ANNEX 7: DETAIL COST COMPARISON ANALYSIS OF REED BEDS TO MECHANICAL DEWATERING

Annex compares the capital and operational expenditures of RBs in Mojkovac to alternative – mechanical dewatering.

1.1 Investment costs

Based on WWTP implementation experience in the Western Balkans, consultant estimation of construction costs for mechanical dewatering is cc. 80.000 EUR. Capital expenditures (Table 1) for mechanical dewatering are 42% lower compared to capital expenditures for reed beds and amount to 32 EUR/PE.

Table 1: Comparison of capital expenditures of RBs in Mojkovac compared to alternative

CAPEX	Reed beds	Mechanical dewatering
Construction costs (EUR/PE)	55	32

Main costs categories for construction CAPEX are:

- civil works and other services,
- mechanical equipment and installations,
- electrical equipment and installations.

A simplified most common categories expressed in % of construction costs are presented in the Figure below. Figure 1 shows the different technical options and the corresponding share of construction works. Assets split into these categories give us an overview of the % of mechanical and electrical equipment, where lifetime has an impact on the level of replacement and O&M costs. The assumed share of mechanical and electrical equipment is higher in the mechanical dewatering system (83%) compared to the on in reed beds (15%).

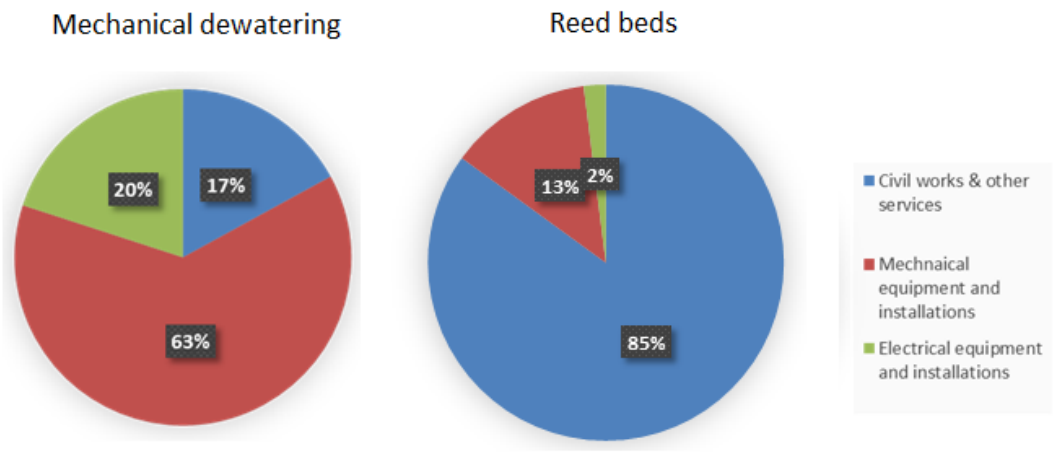

Figure 1: Main cost categories for CAPEX for mechanical dewatering and reed beds.

Total investment costs for implementation of RBs and its alternative – mechanical dewatering is presented in the Table below. It is assumed that all other costs, such as elaboration of project documentation, staff training, and dissemination, would costs the same, regardless of technology. It is considered that the costs of these other services, besides construction, would be lower if the sludge

treatment is built at the same time as WWTP. As stated before, WWTP was built in 2008, while RBs were constructed in 2016, so it was necessary to elaborate project documentation separately from the final design of WWTP Mojkovac and educate operating staff. Dissemination was included because these sludge drying reed beds were the first ever built in the region.

Table 2: Overview of total investment costs of sludge drying reed beds compared to an alternative - mechanical dewatering for sludge treatment in Mojkovac

Project investment cost	Reed beds	Mechanical dewatering
Project documentation	25.00,00	25.00,00
Construction	138.525,00	80.000,00
Operation staff training	14.475,00	14.475,00
Dissemination	15.000,00	15.000,00
TOTAL INVESTMENT COSTS (EUR):	193.000,00	134.475
CAPEX (EUR/) PE	**77**	**54**

1.2 O&M costs

1.2.1 Labour costs

Labor costs for mechanical dewatering can be expressed in man-hours, required to support the sludge treatment process. For the sludge reception from individual small treatment plants, the same employee spends about 4 hrs, twice a month, totaling 8 hours. The quantity is dependent on sludge volumes.

The WWTP (Slovenian case Grosuplje, 20.000 PE) requires one full-time equivalent (FTE) for conducting sludge dewatering process (start, control, flocculant dosage, clean-up). The WWTP of minor size (Slovenian case Ivančna Gorica, 6.000 PE) requires 0,5 FTE for performing the same activities. Therefore, one can infer that for mechanical dewatering performance in Mojkovac, 0,3 FTE would be required.

Table 3: Overview of labour cost of sludge drying reed beds compared to mechanical dewatering of sludge in Mojkovac

Labour costs	Reed beds	Mechanical dewatering
Labour costs (hours/year)	257	573
TOTAL (EUR/year):	**949**	**2.022**

1.2.2 Electricity consumption

Electricity consumption of mechanical dewatering is much higher than in reed beds and could amount to 49.800 kWh per year (Table 4). The real reason for this difference lies in the number of working hours and the complexity of mechanical equipment.

Table 4: Overview of electricity consumption if sludge drying reed beds compared to mechanical dewatering of sludge treatment in Mojkovac

Electricity consumption	Reed beds	Mechanical dewatering
Electricity (kWh/year)	180	49.800

Electricity consumption	Reed beds	Mechanical dewatering
Electricity consumption (PE load in kWh/year)	0,006	19,921
TOTAL (EUR/year):	**14,47**	**4.009,0**

1.2.3 Monitoring costs

In the table below are presented monitoring costs for reed beds to mechanical dewatering. As shown, mechanical dewatering does not require any sludge sampling.

Table 5: Estimated monitoring costs

Monitoring	Reed beds in Mojkovac	Mechanical dewatering
Sludge analysis before final disposal (once per operating cycle of RBs)	563 EUR	0
*Soil analysis	875 EUR	0
TOTAL (EUR/operating cycle):	**1.438 EUR**	

* Soil analysis are required only if biosolids will be deposited on soil.

1.2.4 Polymers for sludge handling

Reed beds technology does not require polymers while mechanical dewatering does. The polymer purchase costs arise only at mechanical dewatering.

Table 6: Forecasted polymer requirements

Other works	Reed beds in Mojkovac	Mechanical dewatering
Polymers for dewatering	0	*1.927
TOTAL (EUR/year):	**0**	**1.927**

* Polymers: 567 kg. Used unit price: 3,4 EUR/kg.

1.2.5 Maintenance costs of mechanical equipment

Maintenance of mechanical equipment and installations of reed beds and mechanical dewatering is presented in the following table.

Table 7: Forecasted maintenance of mechanical equipment

Maintenance of mechanical equipment	Reed beds in Mojkovac	Mechanical dewatering
1, 5 % of the CAPEX for mechanical equipment	270	432
TOTAL (EUR/year):	**270**	**432**

1.2.6 Replacement costs and repairs

The periodic maintenance can also be estimated using a percentage of the CAPEX expenditure for sludge treatment (1% of civil works, :

- Sludge drying reed beds

- Civil works: 1 %
-

- Mechanical dewatering
  - %

Table 8: Overview of periodic maintenance works

Works	Reed beds**	Mechanical dewatering*
Periodic maintenance works	2.681	436
TOTAL (EUR/year):	**2.681**	**436**

*Civil works: 0,5 %; Electrical equipment and installations: 2,0

** Described in Report

1.2.7 Final disposal or reuse costs

Cost analysis considers two options for sludge final disposal according to sludge treatment technology (Figure 2):

- Reed Beds
  - Option 1: Reuse of biosolids
  - Option 2: Incineration
- Mechanical dewatering
  - Incineration

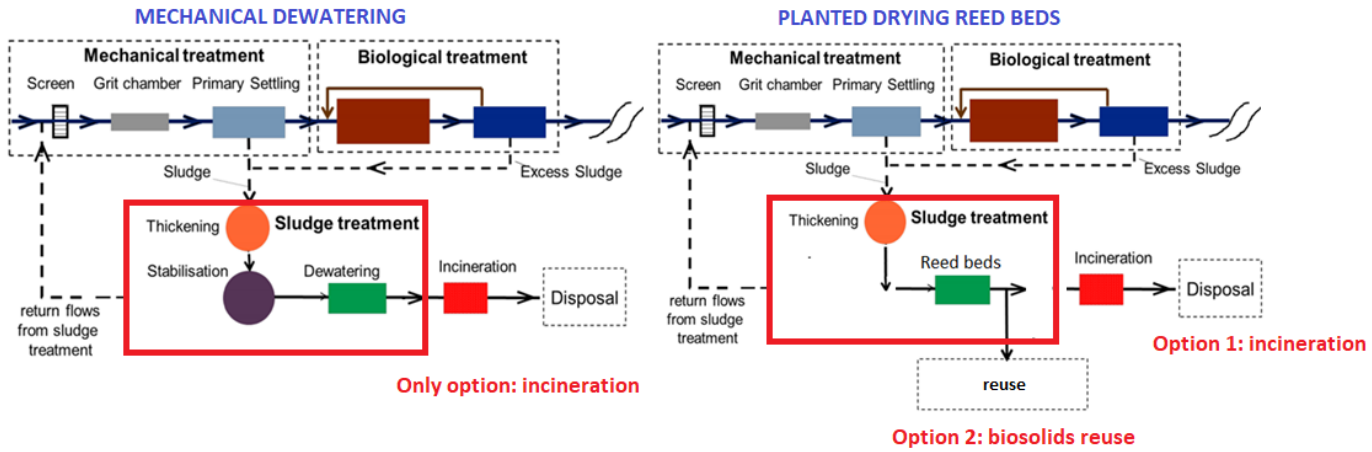

Figure 2: Sludge flow diagram for final disposal[1]

Used variable unit costs, which are market based:

- incineration: 60 EUR/ton
- biosolids reuse: 15 EUR/ton

Table 9: Final disposal costs options according to the technology (design values)

Reed beds		Mechanical dewatering
Optimal scenario	**Regular scenario**	
40% dry matter 40% mineralization	25% dry matter 40% mineralization	20% dry matter /
94 ton/year	151 ton/year	315 ton/year

[1] http://site.iugaza.edu.ps/rkhatib/files/2015/02/Sludge-Managemant-Chapters-1-and-2.pdf

Reed beds		Mechanical dewatering
Optimal scenario	**Regular scenario**	
5.667 EUR/year for incineration 1.417 EUR/year biosolids reuse	**9.067 EUR/year for incineration 2.267 EUR/year biosolids reuse**	**18.900 EUR/year for incineration ***

*Reuse of dehydrated sludge is not feasible.

The process of drying sludge on reed beds reduces volume of sludge and attains a dry solids content up to 40%, making sludge volume for final disposal much smaller compared to mechanical dewatering that has dry solid content around 20 %.

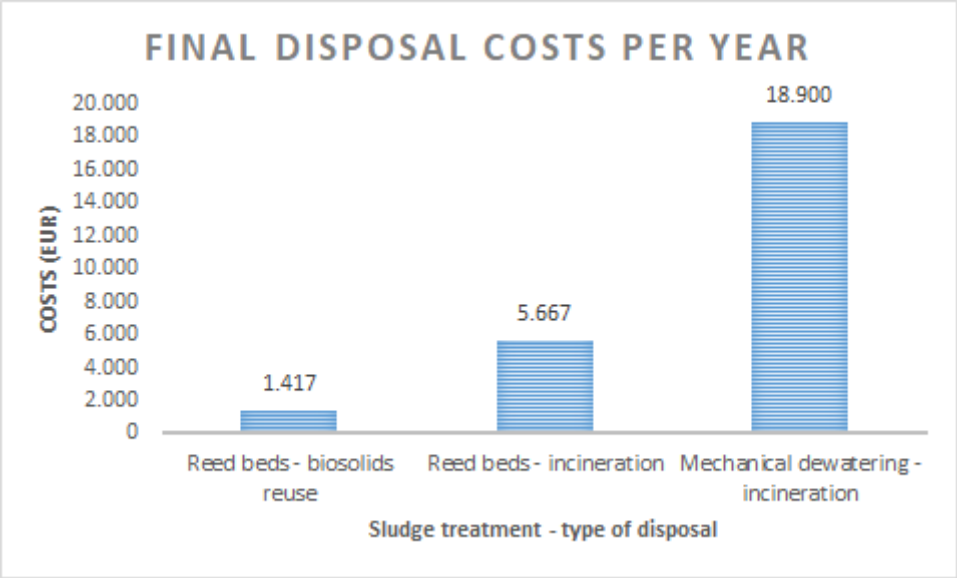

Figure 3: Overview of disposal costs per year for WWTP Mojkovac (theoretical values).

1.2.8 Overview of all O&M costs and comparison to mechanical dewatering

Table 10: Comparison of operational expenditures of RBs in Mojkovac compared to alternative

OPEX	Reed beds	Mechanical dewatering
Labour costs (EUR/year)	949	2.022
Electricity consumption (EUR/year)	15	4.009
Monitoring (EUR/year)	72	0
Reagents (EUR/year)	0	1.927
Maintenance (EUR/year)	2.951	868
TOTAL (without disposal) in EUR/year:	**3.987**	**8.826**
TOTAL (without disposal) in EUR/PE/year:	**1,57**	**3,53**
Disposal – incineration (EUR/year)	5.667	18.900
TOTAL with incineration in EUR/year:	**9.654**	**27.726**
TOTAL with incineration in EUR/PE/year:	**3,86**	**11,09**
Disposal – biosolids reuse (EUR/year)	1.417	
TOTAL with biosolids reuse in EUR/year:	**5.404**	-
TOTAL with biosolids reuse in EUR/PE/year:	**2,16**	-

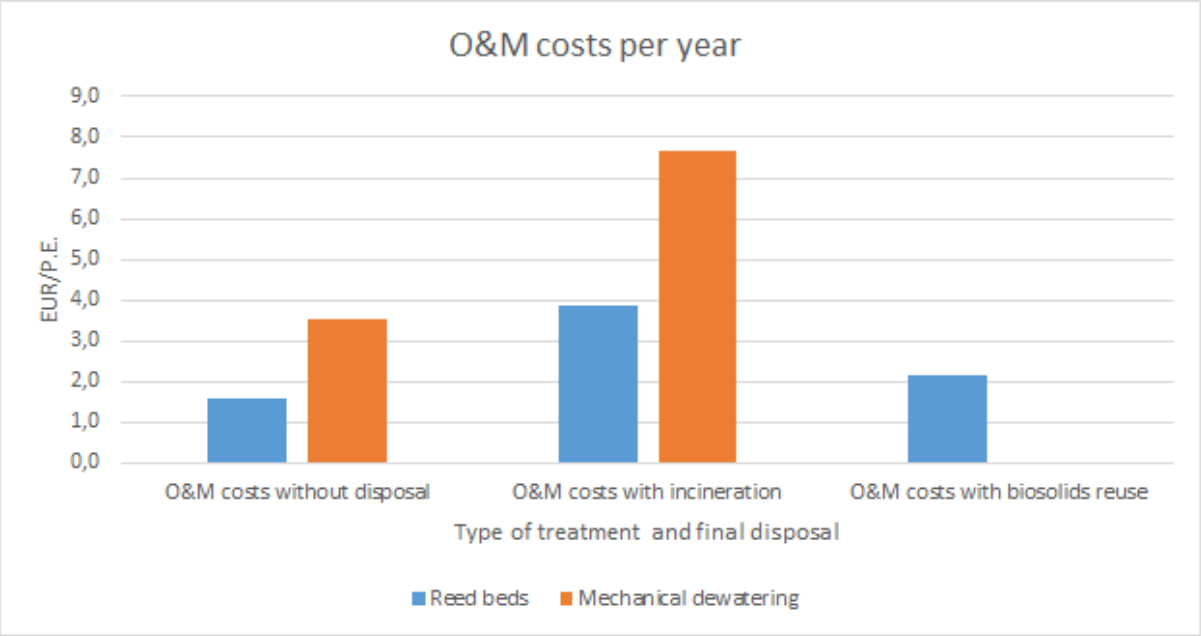

Figure 4: O&M costs for sludge treatment per year

1.3 Tariff revenues

The project revenues are defined as the 'cash in-flows directly paid by users for the goods or services provided by the operation, such as charges borne directly by users for the use of infrastructure, sale or rent of land or buildings, or payments for services' (Article 61 (Operations generating net revenue after completion) of (EU) Regulation 1303/2013).[2]

Cash flow projections are relevant for calculating the return on investment (Chapter 1.5) and are based on a realistic estimate of wastewater tariffs. It should assess whether cumulative cash flow will meet cash operating costs, debt service, and capital replacement, particularly of mechanical and electrical equipment.

4.3.1 Comparison of projections of flow-cash with grant

In the table below are presented flow-cash projections with the use of grant for two technological options (mechanical dewatering and reed beds) with two scenarios for final disposal (incineration or biosolids use). The biggest revenues can be obtained with the application of reed beds together with biosolids reuse.

Table 11: Projections of flow-cash with grant

Scenario	In-flow/out-flow	Flow	NPV (EUR)
Mechanical dewatering + incineration	Cash in-flow	Grant	134.475
		Revenues	721.460
	Cash out-flow	Investment	-134.475
		O&M	-479.439
		INFLOW-OUTFLOW:	**242.021**
Reed beds + incineration	Cash in-flow	Grant	193.000
		Revenues	721.460
	Cash out-flow	Investment	-193.000
		O&M	-166.931
		INFLOW-OUTFLOW:	**554.529**
Reed beds + reuse	Cash in-flow	Grant	193.000

[2] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

Scenario	In-flow/out-flow	Flow	NPV (EUR)
		Revenues	721.460
	Cash out-flow	Investment	-193.000
		O&M	-93.440
		INFLOW-OUTFLOW:	**628.020**

Required prices for water tariff, which would cover O&M activities are presented in the table below. Mechanical dewatering requires the biggest water tariff.

Table 12: Assessment of water tariff rates to cover operation and maintenance of sludge treatment

Type of sludge treatment and final disposal	Water tariff for OPEX (EUR/m^3)	% of existing water tariff (0,56 EUR/m^3) for persons	Rank
Mechanical dewatering + incineration	0,38	67 %	3
Reed beds + incineration	0,13	23 %	2
Reed beds + biosolids use	0,07	13 %	1

4.3.2 Comparison of projections of flow-cash with loan

In case Municipality Mojkovac would not obtain the grant, the alternative would be a loan. In the next table are compared flow-cash projections with loan for reed beds and their alternative – mechanical dewatering. The results showed that the biggest revenues could be created with application of reed beds and biosolids use.

Table 13: Projections of flow-cash with loan

Scenario	In-flow/out-flow	Flow	EUR
Mechanical dewatering + incineration	Cash in-flow	Revenues	721.460
	Cash out-flow	Investment (loan)	-134.475
		Interest rate (0,7 %)	-14.666
		O&M	-479.439
		INFLOW-OUTFLOW	**92.880**
Reed beds + incineration	Cash in-flow	Revenues	721.460
	Cash out-flow	Investment (loan)	-193.000
		Interest rate (0,7 %)	-21.068
		O&M	-166.931
		INFLOW-OUTFLOW	**340.461**
Reed beds + reuse	Cash in-flow	Revenues	721.460
	Cash out-flow	Investment (loan)	-193.000
		Interest rate (0,7 %)	-21.068
		O&M	-93.440
		INFLOW-OUTFLOW	**413.952**

Required prices for water tariffs to recover the capital cost through loan repayments, the operating and maintenance costs (cost-recovery principle) are presented in the following table. Mechanical dewatering requires the most significant water tariff.

Table 14: Assessment of water tariff rates to cover investment costs through loan and operation costs of sludge treatment

Type of sludge treatment and final disposal	Water tariff for CAPX and OPEX (EUR/m³)	% of existing water tariff (0,56 EUR/m³) for persons	Rank
Mechanical dewatering + incineration	0,49	88%	3
Reed beds + incineration	0,30	53%	2
Reed beds + biosolids reuse	0,24	43%	1

1.4 Net present value

The overall project performance is measured by indicators, namely the economic net present value (NPV), expressed in monetary values, and the economic rate of return (ERR), allowing comparability and ranking for competing projects or alternatives.[3]

Net present value on investment is defined as the sum that results when the expected investment and operating costs of the project are deducted from the discounted value of the expected revenues.

Net present values were calculated for both technological scenarios (reed beds and mechanical dewatering) and disposal options (incineration or reuse). NPV is used for ranking the options from a financial point of view (Table 15).

Table 15: Net present value of sludge treatment in EUR (design values)

Sludge treatment + disposal	NPV O&M	NPV Investment	NPV Total	Ranking
Reed beds + incineration	-166.931	-214.068	**-380.999**	**2**
Reed beds + biosolids reuse	-93.330	-214.068	**-307.398**	**1**
Mechanical dewatering + incineration	-479.439	-134.475	**-613.914**	**3**

The alternatives for final handling and re-use of the biosiolids are based on the following assumptions:

- Option 1: Sludge treatment on reed beds and biosolids re-use.
  - Sludge quality meets the criteria of the "Official Gazette of Montenegro, No. 89/09 from 31.12.2009 and there is adequate land available for biosolids re-use;
- Option 2: Sludge treatment on reed beds and incineration.
  - Sludge is processed at the WWTP and dewatered to a total solid concentration of 40%. Dewatered material, collected at the WWTP and transported to the nearest incineration plant.
- Option 3: Sludge treatment with mechanical dewatering and incineration.
  - Sludge is processed at the WWTP and dewatered to a total solid concentration of 20%. Dewatered material is collected at the WWTP and then transported to the nearest incineration plant.

[3] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

The source of financial revenues in the wastewater project comes from the application of charges to users for wastewater collection and treatment, sludge management, sale of purified water for industrial and agricultural purposes, etc. Knowing the NPV value of the planned wastewater project is essential from affordability, financial and economic analysis aspects.

1.5 Return on investment

The rate of return on direct investment is calculated as a ratio of direct investment income to direct investment positions at a given point in time[4]. Operating cost-savings generated by the operation can be treated as net revenue. We have compared NPV O&M costs among sludge treatment technologies. O&M savings are expressed in EUR/year for a period of 30 years.

Estimating of annual cost savings (avoided costs) deriving from changed sludge treatment technology (from mechanical dewatering to reed beds) are presented in Table 16. Chosen sludge disposal for analysis below is incineration. The potential of cost savings is forecasted through the calculation of return on investment (ROI) obtained from O&M savings only. RBs can generate revenues big enough for re-investing in significant capital investments. In 10 years, cost savings to the wastewater sector would be 146.582 EUR, which is enough to repay construction costs for RBs.

Table 16: O&M savings if we select reed beds over mechanical dewatering (final sludge disposal – incineration)

Years	O&M costs for mech. dewatering + incineration (EUR/year)	O&M costs for reed beds + incineration (EUR/year)	Annual savings (EUR/year)	Total savings – Net revenue (EUR)	The potential of cost savings (ROI)
0	0	0	0	0	
1	26.660	9.282	17.378	17.378	
2	25.634	8.925	16.709	34.087	
3	24.648	8.582	16.066	50.153	
4	23.700	8.252	15.448	65.601	
5	22.789	7.935	14.854	80.455	
6	21.912	7.629	14.283	94.738	
7	21.069	7.336	13.733	108.471	
8	20.259	7.054	13.205	121.676	
9	19.480	6.783	12.697	134.373	
10	18.731	6.522	12.209	146.582	Saved for construction costs for reed beds (138.525 EUR).
11	18.010	6.271	11.739	158.321	
12	17.318	6.030	11.288	169.609	
13	16.652	5.798	10.854	180.463	
14	16.011	5.575	10.436	190.899	
15	15.395	5.360	10.035	200.934	Saved for investment costs for reed beds (193.000 EUR).
16	14.803	5.154	9.649	210.583	

[4] https://read.oecd-ilibrary.org/industry-and-services/measuring-globalisation-oecd-economic-globalisation-indicators-2010/rate-of-return-on-direct-investment_9789264084360-40-en#page1

Years	O&M costs for mech. dewatering + incineration (EUR/year)	O&M costs for reed beds + incineration (EUR/year)	Annual savings	Total savings – Net revenue	The potential of cost savings (ROI)
			(EUR/year)	(EUR)	
17	14.234	4.956	9.278	219.861	
18	13.686	4.765	8.921	228.782	
19	13.160	4.582	8.578	237.360	
20	12.654	4.406	8.248	245.608	
21	12.167	4.236	7.931	253.539	
22	11.699	4.073	7.626	261.165	
23	11.249	3.917	7.332	268.497	
24	10.817	3.766	7.051	275.548	
25	10.400	3.621	6.779	282.327	
26	10.000	3.482	6.518	288.845	
27	9.616	3.348	6.268	295.113	
28	9.246	3.219	6.027	301.140	
29	8.890	3.095	5.795	306.935	
30	8.548	2.976	5.572	312.507	
SUM:	**479.437**	**166.930**	**312.507**	-	

Comparison of different sludge management options displayed satisfactory economic indicators when biosolids reuse was an option to consider. Table 17 shows how cost savings with RBs and biosolids reuse are expected to be higher than the common practice of incineration. In 8 years, cost savings to the wastewater sector would be 150.290 EUR, which is enough to repay construction costs for RBs.

Table 17: O&M savings if we select reed beds over mechanical dewatering (final sludge disposal – incineration vs. biosolids reuse)

Years	O&M costs for mech. dewatering + incineration (EUR/year)	O&M costs for reed beds + biosolids reuse (EUR/year)	Annual savings	Total savings – Net revenue	The potential of cost savings (ROI)
			(EUR/year)	(EUR)	
0	0		0	0	
1	26.660	5.196	21.464	21.464	
2	25.634	4.996	20.638	42.102	
3	24.648	4.804	19.844	61.946	
4	23.700	4.619	19.081	81.027	
5	22.789	4.441	18.348	99.375	
6	21.912	4.271	17.641	117.016	
7	21.069	4.106	16.963	133.979	
8	20.259	3.948	16.311	150.290	Saved for construction costs for reed beds (138.525 EUR).
9	19.480	3.797	15.683	165.973	
10	18.731	3.651	15.080	181.053	
11	18.010	3.510	14.500	195.553	Saved for investment costs for reed beds (193.000 EUR).

Years	O&M costs for mech. dewatering + incineration (EUR/year)	O&M costs for reed beds + biosolids reuse (EUR/year)	Annual savings	Total savings – Net revenue	The potential of cost savings (ROI)
			(EUR/year)	(EUR)	
12	17.318	3.375	13.943	209.496	
13	16.652	3.245	13.407	222.903	
14	16.011	3.120	12.891	235.794	
15	15.395	3.000	12.395	248.189	
16	14.803	2.885	11.918	260.107	
17	14.234	2.774	11.460	271.567	
18	13.686	2.667	11.019	282.586	
19	13.160	2.565	10.595	293.181	
20	12.654	2.466	10.188	303.369	
21	12.167	2.371	9.796	313.165	
22	11.699	2.280	9.419	322.584	
23	11.249	2.192	9.057	331.641	
24	10.817	2.108	8.709	340.350	
25	10.400	2.027	8.373	348.723	
26	10.000	1.949	8.051	356.774	
27	9.616	1.874	7.742	364.516	
28	9.246	1.802	7.444	371.960	
29	8.890	1.733	7.157	379.117	
30	8.548	1.666	6.882	385.999	
SUM:	**479.437**	**93.438**	**385.999**	-	

The importance of optimizing sludge treatment and disposal to ensure, not only municipal financial savings, but also direct savings to users and other benefits (e.g., resource savings). Project net revenues can repay the investment as presented in the Table 18.

Table 18: Forecasted repayment of construction costs through O&M savings

Mechanical dewatering changed to:	Total savings (EUR)	When net revenues (avoided costs) can repay the construction costs, regardless of the sources or methods of financing
Reed beds + incineration	146.582	10 years
Reed beds + biosolids reuse	150.290	8 years