK or Germany. These MS already invested in digesters and produce electricity on the plant decreasing their net electricity demand.

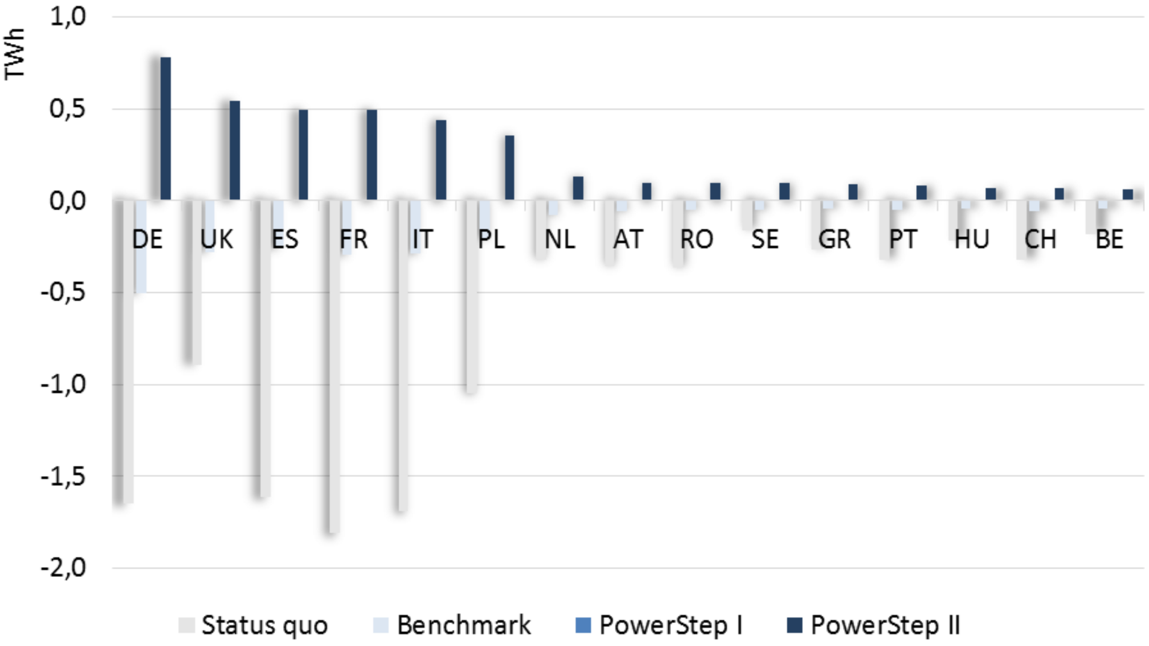


Figure 23: Annual net electricity generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II with respect to different MS (top 15)

The net electricity generation combines both effects energy efficient wastewater treatment provide – a reduced energy demand and an increased energy production. Figure 24 shows that switching to PowerStep II technologies increases the electricity generation by 266% yielding more than 13 TWh of electricity generated.

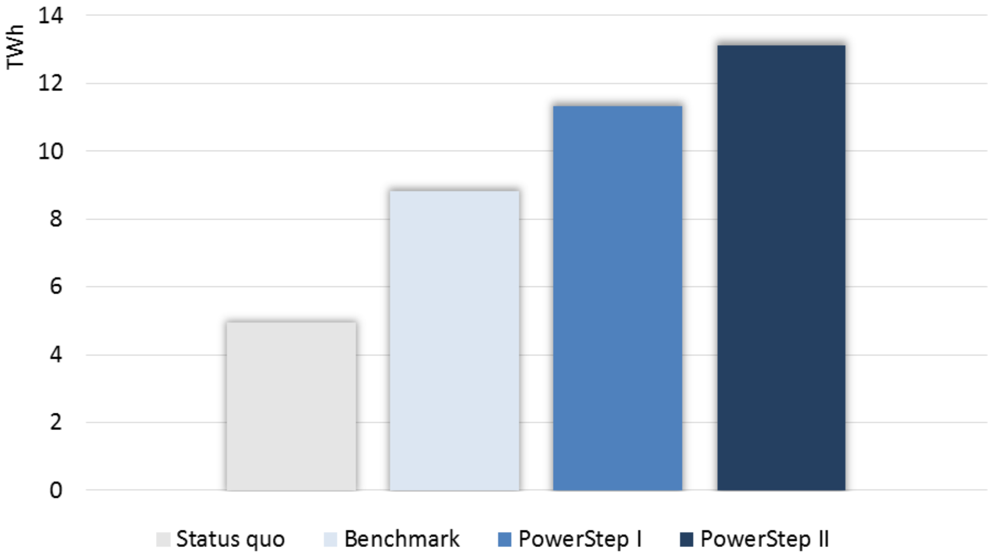


Figure 24: Annual electricity generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II for medium and large sized WWTP

The electricity generation also depends on the WWTP scale. First, Figure 25 shows that large WWTP generate more electricity than medium WWTP. Second, it increases even further with the implementation of PowerStep II technology leading to an increase of 285% for large WWTP and 239% for medium WWTP. With respect to electricity generation, PowerStep II technology has the biggest impact on large WWTP.

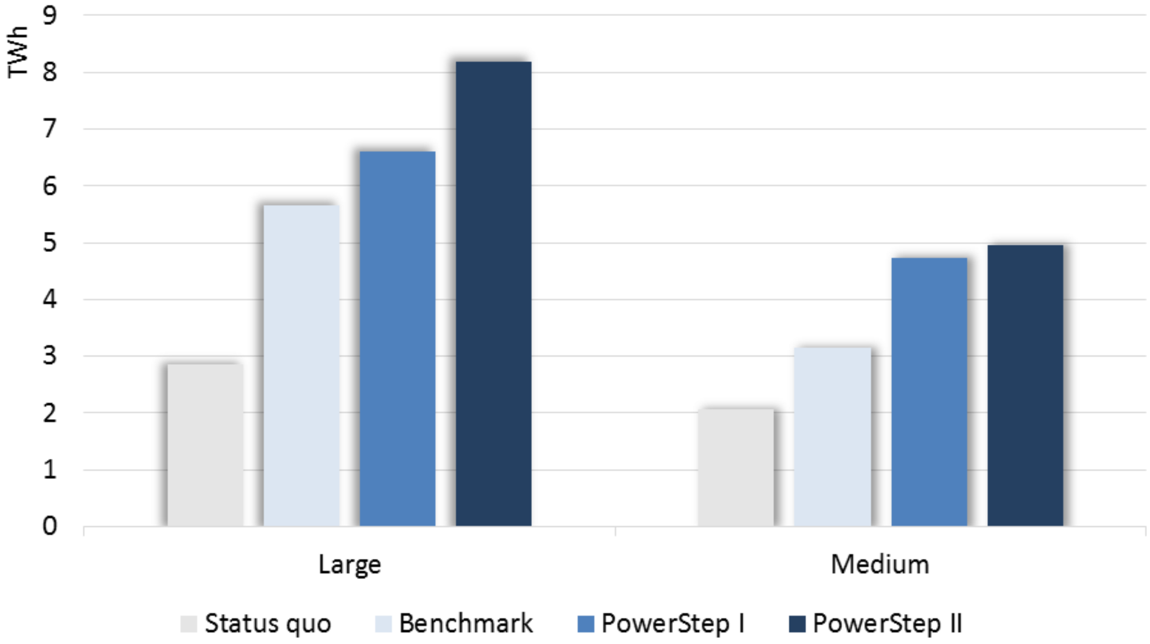


Figure 25: Annual electricity generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II

Figure 26 deals with the electricity demand of European WWTP. Compared to the electricity generation, the demand has a quite similar overall savings potential resulting in more than 8 TWh difference between the status quo and PowerStep II. Upgrading WWTP to the benchmark leads to a decrease of almost 6 TWh.

Again, the electricity savings differ from large to medium plants (Figure 27).

Due to the missing data on the European level the current status is represented by German values possibly decreasing both the actual amount of savings and the electricity demand of the status quo.

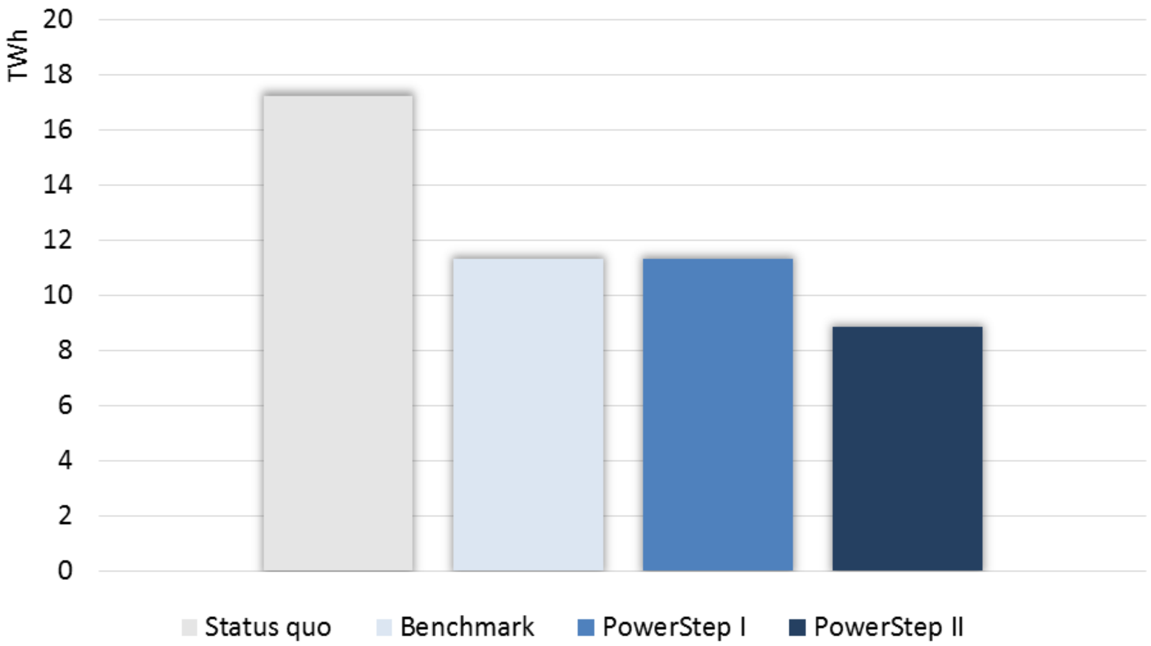


Figure 26: Annual electricity demand in Europe for the status quo, the benchmark, PowerStep I and PowerStep II for medium and large sized WWTP

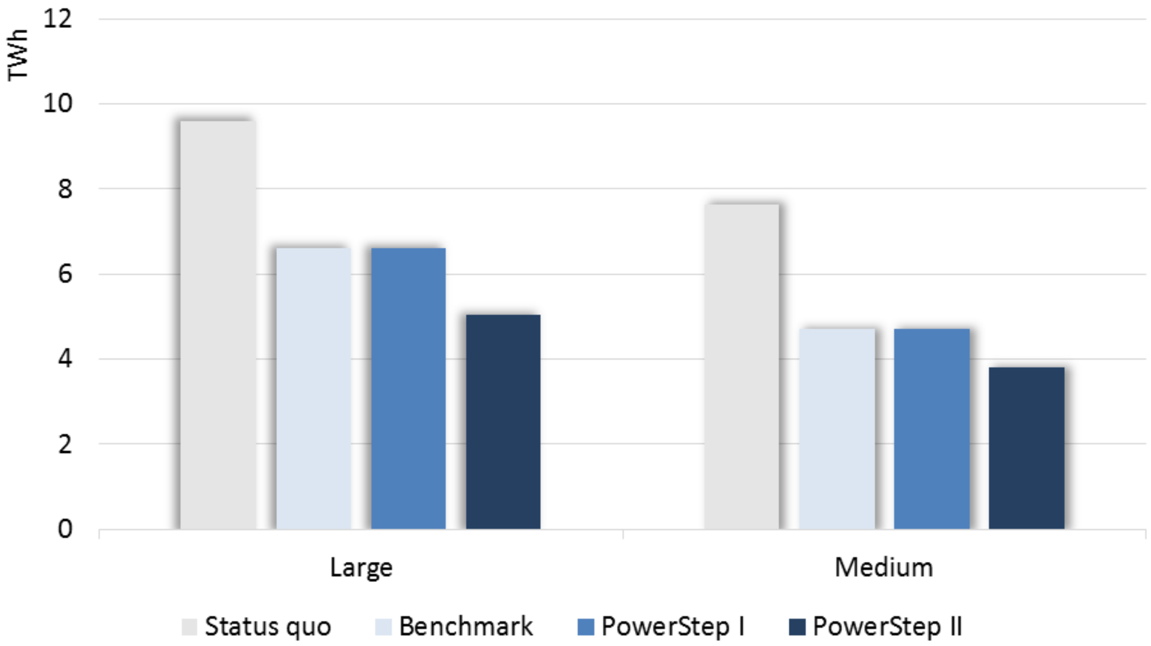


Figure 27: Annual electricity demand in Europe for the status quo, the benchmark, PowerStep I and PowerStep II

3.4. Potential Heat Generation in Europe

After sewage gas as the primary energy source and electricity, heat is the third form of energy WWTP provide within the boundaries of the PowerStep project. Traditionally, exporting heat has not played a major role in most European countries. This has several reasons ranging from a generally low demand for heat (southern Europe) to non-existing heat networks (Germany) and strong fossil competitors (Poland). Therefore, WWTP in central and southern Europe need additional structures (including on plant management systems) if they want to provide heat. PowerStep focused only on the excess heat that is created when generating more electricity also taking the additional heat for sludge treatment into account (insulation or different sludge heating processes have not been part of the analysis). Figure 28 shows that the heat generation increases by 2 TWh when investing in PowerStep II technology. PowerStep I and the benchmark also increase the heat generation leading to a heat surplus.

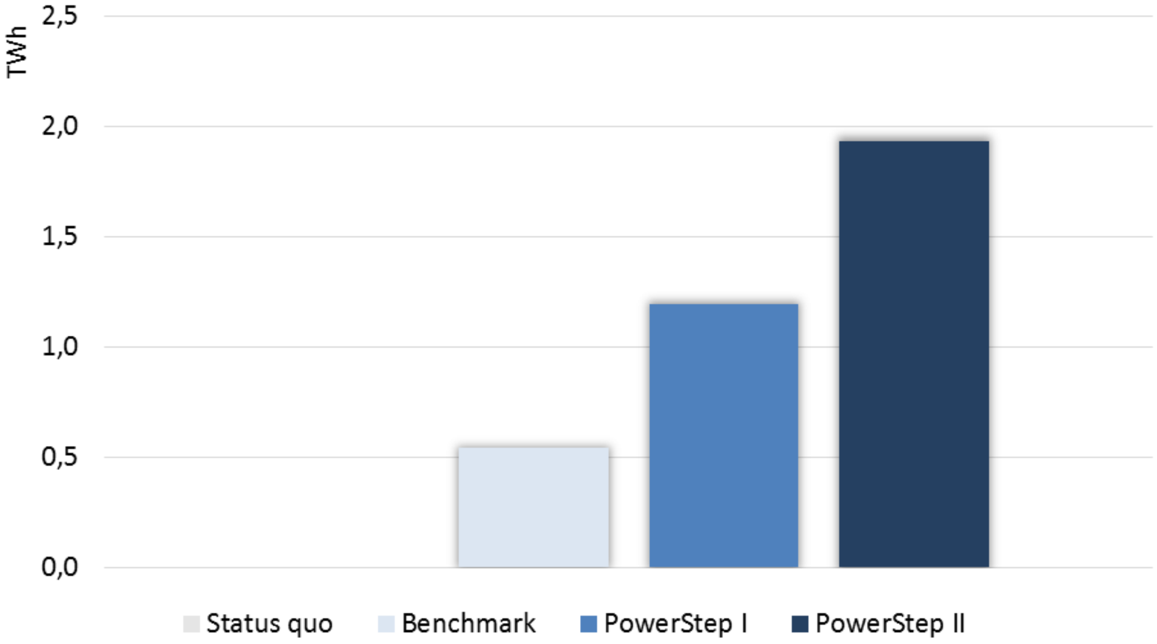


Figure 28: Annual heat generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II

Heat may only play a minor role in southern European states, but in some northern European MS, providing heat is one of the key elements with respect to energy generation on WWTP. Figure 29 shows several northern European states and the respective heat generation. The increase is rather small, however, existing networks and the demand for heat could provide effective drivers to increase heat production on WWTP.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

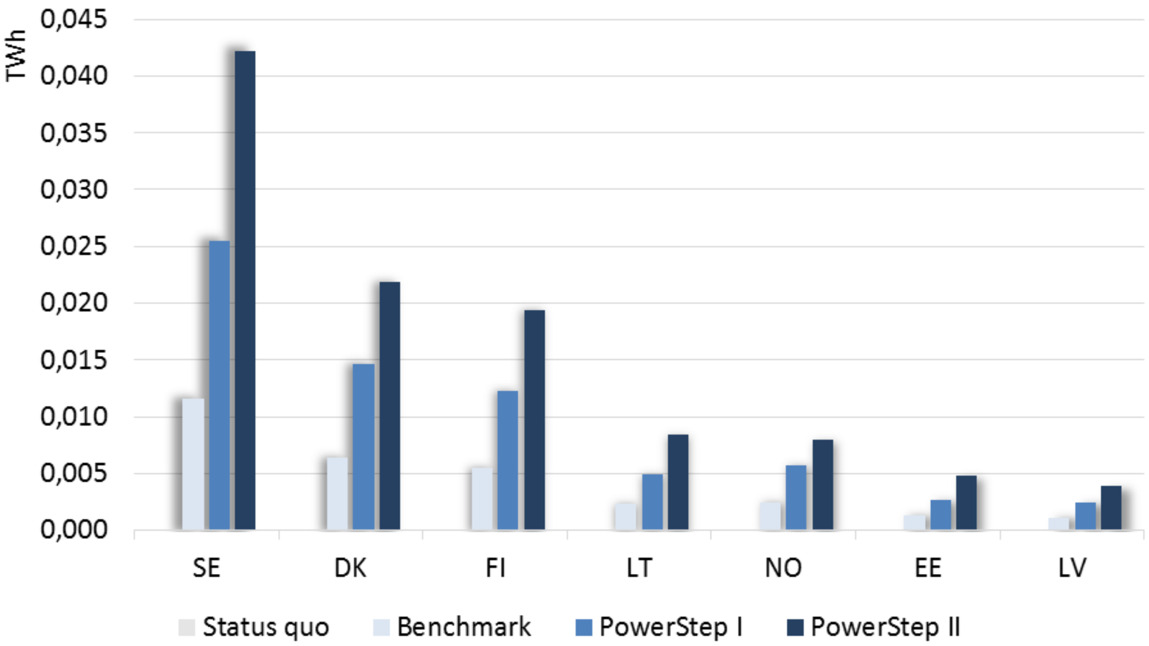


Figure 29: Annual heat generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II with respect to selected northern European states

3.5. Potential Operational Expenditures (OPEX) Reduction in Europe

OPEX are one of the key criteria for investment and especially for investment in innovative technologies (Tauchmann 2006). Even though, the capital expenditures (CAPEX) play a huge role in WWT due to their additional, unwanted effects like technological lock-ins and long payback times, technologies with lower OPEX compensate for higher CAPEX relatively fast. In addition, reduced OPEX are compensating for other increasing costs (e.g. electricity prices).

Figure 30 shows the OPEX of the status quo, the benchmark, PowerStep I and PowerStep II for medium and large sized WWTP. First of all, WWT in Europe costs more than 8.5 Billion Euros annually. An investment in the benchmark or PowerStep I decreases the OPEX to 7 Billion Euros, a reduction of almost 20%. This reduction reaches almost 25% when investing in PowerStep II technology, which costs around 6.5 Billion Euros a year.

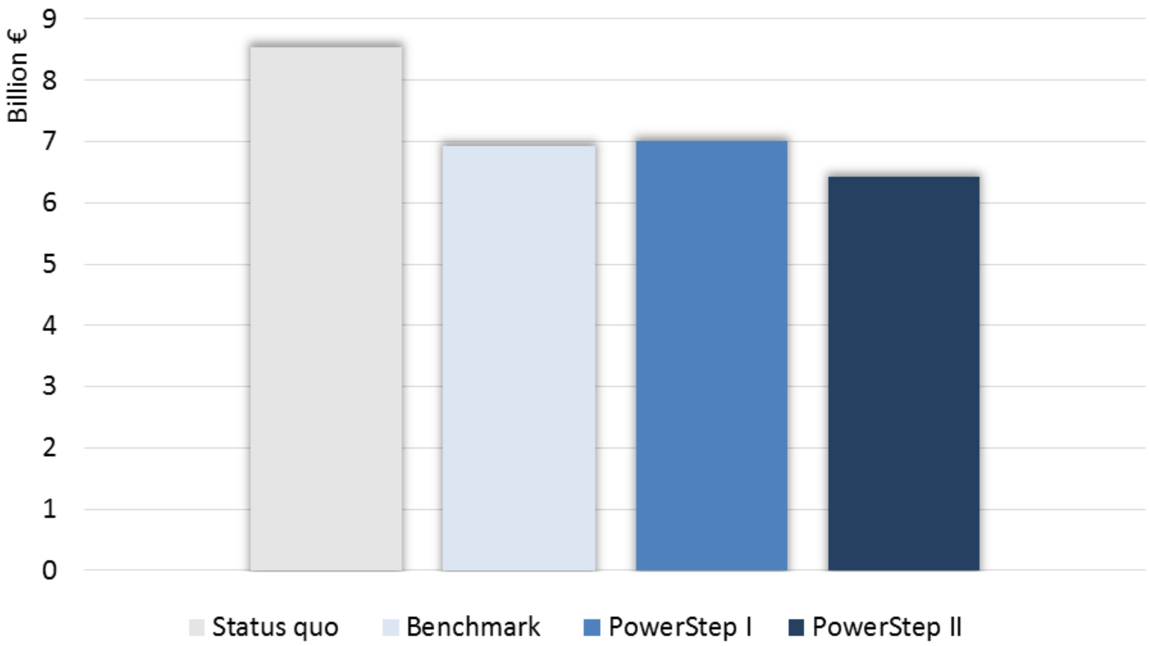


Figure 30: Annual OPEX in Europe for the status quo, the benchmark, PowerStep I and PowerStep II for medium and large sized WWTP

Again, large WWTP contribute more to the decreasing OPEX (Figure 31) than medium WWTP. Especially with respect to PowerStep II, the OPEX difference to the benchmark and PowerStep I is higher on large WWTP than on medium WWTP.

According to the analysis performed by Christian Remy, the OPEX are largely dependent on electricity prices in the various member states and therefore MS with high electricity costs decrease the OPEX for WWT more than MS with low electricity costs (for a cost overview, see section Energy Prices per Country). Figure 32 shows that OPEX for WWT are significantly higher in Germany than in Italy, France, the UK, Spain and Poland. Compared with France, the UK and Spain, Italy shows an additional OPEX saving potential by investing in PowerStep and benchmark technology.

These outcomes add another layer to decision making processes. In Germany, the electricity gains (status quo – PowerStep II) are smaller than the gains in Italy, France or Spain; however, high electricity prices yield higher OPEX reductions and therefore increase the cost saving potential of PowerStep.

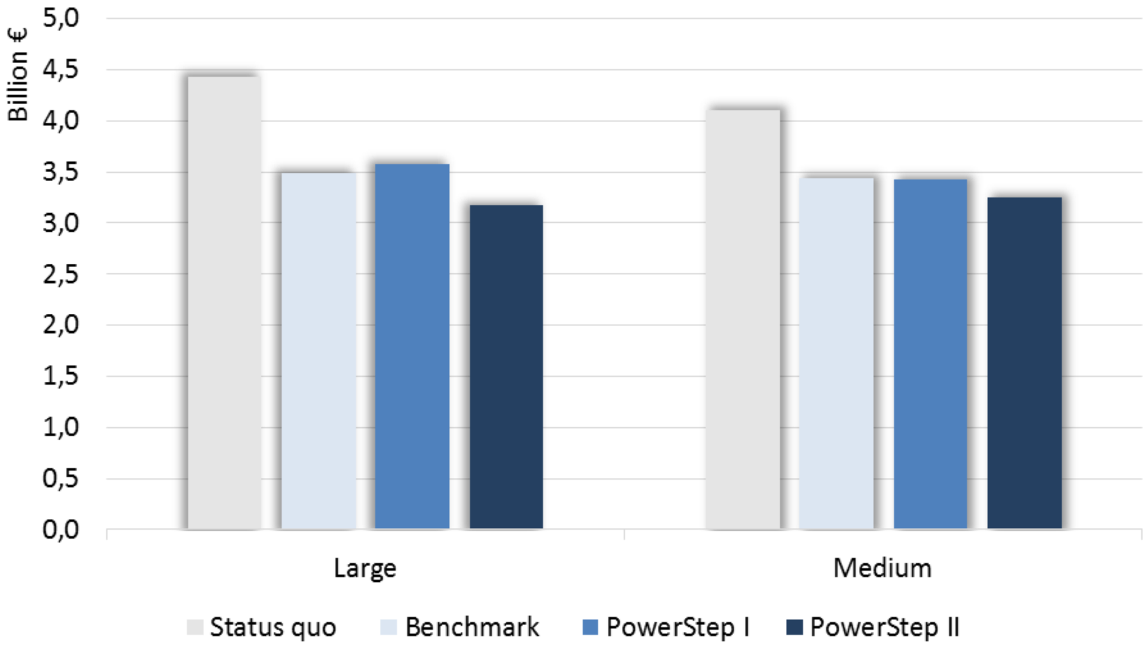


Figure 31: Annual OPEX in Europe for the status quo, the benchmark, PowerStep I and PowerStep II

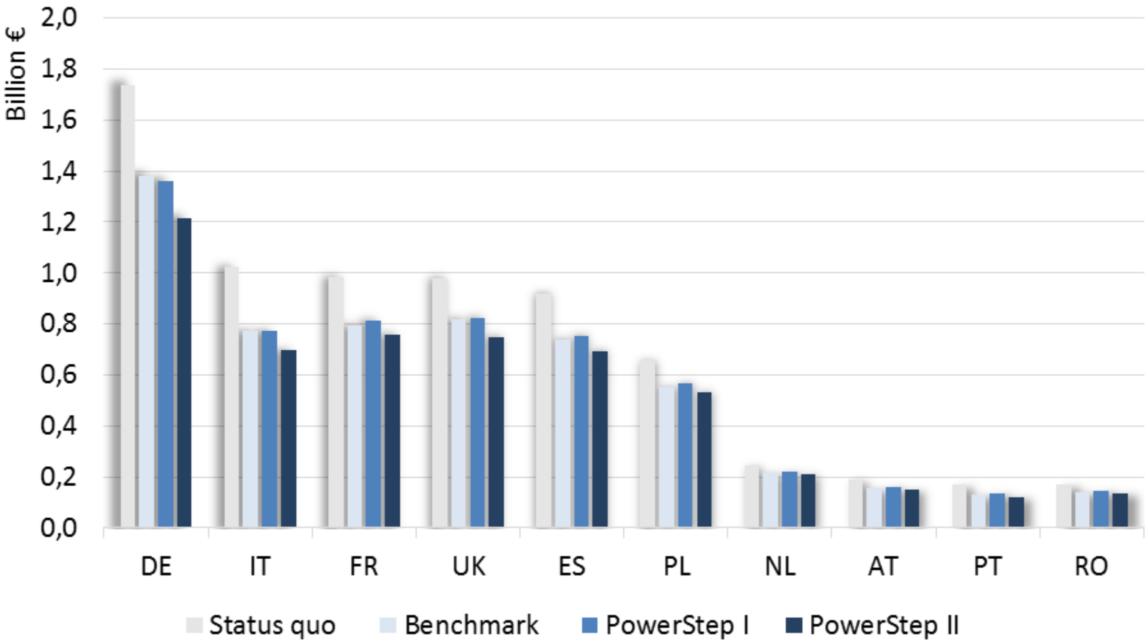


Figure 32: Annual OPEX in Europe for the status quo, the benchmark, PowerStep I and PowerStep II with respect to different MS (top 10)

3.6. Potential Capital Expenditures (CAPEX) Reduction in Europe

Figure 33 provides data on CAPEX in Europe for the benchmark and PowerStep II for medium and large sized WWTP. There is no data available for both the status quo and PowerStep I and the numbers in Figure 33 should be regarded as an educated guess.

Additionally, this data relates to the greenfield construction of a new WWTP; however, most European MS are retrofitting existing plants and might experience different annual costs.

Nevertheless, the CAPEX for WWT in Europe amount to around 6 Billion Euros per a and the annual CAPEX of PowerStep II are slightly above the benchmark values. Considering the fact, that PowerStep II requires totally new technology, further cost decreases are probable.

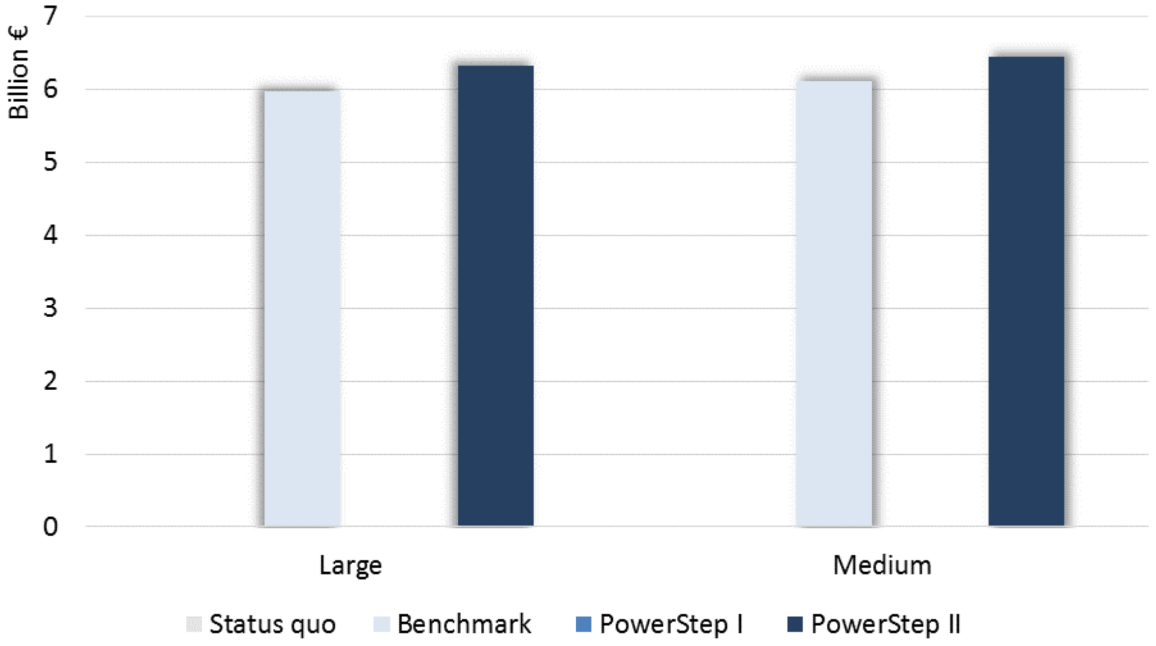


Figure 33: Annual CAPEX in Europe for the benchmark and PowerStep II for medium and large sized WWTP

Figure 34 shows the annual CAPEX expenditure that should serve as a proxy for the investment volume. Compared to the available data from Germany (see Table 4 in Part One of this assessment), the values in Figure 34 seem to be slightly higher than the upper investment bound estimates. This overestimation is likely since the CAPEX in Figure 34 consider the construction of state of the art WWTP with advanced technologies compared to the status quo technology in the first part of this analysis.

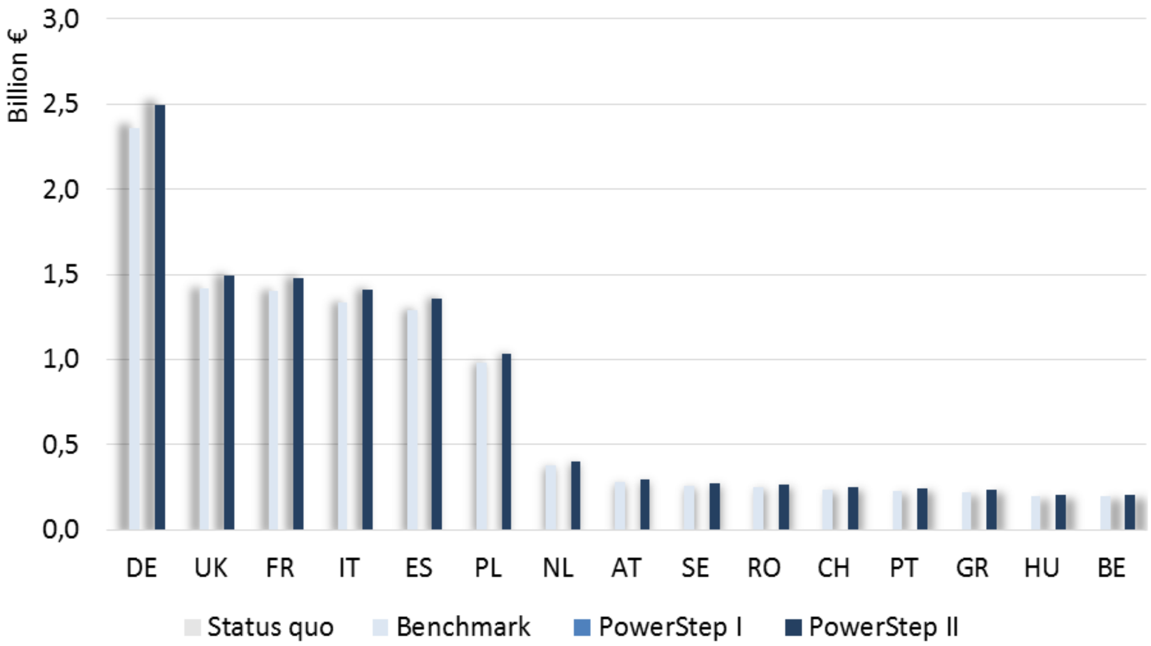


Figure 34: Annual CAPEX in Europe for the status quo, the benchmark, PowerStep I and PowerStep II with respect to different MS (top 15)

3.7. Potential CO_2-Equivalent Savings in Europe

The negative impacts of climate change are the main drivers for shifting our energy system to a more sustainable one, which focuses renewable energies in the different sectors. However, increasing the production of renewable energy might also relate to unintended negative consequences with respect to CO_2-Equivalent savings that occur if additional resources are necessary (e.g. chemicals) or if different processes take place (e.g. anammox) that have a higher CO_2-Equivalent emission than current technologies.

Currently, electricity is the major resource WWTP provide and hence, the CO_2-Equivalent of the national electricity mix is important for benefits of PowerStep. If PowerStep technology is used to generate heat or upgraded sewage gas usable in the transport sector, the replacement of fossil fuels in both sectors have a higher impact CO_2-Equivalent wise than the replacement of electricity with an already high share of renewable energy. Figure 35 shows that CO_2-Equivalent emissions are almost cut by 50% by investing in PowerStep II technology. Again, the benchmark already decreases CO_2-Equivalent emissions by around 6 Million Tons with PowerStep I emitting slightly more CO_2-Equivalent than the benchmark. Figure 36 shows that the impact is bigger on large WWTP than on medium sized WWTP

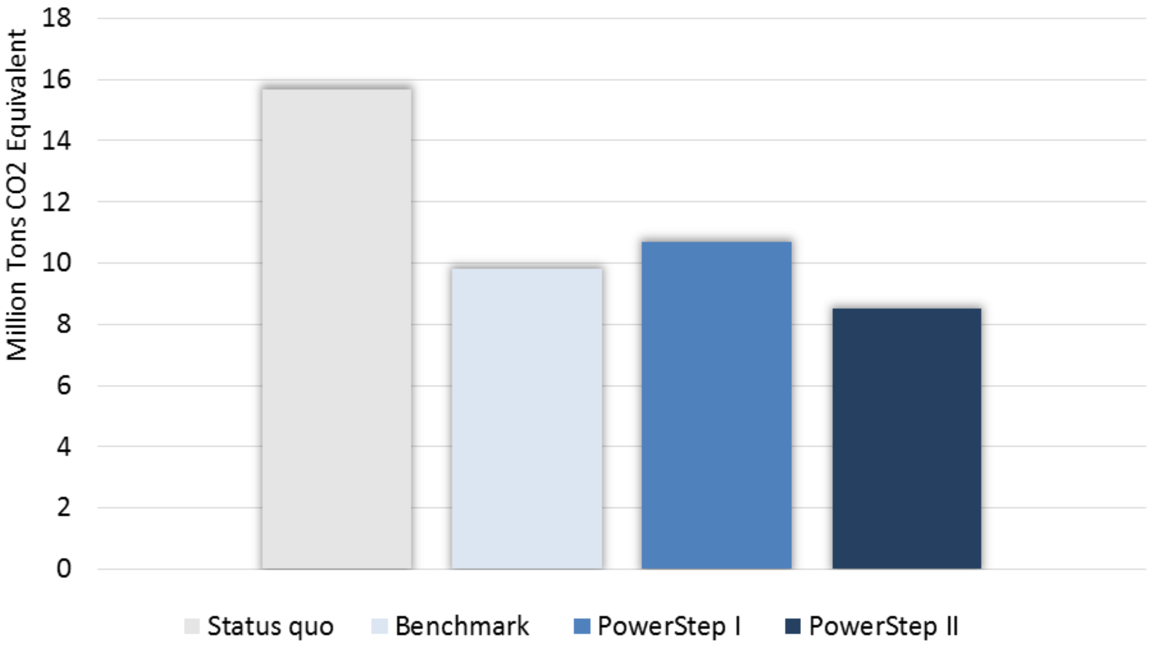


Figure 35: Annual CO_2-Equivalent savings in Europe for the status quo, the benchmark, PowerStep I and PowerStep II for medium and large sized WWTP

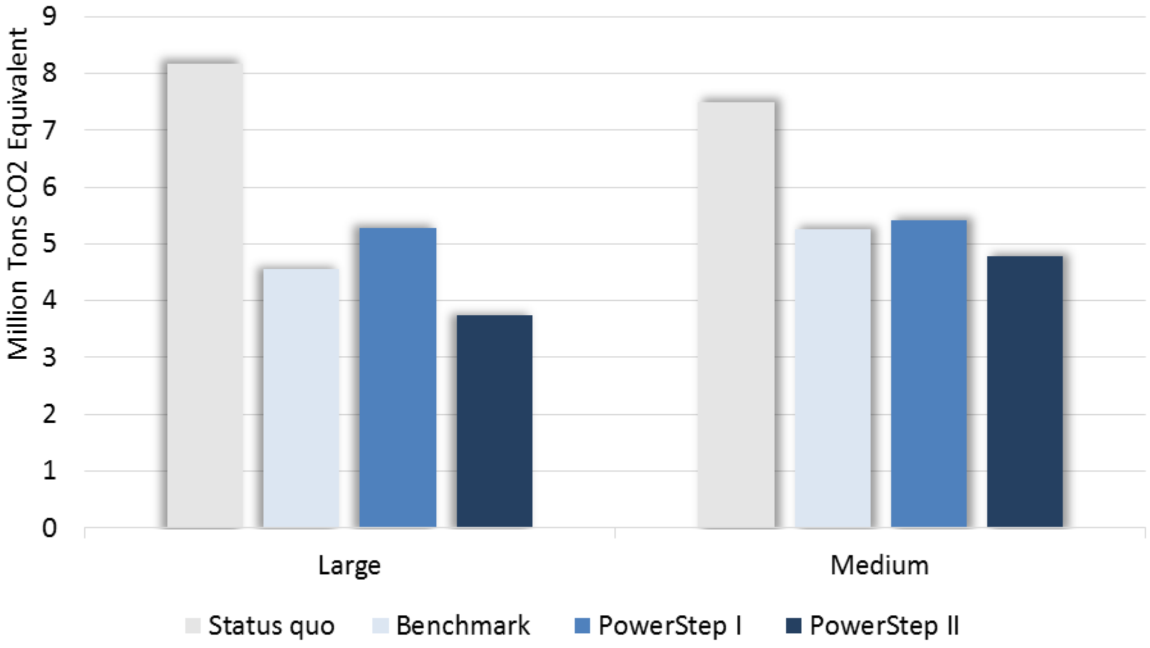


Figure 36: Annual CO_2-Equivalent savings of large and medium WWTP in Europe for the status quo, the benchmark, PowerStep I and PowerStep II

As stated earlier in this section, the CO_2-Equivalent composition of the electricity mix is pivotal for the assessment of CO_2-Equivalent saving potential by providing additional electricity on the plant level. Figure 37 reveals significant differences on the MS level. Germany decreases its CO_2-Equivalent emissions by almost 50% while France increases its emissions with an investment in PowerStep technology. This is largely due to the high amount of nuclear power in France's electricity mix and its corresponding low CO_2-

Equivalent emission electricity mix. This highlights another important issue: with additional renewables in the electricity mix, the CO_2-Equivalent savings provided by PowerStep decrease if electricity is replaced. This is obvious when looking at Austria, a MS with a very high share of renewable energies (see section Power Mix per MS).

Another very interesting MS is Poland with a low share of renewables within its electricity mix and a CO_2-Equivalent reduction by almost 75%. As with the OPEX, the CO_2-Equivalent savings add an additional layer to the decision making process. For example, in Germany the overall sewage gas production gains are comparably small, however, OPEX and CO_2-Equivalent savings are comparably higher. In France, sewage gas production is comparably high, OPEX savings are average and there are no CO_2-Equivalent savings using PowerStep technology. From the climate perspective, instead of electricity, other energy sources that include a higher share of fossil fuels should be substituted.

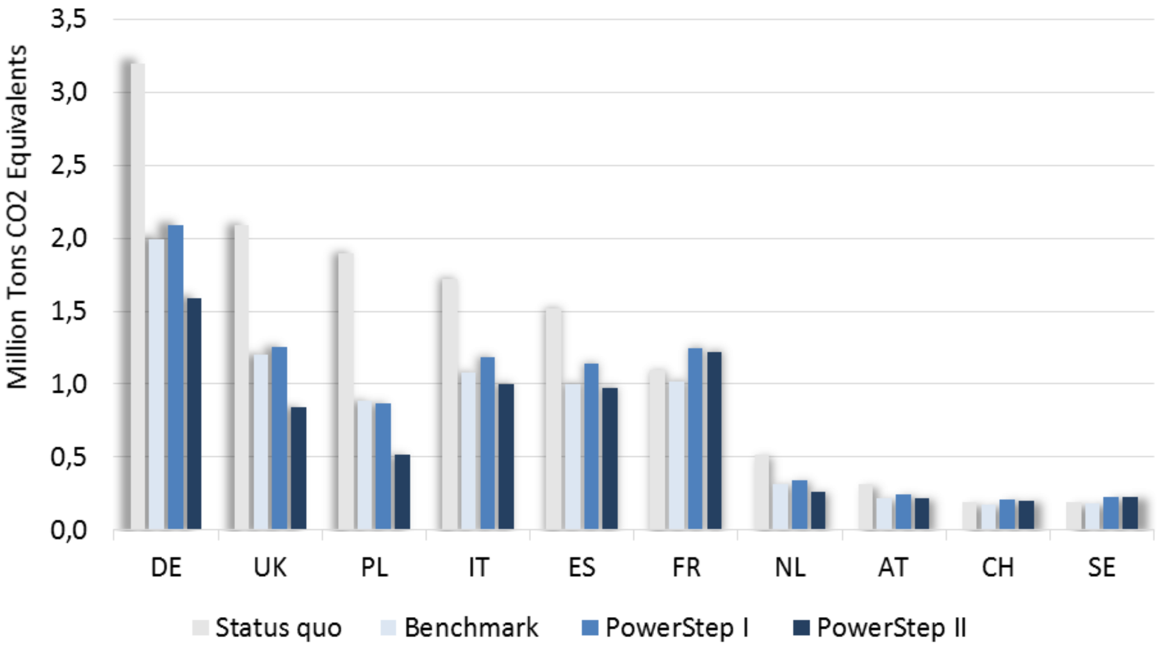


Figure 37: Annual CO_2-Equivalent savings in Europe for the status quo, the benchmark, PowerStep I and PowerStep II with respect to different MS (top 10)

4. Part Three: PowerStep's Impact on the Future - Cost of Inaction Study

In the United Nations Conference on Climate Change in Paris (COP 21) the world agreed upon reducing Greenhouse Gas (GHG) emissions to keep global warming below 2° Centigrade. In order to reach this goal, a drastic reduction (80-95%) of national GHG emissions will change our current way of living dramatically.

With the demanded reduction of at least 80%, keeping our lifestyle will largely depend on our capability to decouple economic growth and stability from the consumption of fossil fuels as primary sources of energy. This leaves two basic possibilities to reduce GHG emissions: first, reducing the consumption and second, substituting non-renewable fuels, heat and electricity with renewable energy sources (RES).

With his assessment of the economic effects of climate change (Stern 2011), Nicholas Stern laid out the foundation of cost of inaction (COI) as we use it within this analysis. This approach is not straight forward. The effects of wastewater treatment go beyond the emission of GHG and the COI study could include land use, possibilities for paradigm shifts in WWT as well as advanced wastewater treatment as a result of an energy surplus. However, uncertainty is high in these fields and an analytical framework to assess effects is either missing or hard to apply with respect to WWT[14].

Most research in this cost related issue and the monetarization of environmental effects has been done in the field of climate change and GHG emission reduction and this analysis also focuses explicitly on GHG emissions. The results of the market analysis in part two provide the base for the COI study.

4.1. Assessment of GHG Saving Potential using PowerStep Results

PowerStep contributes to the reduction of GHG through the additional generation of the renewable energy sewage gas. At the present, combined heat and power plants (CHP) combust the sewage gas for electricity generation and use the electricity on the WWTP. This means that, currently PowerStep substitutes the member state (MS) specific electricity mix and has a different impact on the GHG emissions of each MS.

Compared with standard WWT, PowerStep demands additional chemicals for WWT and emissions of the process itself might be higher due to the potential emission of GHG like N_2O (see deliverable 5.5 for further information) resulting in a possible negative impact of PowerStep with respect to GHG emissions.

Figure 35 shows that energy and process related GHG emissions of WWTP in Europe are slightly below 16 Million MG of CO_2-Equivalent on the European level. The process related GHG emissions from WWT include various stages including the emissions during the biological treatment stage (CO_2 and N_2O and other), the CHP exhaust gas, the sludge transport and the mono incineration of the sludge. PowerStep II cuts GHG emissions by almost 50% and PowerStep by more than a third. However, it also becomes obvious that the benchmark leads to a GHG emission reduction that is slightly

---

[14] Even though the Water Framework directive includes resource costs, a framework to assess and monetarize these effects is still missing. This is also due to the basic philosophical questions that remain unanswered. See Gawel, E. (2014). "Zur Berücksichtigung von Umwelt- und Ressourcenkosten nach Art. 9 der EG-Wasserrahmenrichtlinie." UFZ Discussion Papers(1/2014). for further information.

lower than PowerStep I and 2 Million MG of CO_2-Equivalent higher than PowerStep II on the European scale.

A look at the MS specific savings in Figure 37 reveals that the GHG emission saving potential differs significantly from MS to MS. France, with a large share of nuclear power increases its GHG emissions with a switch to PowerStep technology due to the small GHG emissions of the French electricity mix. Austria, a MS with a high share of renewable energy (see deliverable 5.3) improves its GHG emissions only slightly compared to the major GHG emission savings in Poland, a MS with a high share of fossil fuels.

With a focus on climate change, the main results of Figure 37 are:

- The GHG emission saving potential differs significantly from MS to MS
- MS with a high share of renewable energy in the electricity mix decrease their GHG emissions only slightly
- MS with a low GHG emission electricity mix increase their GHG emissions using PowerStep technology
- MS with a high share of fossil fuels in the electricity mix decrease GHG emissions significantly
- The high share of renewable energy in the electricity sector (compared to the transport and heating and cooling sector) leads to small GHG emission savings (again, compared to the transport and heating and cooling sector)

4.2. General Information on Cost of Inaction Studies

The basic idea of COI studies is to compare the costs of an action in the present with the costs of an action that reaches similar goals in the future. The comparability of these two actions relates, among others, to:

- Available technology in the future
- Cost developments (e.g. discount rates)
- Impacts due to deterioration between the first action and the future action

With respect to climate change, outweighing the benefits of cost developments and new technologies (first and second bullet point) and the drawbacks of inaction (third bullet point) lead to several studies and different opinions about the time and magnitude of action.

William Nordhaus favoured increasing medium and long term reduction in his early studies in addition to modest near term reductions (compare with Harris, Roach et al. (2017)). Nicolas Stern on the other hand, recommends immediate action stating that “[..] the benefits of strong and early action far outweigh the economic costs of not acting.” (Stern 2011)

The impact due to deterioration have a high level of uncertainty, so do the cost development and the future technology analyses. Especially with respect to long time periods, uncertainty increases even further impeding the calculation of sound marginal abatement costs. Costs are directly related to investments and the value of a certain amount of money in the present has to be compared to investments made in the future. This cost projection is done with discount rates that try to assess the value of today's action in the future.

Figure 38 shows the investment cost projection to 2050 using different discount rates from 1% to 5%. With a discount rate of 1%, the investment value decreases by 27% to 727.000 Euros, with a discount rate of 5%, this changes to a decrease of 79% and a remaining value of 210.000 Euros. In this case, investing the 1.000.000 Euros to reach the goal in 2018 seems rather non-advisable compared to investing 210.000 Euros in 2050.

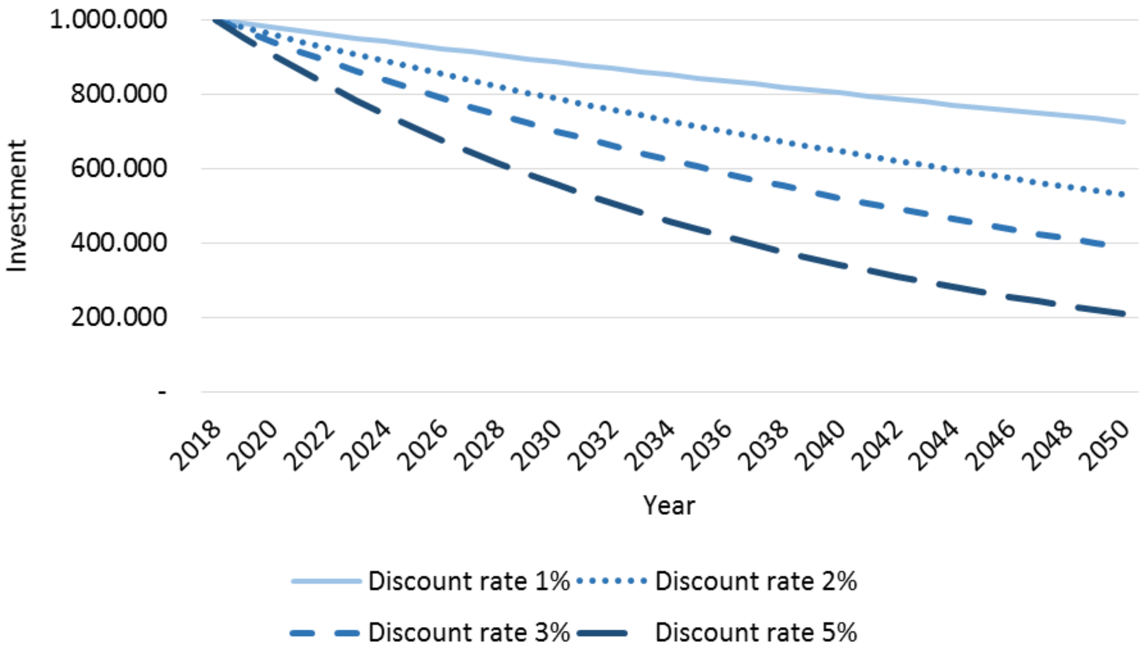


Figure 38: Investment cost projected to 2050 using different discount rates

In order to calculate the social costs of reducing GHG, both Nordhaus and Stern provide figures that range quiet differently, depending on the effects and the probability of climate related events. The lowest estimated value is 16 $/ton (~13€/ton) per MG of GHG and the highest estimated value almost 17 times the lowest value: 271 $/ton (~226€/ton) (Nordhaus (2017), Dietz and Stern (2015)). In addition, the discount rate is set to lay within 1.5% and 2.0%.

4.3. Cost of Inaction of PowerStep Technologies

The GHG emission savings of PowerStep are directly related to the MS electricity mix. If the share of renewable energy increases, GHG emission savings decrease and PowerStep produces more GHG emissions substituting electricity than a comparable benchmark WWTP (see Austria in Figure 37). This means that, from a climate perspective, investing in PowerStep technology and the substitution of electricity makes sense as long as the electricity mix has a high share of fossil fuels. When the share of fossil fuels reaches a low level, investing in PowerStep's substitution of electricity is worse than upgrading existing plants to benchmark values. For 2050, renewable energies reduce the GHG emission of the electricity sector to 0. With GHG emission free electricity, PowerStep is no longer reducing emissions compared with the benchmark, it produces 20% more.

Nevertheless, PowerStep's primary renewable energy source is sewage gas, which can be used for other purposes, not just electricity. With an explicit focus on electricity, investing in PowerStep technology is not the solution to reduce GHG emissions in the long term.

It becomes clear that due to the increased GHG emission of PowerStep compared with the benchmark technology, only a substitution of fossil fuels leads to an advantage of PowerStep technology.

Figure 39 shows the annual sewage gas generation in Europe for the status quo, the benchmark, PowerStep I and PowerStep II. Using PowerStep technology to produce electricity sector will not yield a GHG emission reduction.

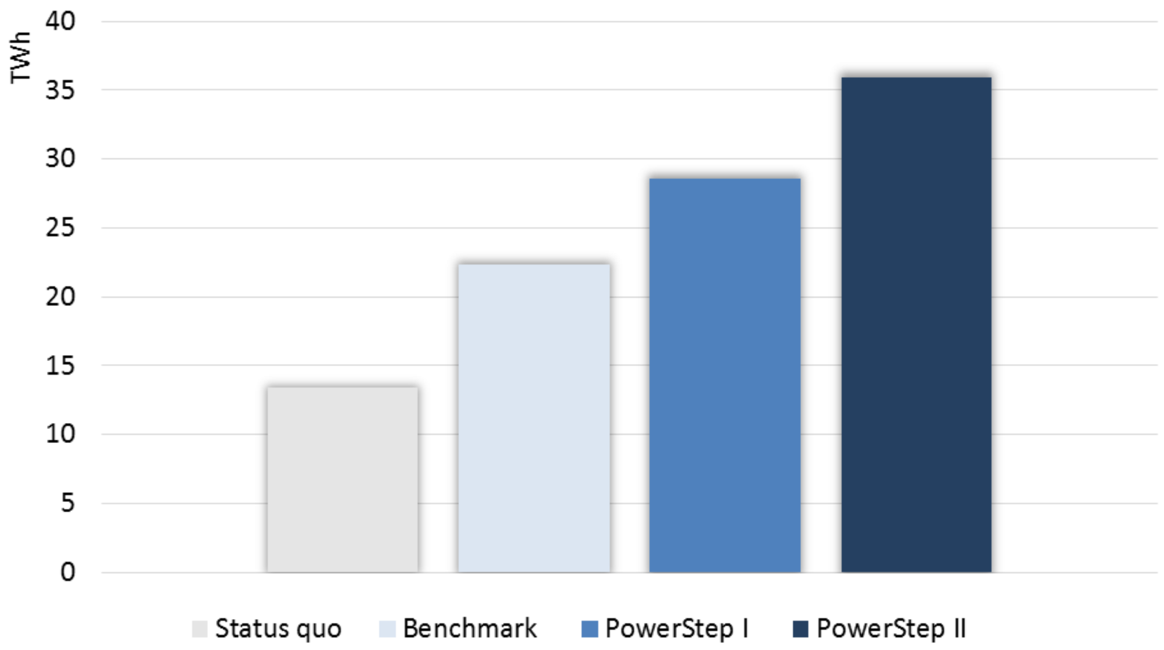


Figure 39: Market data - Annual sewage gas generation in Europe for the status quo, the benchmark, PowerStep I, and PowerStep II for medium and large sized WWTP

However, we proclaim that PowerStep technology will be used to replace fossil fuels and take natural gas for the sake of simplicity (e.g. natural gas in the transport sector). This leads to a reduction of GHG emissions of 19.4 Mio. MG without considering the increased GHG emission of PowerStep technology. This increase compared with Figure 35 is due to the substitution of 100% natural gas and no losses during the process. The necessary electricity for treating wastewater is 100% renewable. Again, this setup is purely fictional and does not represent current developments nor does it include the increased GHG emissions of PowerStep.

In the next step, we compare the costs of investing in PowerStep technology with the savings induced by reduced GHG emissions.

First, based on the capital expenditures (CAPEX) assessed in the market analysis we calculate a necessary investment that starts at around 255 Billion Euros and decreases to a range from 160 Billion Euros to 135 Billion Euros based on an expected write off time of 20 years. Figure 40 shows the decreasing investment costs due to the different discount rates.

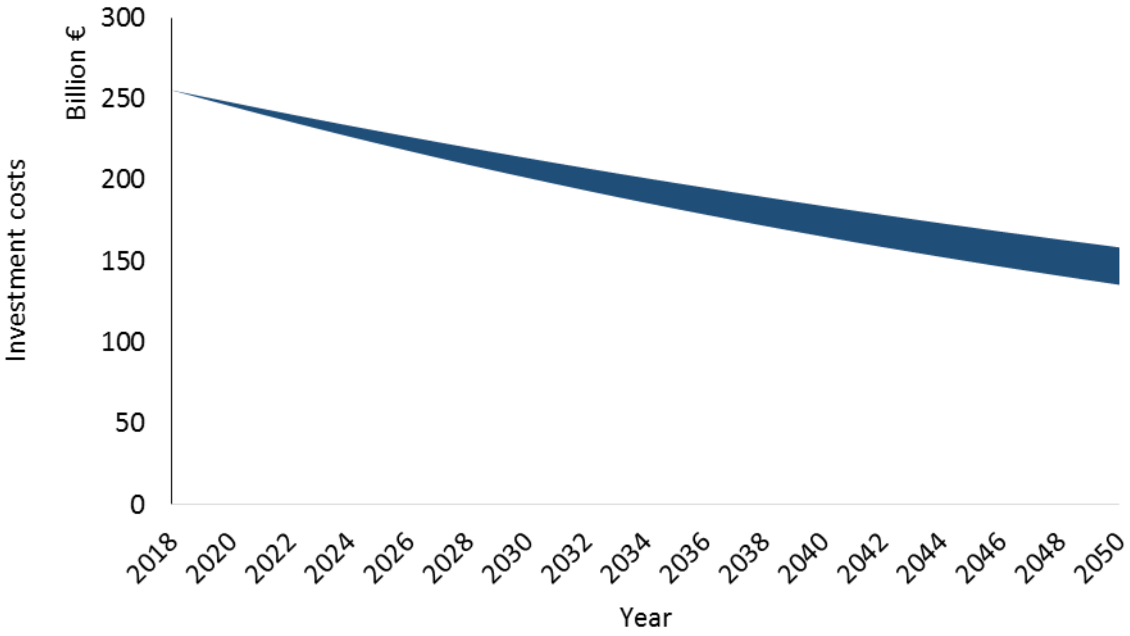


Figure 40: Investment costs with a discount rate between 1.5% and 2.0% until 2050

Second, the accumulated savings based on the year 2050 reach 8 Billion € to 145 Billion € depending on the CO_2 price elaborated above. This value decreases to 250 Million € and 4 Billion € respectively with the latest possible investment in 2050. Comparing the investment and cost savings in Figure 42 reveals, that an investment in PowerStep technology cannot be justified by cost savings due to GHG emission reduction. The total costs are significantly higher than the accumulated savings.

The project "Full scale demonstration of energy positive sewage treatment plant concepts towards market penetration" (POWERSTEP) has received funding under the European Union HORIZON 2020 – Innovation Actions - Grant agreement° 641661

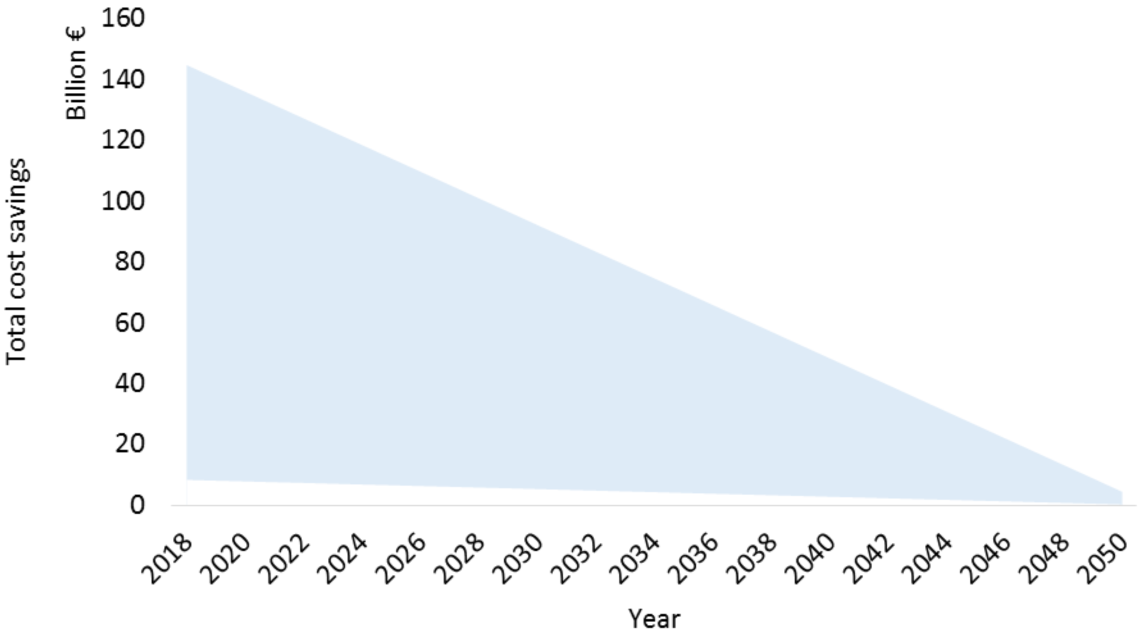


Figure 41: Accumulating cost savings of PowerStep technologies with 2050 as the reference year

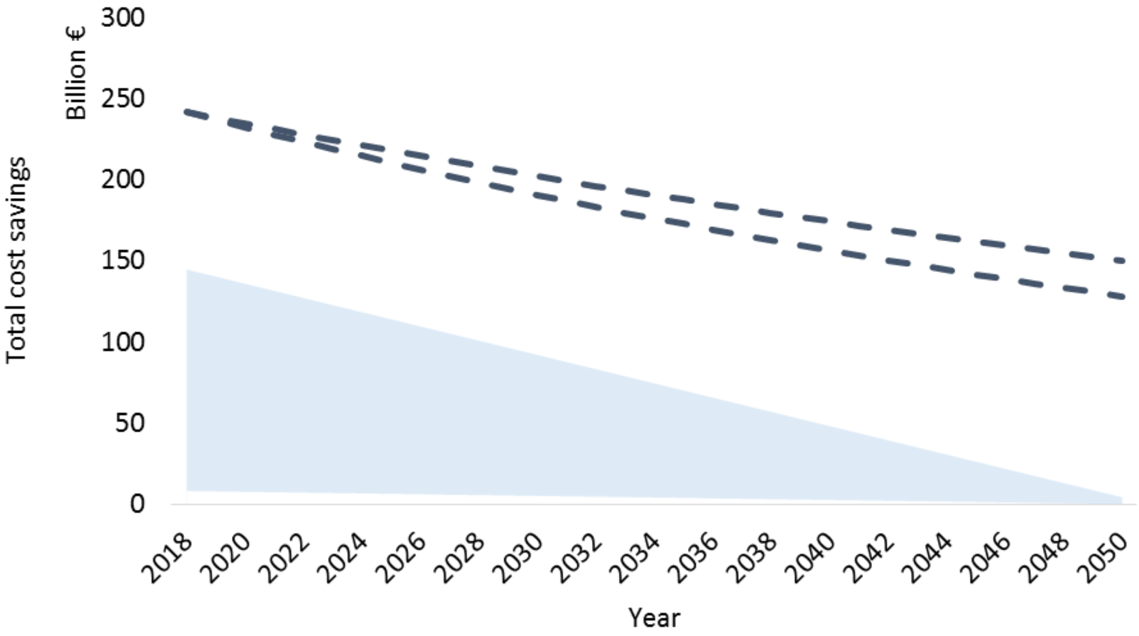


Figure 42: Comparison of total savings and additional investment costs for PowerStep technology (dotted line, with a discount rate of 1.5% and 2%)

However, WWTP's primary task is to treat wastewater - instead of focusing exclusively on the construction of WWTP with PowerStep technology with respect to GHG emission savings, we could focus on the difference between benchmark WWTPs and WWTPs with PowerStep technology. In order to do this, we have to further simplify the analysis and ignore different time related predicaments as well as additional effects of the operational expenditure (OPEX) changes between PowerStep and benchmark systems.

Therefore, we state that the transition between PowerStep and the benchmark is in 2018 and it does not have any additional effects on the cost structure leading to a necessary investment of 14 Billion Euros in 2018 that decreases to 7 Billion Euros/8 Billion Euros depending on the discount rate, which is also set to range between 1.5% and 2.0% (see Figure 43).

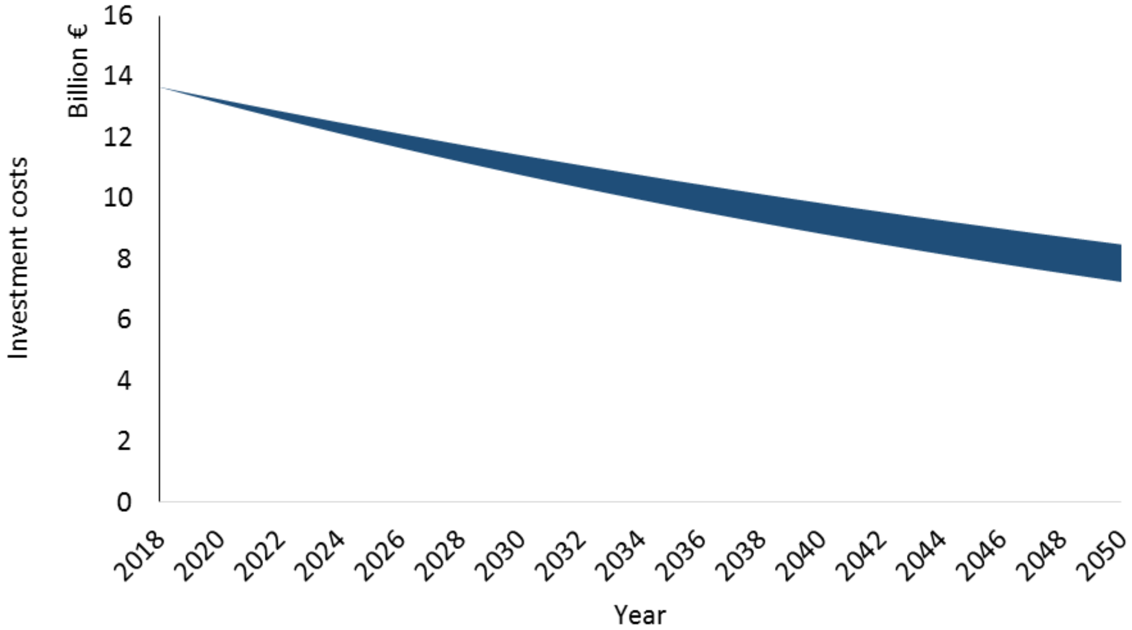


Figure 43: Investment costs with a discount rate between 1.5% and 2.0% until 2050 based on the cost difference between PowerStep II and the benchmark

Finally, Figure 44 compares the cost differences between the benchmark and PowerStep with the savings and reveals, that besides investing very late (the savings exceed the costs until 2048), an investment in PowerStep technology leads to a cost efficient reduction of GHG, as long as the substitute is 100% fossil fuel and the dotted investment cost line is lower than the total cost savings. This is true for the majority of CO_2 emission prices. In addition to that, very low CO_2 emission prices normally include a sharp price increase due to the decreasing amount of available permits. This effect has not been displayed in Figure 44.

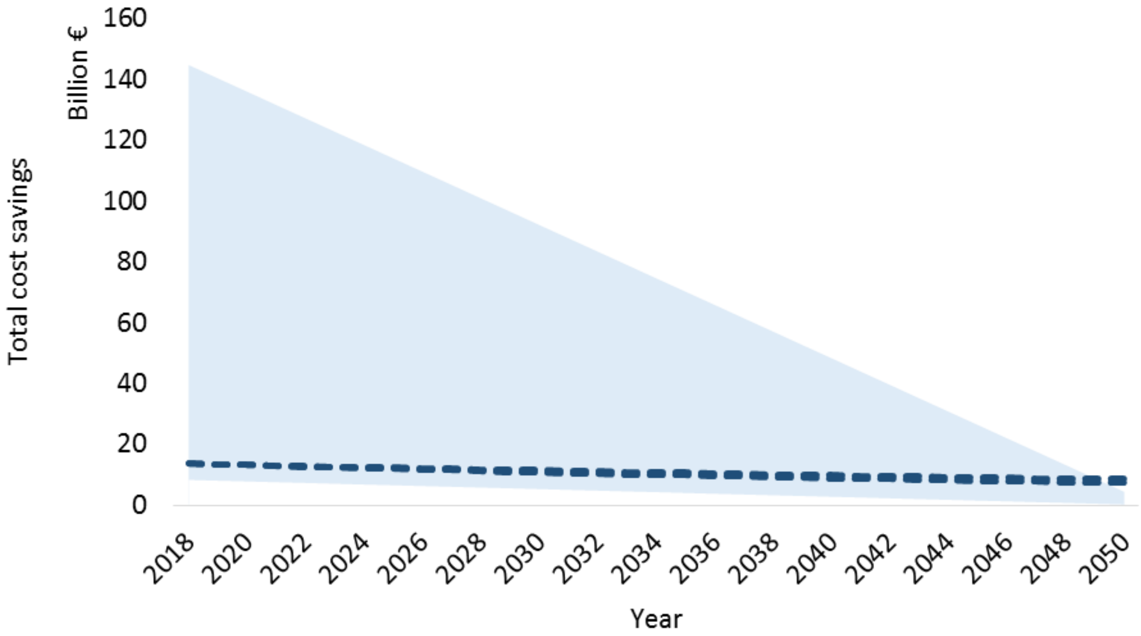


Figure 44: Comparison of total savings and additional investment costs for PowerStep technology (dotted line, with a discount rate of 1.5% and 2%)

As stated in previous sections, uncertainty is a central element of COI studies. This is also true for the COI of PowerStep technology. Without the numerous simplifications, an analysis would not be possible. However, this also influences the outcome:

- ○ The COI uses the complete substitution of fossil fuels with sewage gas instead of the currently predominant substitution of electricity. With an electricity mix with low GHG emissions, PowerStep produces more GHG emissions than the status quo or benchmark systems due to its increased emissions in the treatment process.
- ○ The GHG emissions of natural gas depends on a variety of parameter, due to the already high amount of uncertainty, varying these parameters would have added another layer of uncertainty without increasing the outcomes accuracy.
- ○ The investment in PowerStep technology in order to save GHG is not feasible. However, the upgrading and renovation of existing WWTP is a continuous process and we state that instead of investing in benchmark technologies, investments in PowerStep technologies could be possible. Due to the temporal differences that occur because of the different construction dates, renovation scheduling etc. we have to define a date, which is set to 2018.

The most important outcome of the COI is, that substituting renewable electricity with PowerStep does not lead to costs of inaction, it yields benefits due to the increased GHG emissions of the treatment process itself. Therefore, from a climate point of view, replacing renewable electricity cannot be a future goal of energy efficient WWTPs operating with PowerStep technology. The replacement of other sources that include a higher share of fossil fuels or fossil fuels itself like natural gas shows the full potential PowerStep has to offer and GHG emission savings outweigh the additional investment costs for all but the lowest CO_2 emission prices.

5. Conclusion

The first part of this deliverable describes the existing market and differences between the MS, the second part compares PowerStep with the status quo and the benchmark and the third part takes the results with respect to GHG emission savings and assesses the cost of inaction.

The European wastewater market is highly complex and the differences between MS are significant. Among those differences are the wastewater composition, the temperature, the need for further investment, cost recovery, organizational structures and a couple of energy related issues

The analysis of PowerStep and its potential impact on the European level shows significant savings on the one hand and probably very different approaches within the various MS on the other. With PowerStep II, the sewage gas generation on WWTP increases by 22.5 TWh/a to 35.9 TWH/a. In the electricity sector, due to its increased generation and the decreased consumption, PowerStep II generates 4 TWh/a of electricity instead of consuming 12 TWh/a leading to a net increase of 16 TWh/a. Heat generation also increases by 2 TWh/a.

The OPEX decrease from 8.5 Billion Euros/a to 6.5 Billion Euros/a while CAPEX remain at approximately the same level of 6 Billion Euros/a with PowerStep II being slightly more expensive than the benchmark and no actual data on the status quo and PowerStep I. The CO_2-Equivalent emissions decrease to about 8 Million MG/a, down from 16 Million MG/a, which is a significant reduction.

In Germany and in the UK, sewage gas generation is common whereas France, Spain, Italy, and Poland show a high potential. This is also true for the electricity sector. In the heat sector, especially northern European states could benefit from PowerStep's additional heat output.

The OPEX correlate with existing electricity prices. In Germany and Italy, the savings are higher than in the other MS. The CO_2-Equivalent emissions include the current electricity mix of the different MS and show that while Germany and Poland save significant amounts, France actually increases its emissions due to the large share of nuclear power. This is also true for countries with a high share of renewables.

Tackling climate change is one of the key challenges of our time and PowerStep technology is able to reduce the emission of GHG significantly as long as fossil fuels are substituted and not renewable electricity. From a climate point of view, replacing renewable electricity cannot be a future goal of energy efficient WWTPs operating with PowerStep technology.

Overall, we come to the conclusion that due to the many differences with respect to the MS level that were shown in both the first and the second part of this deliverable, investing in PowerStep technology has to be decided on the plant level. This also means that MS have to provide a long-term development path for energy on WWTP.

Nevertheless, upgrading existing plants to meet the performance standards shown with the benchmark WWTPs could be a first step for operators to reach an improved energy efficiency. Investing in PowerStep technology will increase this energy efficiency even further. The potential impact of PowerStep and the benchmark is probably even higher due to the underestimation of the electricity demand and the overestimation of the electricity generation of status quo WWTP. The potential of PowerStep varies between the different MS and their respective targets that could range from increasing electricity generation on WWTP to decreasing operational costs and CO_2-equivalent emissions.

6. Publication bibliography

de Boer, J., K. Erdmann and O. Fricke (2015). "Ganzheitliche Optimierung der Kläranlage Oldenburg." KA - Korrespondenz Abwasser, Abfall **10**.

Dietz, S. and N. Stern (2015). "Endogenous Growth, Convexity of Damage and Climate Risk: How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions." Economic Journal(583): 574-620.

DWA (2011). Leistungsvergleich kommunaler Kläranlagen 2011 : Stromverbrauch: 4.300 Kläranlagen unter der Lupe. Hennef.

DWA (2015). 28. Leistungsvergleich kommunaler Kläranlagen: Stromverbrauch und Stromerzeugung.

European Commission (2012). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS: A Blueprint to Safeguard Europe's Water Resources. COM(2012) 673.

European Economic Community (1991). COUNCIL DIRECTIVE of 21 May 1991 concerning urban waste water treatment.

Gawel, E. (2014). "Zur Berücksichtigung von Umwelt- und Ressourcenkosten nach Art. 9 der EG-Wasserrahmenrichtlinie." UFZ Discussion Papers(1/2014).

Harris, J. M., B. Roach and A.-M. Codur (2017). The Economics of Global Climate Change. Environmental and Natural Resource Economics: A Contemporary Approach,.

Hvitved-Jacobsen, T., J. Vollertsen and A. H. Nielsen (2013). Sewer Processes: Microbial and Chemical Process Engineering of Sewer Networks, Second Edition, Taylor & Francis.

Lieberherr, E. and B. Truffer (2015). "The impact of privatization on sustainability transitions: A comparative analysis of dynamic capabilities in three water utilities." Environmental Innovation and Societal Transitions **15**: 101–122.

Nordhaus, W. D. (2017). "Revisiting the social cost of carbon." Proceedings of the National Academy of Sciences **114**(7): 1518-1523.

Oelmann, M., B. Roters, A. Hoffjan, M. Hippe and T. Wedmann (2017). "Investitionsstau in der Abwasserentsorgung."

Stern, N. (2011). The economics of climate change : the Stern Review. Cambridge, Cambridge University Press.

Tauchmann, H. (2006). Innovationen für eine nachhaltige Wasserwirtschaft: Einflussfaktoren und Handlungsbedarf. Heidelberg, Physica-Verlag.

Tauchmann, H. and H. Clausen (2004). Innovativeness in the German Waste Water sector—a micro-econometric approach. Essen, RWI.