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LOT 1 TREATMENT OF WASTEWATER SLUDGE OR MANURE FROM LIVESTOCK (TSM) IN A NORDIC OR ALPINE ENVIRONMENT

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LIST OF ABBREVIATIONS

BM	business model
BOD	biological oxygen demand
BTM	benefit transfer methods
CAPEX	capital expenditures
Cfb	temperate oceanic climate (Köppen climate classification)
COD	chemical oxygen demand
CW	constructed wetland
DM	dry matter
EPA	Environmental Protection Agency
GHG	greenhouse gas
IUCN	International Union for Conservation of Nature
MD	mechanical dewatering
NBS	nature based solutions
NPV	net present value
O&M	operation and maintenance
OPEX	operating expenditures
PE	population equivalent
SLR	sludge loading rate
(SD)RB	(sludge drying) reed beds
TN	total nitrogen
TP	total phosphorus
TVS	total volatile solids
TSS	total suspended solids
UNIDO	United Nations Industrial Development Organization
VAT	value added tax
WEFE	Water-Energy-Food-Ecosystems (Nexus project)
WW	wastewater
WWTP	wastewater treatment plant

1 INTRODUCTION

1.1 Context

With the combined effects of population growth, economic development, and expanding cities, the pressure on water sources is increasing and will increase even further in the future. Producing more crops will become even more demanding due to water and nutrient needs and scarcity. With adverse effects on natural ecosystems that provide essential services (including soil and water), every aspect of resource recovery must be explored. Integrated approaches are needed while simultaneously tackling water, agriculture (nutrients), and population needs.

Nature-based solutions provide an approach where engineered natural ecosystems can be integrated to address targeted challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits. The challenges include climate change, water security and pollution, food security, human health (from IUCN definition[1]).

The common point of these aspects is the wastewater treatment process and resource recovery that could result in water and particularly nutrient reuse in agriculture. Sewage sludge resulting from the wastewater treatment process is regarded as a potentially useful resource if adequately processed. Its treatment process is relevant for Phosphorus reuse. It is a critical raw material, an essential ingredient of nutrients (mineral fertilizers), and an irreplaceable natural resource. Being a pillar of intensive agriculture, the threats of depletion of its natural reserves (phosphate rock) is realistic to occur in the future decades.

Sludge management, on the other hand, is highly complex and has a cost ranging from 10 to 60 % of the total operating costs of the wastewater treatment plants (WWTP) depending on the sludge treatment technology (although sludge represents only 1 % to 2 % of the treated wastewater)[2]. The adequate final destination of 'biosolids' is a fundamental factor for the success of a sanitation system. Nowadays, it is not limited to treatment and disposal. We need to look at sustainable sewage sludge management, which means "the resources in sludge are recycled, while pollutants are destructed or removed."[3] This position of nutrient reuse has been neglected in many countries so far, particularly outside Western Europe. The design of wastewater treatment plants consider sludge treatment, but a lack of national strategies for sewage sludge reuse or final disposal. This prevents WWTP investors from deciding/recommending sewage sludge treatment according to circular economy principles.

1.2 Purpose

This report explores nature-based solutions (NBS) and their potential in the area of sustainable sludge management. The report aims at the in-depth exploration of a pilot case to build a robust evidence base about the practical feasibility, effectiveness, and limitations of NBS to address a need to link access to resources from sewage sludge with minimal financial costs and environmental impact.

This base of evidence, together with the literature and other examples already known in Europe and elsewhere, will be used for a research synthesis aimed at a generalized assessment at European scale, and production of policy recommendations also in the context of the JRC Water-Energy-Food-Ecosystems (WEFE) Nexus project.

The pilot case study presented here will focus on the treatment of wastewater sludge in sludge drying reed beds in the Nordic or Alpine environment. It includes exploiting natural processes under human control, with well-identified input flows and required effluent standards. The primary purpose of NBS in this category is the control of nutrient surplus and other contaminants.

[1] https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions
[2] https://www.iwapublishing.com/sites/default/files/ebooks/9781780402130.pdf
[3] http://site.iugaza.edu.ps/rkhatib/files/2015/02/Sludge-Managemant-Chapters-1-and-2.pdf

The following questions and aspects will be addressed and are elaborated in the chapters. Firstly, the geographical study area is defined in the second chapter where the pilot case is located, with elements relevant for up-scaling the technology to the (whole) Alpine region.

The third chapter offers an insight into the reed bed technology on the pilot location, the sludge treatment process, technical pilot description of two sludge drying reed beds.

The report should provide insights into the efficiency of NBS reed bed technology for sewage sludge treatment and suitability for Nordic/Alpine areas. The analyses of treated biosolids (product of reed beds) prove the opportunity for future use in agriculture. Furthermore, sewage sludge management is facing increasing challenges regarding nutrient recycling economic justification and disposal behaviour change. Thus, the practise of sludge reuse in agriculture against other management alternatives (incineration) are taken into account and evaluated.

2 STUDY AREA

2.1 Basic information

The Municipality of Mojkovac is situated in the northern part of Montenegro, in the Durmitor area. Mojkovac town is one of the most important agglomerations in Northern Montenegro. The town is located on the left shore of the Tara river upstream of the Tara River Canyon. Tara River Canyon is the longest canyon in Montenegro and Europe and the second-longest in the world after Grand Canyon. The canyon is protected as a UNESCO World Heritage Site and is a part of Biogradska Gora National Park and Durmitor National Park. Tara River, combined with the beautiful landscape of the Tara River Gorge, are valuable assets for the further development of the region's tourist potential, particularly for water sports and water-related recreational activities like angling, rafting kayaking, etc. The municipality of Mojkovac covers an area of 367 km2 and is one of the smallest municipalities in Montenegro by population (8.622). The town Mojkovac is located at an altitude of 853 m (municipality 600 – 2.253 m). Latitude and longitude coordinates for Mojkovac are 42.96044 and 19.5833. The territory of this municipality is bordered by the following municipalities: Kolašin, Šavnik, Žabljak, Bijelo Polje and Berane.

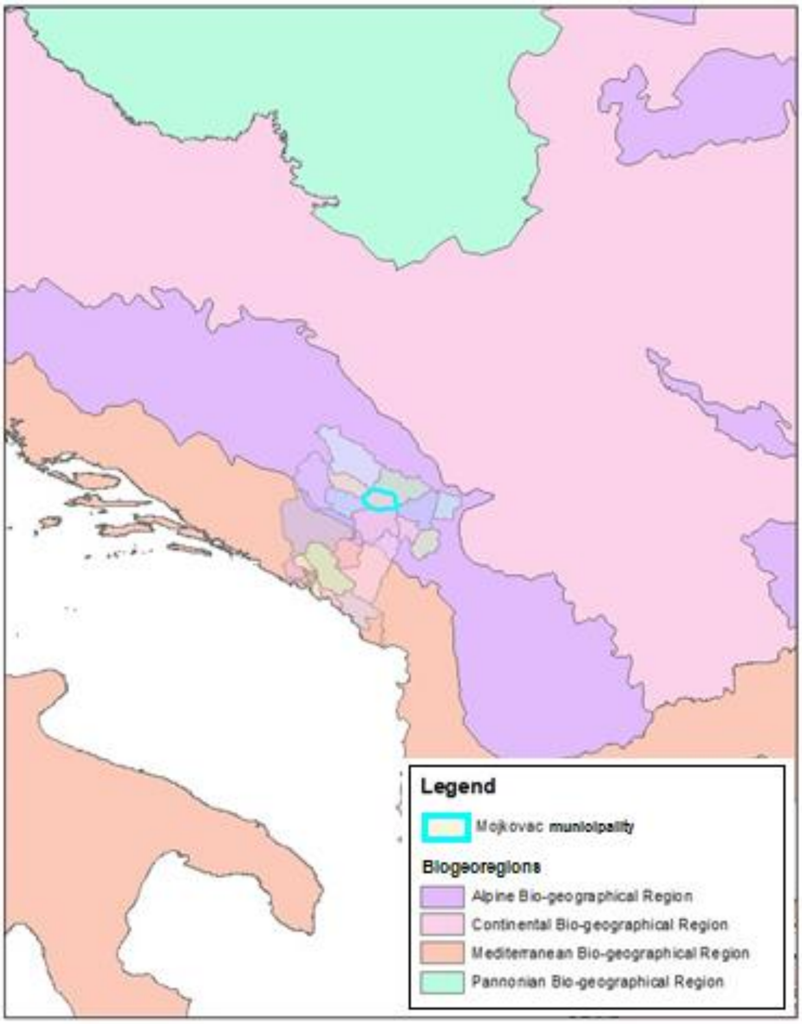

Figure 1: Mojkovac municipality within Montenegro national border and biogeoregions[4][5]

[4] https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3#tab-data-visualisations
[5] https://www.diva-gis.org/gdata

2.2 Problem description

The subject of this report is a case study on sludge drying reed beds in the municipality of Mojkovac. This region is a popular destination for domestic and foreign tourists due to the mountainous landscape, ski slopes, Tara River, and proximity of national park Biogradska Gora. According to statistics, 3.590 (42 %) inhabitants live in the urban part of the municipality, and 58 % live in rural areas. Wastewater treatment plant (WWTP) Mojkovac was designed for 5.250 population equivalents (PE). Since it was constructed in 2005, it is operating below capacity (around 800 house connections x 3 PE = 2.400 PE) due to a lack of wastewater collection lines. Municipality is planning to connect settlements Juskovica Potok, Ambarine, and Podbisce (*Figure 2*) to WWTP in the next years and ensure around 700 new house connections. WWTP Mojkovac will than operate with full capacity.

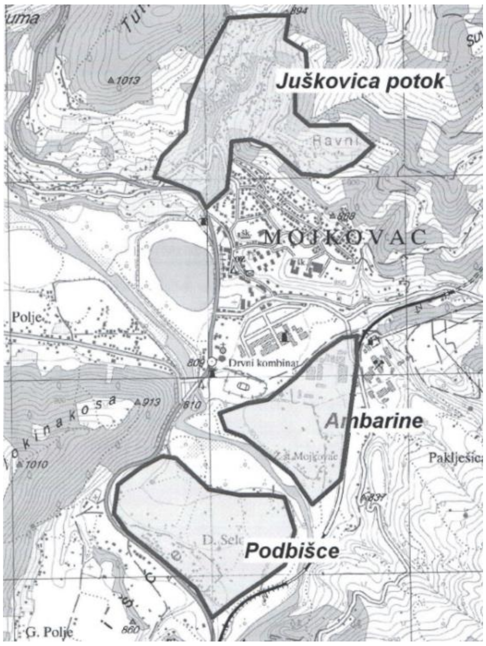

Figure 2: Planned settlement to connect to WWTP Mojkovac[6]

The sewage sludge management and knowledge in the Alpine region has evolved in time. A review of NBS practice in Mojkovac (Montenegro) is expected to bring useful recommendations to lift the confidence and support co-operation of different stakeholders for biosolids reuse.

2.3 Site characteristics

2.3.1 Climate

In Mojkovac, a continental-mountainous and sub-mountainous climate prevails (temperate oceanic climate (Cfb) by the Köppen-Geiger system). The rainfall in Mojkovac is significant, with precipitation even during the driest month, with an average 1.664 mm annually. The driest month is July, with 72 mm of rainfall. In November, the precipitation reaches its peak, with an average of 136 mm. The average annual temperature in Mojkovac is 8,9 °C. The number of snow days per year is around 120, and the height of the snow cover reaches up to 150 cm, and in the mountains much more.

The vegetation period (also the growing season) is the duration of the annual plant growing season at a time between the day when the average daily air temperature in the springtime exceeds the temperature threshold of 5° C and the day when it falls again below this value in the autumn. For Mojkovac that means that the growing

[6] http://www.mojkovac.me/images/stories/dokumenti/gradj/zahtjev_fekalna.pdf

season is between April and October. Since the alpine climate is harsh, this also means a shorter vegetation period, which results in the planning of planting reed beds and sludge dosing on reed beds. Sludge is being slower to mineralize on reed beds in the Alpine bioregion due to slower biological processes.

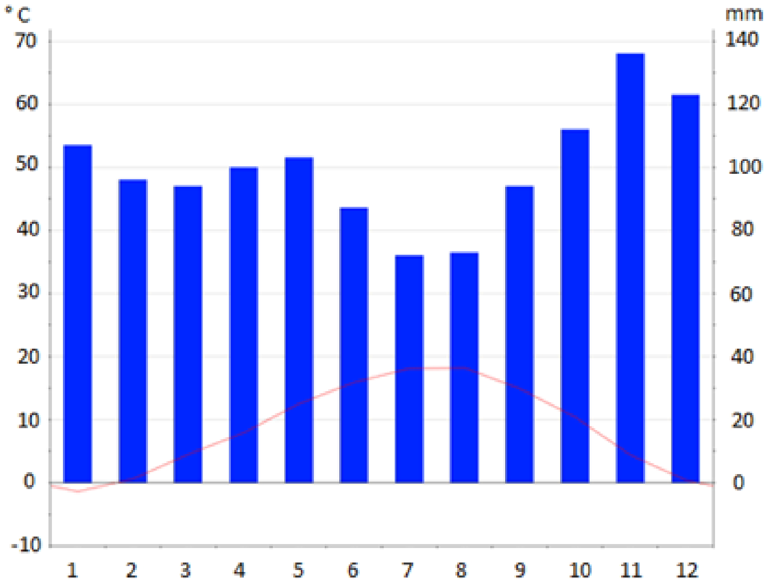

Figure 3: Climate graph of Mojkovac[7]

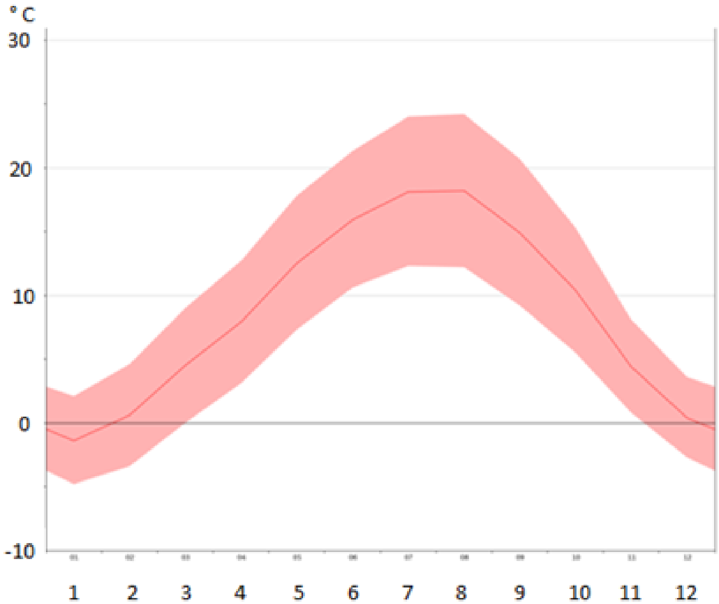

Figure 4: Temperature of Mojkovac during the year[8]

Weather averages are presented in Table 1 and illustrated in Figure 4.

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[7] https://en.climate-data.org/europe/montenegro/mojkovac/mojkovac-31454/#temperature-graph
[8] https://en.climate-data.org/europe/montenegro/mojkovac/mojkovac-31454/#temperature-graph

Table 1: Mojkovac weather averages by month from January to December[9]

	1	2	3	4	5	6	7	8	9	10	11	12
Avg. T (°C)	-1,4	0,6	4,5	7,9	12,5	15,9	18,1	18,2	14,9	10,4	4,4	0,4
Min. T (°C)	-4,8	-3,4	0	3,1	7,3	10,6	12,3	12,2	9,2	5,5	0,8	-2,7
Max. T (°C)	2,1	4,6	9	12,7	17,8	21,3	24	24,2	20,7	15,3	8,1	3,6
Precipitation (mm)	107	96	94	100	103	87	72	73	94	112	136	123

2.3.2 Hydrography

The municipality of Mojkovac encompasses the widened valley of the Tara River, which divides the area of the municipality into approximately two equal parts. The Tara valley is of a composite character: the ravines, valleys, and parts of the canyon are thin. From the gorge located north of the confluence of the Shtitaricka River, there is a Mojkovac basin, which from Feratovo Polje, through Podbišće, Donji selo and Mojkovac, passes into the plain of Gornje and Donje Polje. The total length of the basin is 9 km, and the width is 2,5 km. In the canyon part of Tara, which belongs to the municipality of Mojkovac, more significant extensions are around the mouth of Bistrica, and around Gornja Dobrilovina and Black Pine Rainforest in Crni Podi. Reed beds in Mojkovac are secure from flooding.

2.3.3 Soil

The most of the Mojkovac municipality surface is covered with rendzina and distric cambisole. Rendzina is formed on the scattered carbonate substrate. It contains more skeleton than dark soil, and arable surfaces represent the more rooted varieties of swallow holes, karst fields, and smaller plateaus. Brown acid soils (Distric cambisoles) are typical forest soils, and then used as meadows and pastures, and as arable land. Diluvial is an unsorted rough and fine mineral material at the foot of slopes e.g., scree. It is formed at the foot of the slopes, where fine particles of organic and mineral origin and rock debris accumulate. Alluvial soils are typical of the middle and lower parts of Tara river.

2.3.4 Land use

Since the municipality is located in the hilly areas, land use is largely influenced by the topography. Out of the total area of the Municipality of Mojkovac (367 km^2), 18.005 ha (49 %) is forests, 13.686 ha (37 %) is agricultural land, of which 4.696 ha is arable land. Meadows represents 3.944 ha, and other (settlements, roads and stone areas) 5.009 ha (14 %)[10].

In the mountainous region's livestock breeding as the primary economic branch remained to this day. Farming evolved alongside livestock. It takes place on small rural farms running along the left and right banks of the Tara River. They include potato, cabbage, beans, and other continental vegetable crops, and most of the fruits are predominantly of plum, apple, pear, walnut, and the like. The fact that forests cover 49 % of the total territory speaks enough about the great wood resources that this municipality has. The forests of willow, oak, birch, beech, then fir, spruce, pine, and pestilence range from the Tara River to the foot of the largest mountain peaks. Uncontrolled logging and exploitation threaten the forest wealth of this region.

Based on data from Corine Land Cover data[11], under agricultural land falls 31 % of the total area (pastures, complex cultivation patterns, land principally occupied by agriculture with significant areas of natural vegetation, and natural grasslands). 65 % of the area is covered with forest (broad-leaved forest, coniferous forest, mixed

[9] https://en.climate-data.org/europe/montenegro/mojkovac/mojkovac-31454/#temperature-graph
[10] http://www.mek.gov.me/files/1216637502.pdf
[11] https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

forest, transitional woodland-shrub, and sparsely vegetated areas) and only 0,9 % is of urban (continuous urban fabric, and discontinuous urban fabric).

Table 2: Land use for Mojkovac municipality (%)

Land use	%
Continuous urban fabric	0,32%
Discontinuous urban fabric	0,56%
Mineral extraction sites	0,19%
Sport and leisure facilities	0,07%
Pastures	0,18%
Complex cultivation patterns	1,34%
Land principally occupied by agriculture with significant areas of natural vegetation	10,84%
Broad-leaved forest	27,45%
Coniferous forest	2,50%
Mixed forest	16,91%
Natural grasslands	18,96%
Moors and heathland	0,54%
Transitional woodland-shrub	9,89%
Beaches dunes sands	0,77%
Bare rocks	1,26%
Sparsely vegetated areas	8,15%
Water bodies	0,07%

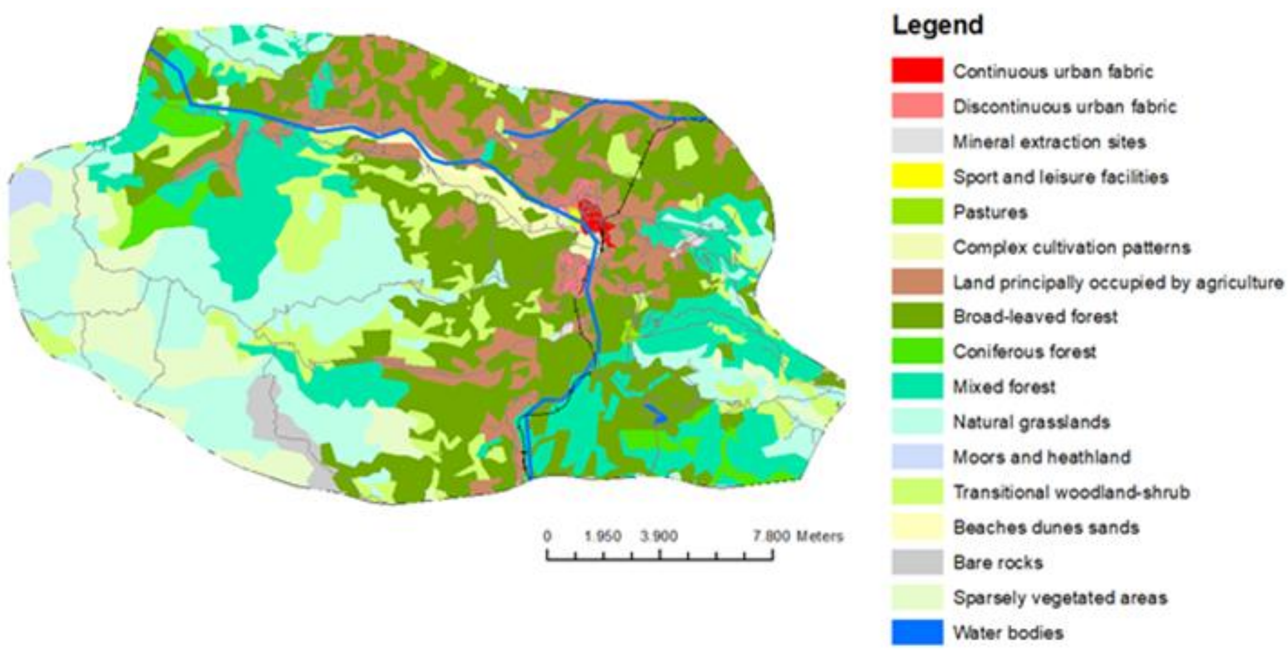

Figure 5: Land use for Mojkovac municipality at the scale that best illustrates the situation, i.e. 1:150.000[12]

2.4 Generalization

A proposed case presents the utilization of sewage sludge applicable for the broader region. Mojkovac is facing common environmental (high vulnerability of environment), economic (a growing problem in a local economy

[12] https://land.copernicus.eu/pan-european/corine-land-cover/clc2018

concerning sludge management suffering from agglomeration disadvantages) and social challenges (high degree of seasonality due to tourism, aging population) specific to the Alpine Region. It must address the question of the balance between remote (rural mountainous areas) and urban areas. The region does not share a conventional Alpine river basin. However, characteristics of the Tara River are similar to other Alpine rivers (torrential high-flows), and the preservation of Alpine water resources is vital to Europe as a whole. In addition to the case of Mojkovac, we have considered another case in the Austrian Alps (Dellach) in order to appreciate the generalizability of the Mojkovac case to the Alpine context. The case findings will provide the foundation for broad generalizability.

The Alpine environment is usually found within other types of environments, so their impacts are also felt. The main features of the Alpine region are presented in ANNEX 1. It is typical of high mountains, associated mountain valleys, and some high plateaus of the Dinarides. Temperatures drop by 0.6 degrees Celsius on every 100 m of altitude. Temperatures are also affected by the proximity to the sea and are lower throughout the year than elsewhere. Additionally, there is more rainfall in the mountainous regions than in the lowlands, and generally fall in the form of snow in the cold periods. Although all cases considered belong to the Cfb climate group by Köppen-Geiger climate classification, ie. moderately warm humid climate with warm summer (beech climate), and in Alpine biogeographical Region, the effects of mountain climate (shorter vegetation period, higher rainfall, etc.) are felt.

Since the nearest weather station for Dellach case is Lienz, climatic data from these two stations was taken.

Table 3: Mojkovac and Dellach comparison

	Mojkovac	**Lienz**[13]
Köppen-Geiger climate classification	Cfb	Cfb
annual temperature, average	8.9 °C	8.4 °C
warmest month, average	August, 18.2°C	July, 18.0 °C
coldest month, average	January, -1.4 °C	January, -2.3 °C
annual rainfall, average	1.664 mm	1.083 mm
driest month, average	July, 72 mm	January, 49 mm
wettest month, average	November, 136 mm	June, 129 mm
wind speed, average	2,24 m/s[14]	1,52 m/s[15]

The settlements in the alpine environment were mainly formed in alpine huts and valleys. From this point of view, Mojkovac example (and others) represents the alpine environment – population density, and, consequently, municipal infrastructure, proximity to watercourses, and, consequently, placement of reed beds suitable location.

[13] https://en.climate-data.org/europe/austria/tyrol/lienz-21509/
[14] https://weatherspark.com/y/84431/Average-Weather-in-Mojkovac-Montenegro-Year-Round
[15] https://weatherspark.com/y/72784/Average-Weather-in-Lienz-Austria-Year-Round

3 TECHNOLOGY PRESENTATION

3.1 Sludge treatment in Mojkovac, Montenegro

3.1.1 Project background

RBs were constructed as a cost-effective solution to solve problems of sludge treatment, storage, and disposal in the Municipality of Mojkovac. In 2004 the town of Mojkovac was equipped with a biological wastewater treatment plant (mechanical, biological, and chemical stage) with an installed capacity of 5.200 PE. Until the construction of RBs in 2016, the generated sludge was poorly managed and mainly stored on the WWTP location. There was a risk of being washed to the Tara River in high-intensity rainfall events. The installed filter press was never in operation due to high operational costs. The municipality had no sustainable concept to manage the accumulating sludge or possibility to dispose of it safely. Dumping of increasing volumes of sewage sludge on the local landfill was not possible; also, there is no incineration plant in the entire country of Montenegro. Limited financial resources and sludge disposal problems were the key drivers of search for alternative sludge treatment solutions. Existing sewage sludge management practices and future trends around Europe are presented in ANNEX 2.

Mojkovac is located on the banks of Tara River (canyon under UNESCO World Heritage site, Durmitor national park - NP) and is surrounded by NP Biogradska Gora, which drew the attention of addressing sludge management more sustainably. All environmental investments (also RBs) were a part of a sanitation process after the closure of mining activities. What used to be tailing lake now serves as a recreational facility; RBs are located next to it. The project's overall goal was to preserve the water quality of Tara River and preserve the Durmitor region's productive touristic development potential. In contrast, the project's immediate objective was to construct a reed bed filter to dewater and safely manage the sludge from Mojkovac town's municipal wastewater treatment plant.

The initiator of the project was the Ministry of Sustainable Development and Tourism of Montenegro. The project started in 2014 and ended in 2016. It was implemented with financial support provided by the government of the Republic of Slovenia to the United Nations Industrial Development Organization (UNIDO). Project total budget incl. 13 % support cost was 243.221 EUR.

Project activities:

- Identification of best available technical solution;
- Preparation of detailed technical design;
- Construction of RBs with monitoring and quality assurance;
- Preparation of documentation for countrywide dissemination and up-scaling;
- Training of plant operators.

3.1.2 The main units of WWTP Mojkovac

The treatment process in Mojkovac consists of a pre-treatment followed by biological treatment and sedimentation, reaching the final effluent discharge parameters for secondary treatment. Line of sludge disposal after biological wastewater treatment (activated sludge process) is simple and consists of a process of sludge thickening and drying of sludge (as opposed to more complex anaerobic digestion and biogas production, which is appropriate for bigger WWTP).

WWTP Mojkovac has three basic groups of units, corresponding to treatment levels and these are:

- Pre-treatment wastewater units;
- Wastewater treatment units;

– Sludge treatment units.

Table 4: WWTP Mojkovac units

Groups of units	Units	*Process
Pre-treatment wastewater units	Coarse screens and grit removal	Mechanical treatment
Wastewater treatment units	Anaerobic/Denitrification tank Aeration/Nitrification tank Secondary Clarifier	Denitrification -Nitrification Aerobic stabilization of sludge Water/sludge separation
Sludge treatment units	Thickener (not in use) Filter press (not in use) Reed beds (in use)	Sludge dewatering

*Differences between sludge treatment process are presented in ANNEX 3. Document also contains the differences between two common technological options – mechanical dewatering and sludge drying reed beds.

Figure 6: Aerial shot of WWTP Mojkovac before (left) and after RBs installation (right)[16]

The units of full wastewater treatment are schematically described and presented (Figure 7) below:

- Coarse screens and grit removal
  - Screening is the first operation unit, followed by grit removal.
  - Coarse screens and grit remove solid materials and sand from wastewater.
- Biological treatment
  - Secondary treatment takes place in anaerobic selector followed by a nitrification/aeration tank using an activated sludge process.
  - The biological reactor (aeration tank) is equipped with the aeration equipment.
- Secondary clarifier
  - Settling tank continuously removes solids deposited by sedimentation.
  - The moving collection units push all the sludge to one end of the clarifier, and dumps it into a low area, called a sump.
- Sludge thickener
  - Gravity tank for sludge thickening uses the natural tendency of higher-density solids to settle out of liquid to concentrate the solids. Sludge thickener is not in use since RBs were established and in operation.
- Options for sludge treatment:

[16] Google map. Satellite view.

- Option 1: Mechanical dewatering – filter press
- Option 2: Natural dewatering - reed beds

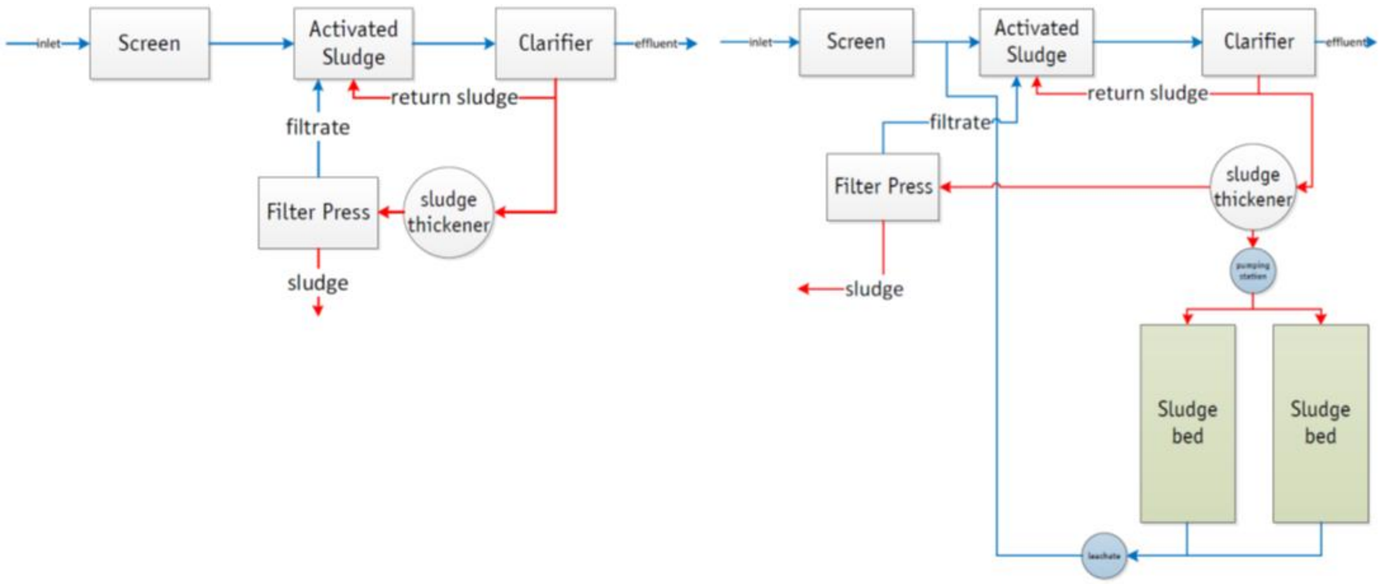

Figure 7: The process flowchart of WWTP Mojkovac with mechanical dewatering (left) and natural dewatering (right)[17]*

* Sludge thickener is not in use since RBs are in operation.

3.1.3. Sludge drying reed beds in Mojkovac

Sludge drying reed beds (for a general description of reed beds technology see ANNEX 4) were established as a solution for sludge disposal, considering the high operation costs of mechanical dewatering. Selected technology of reed beds (RBs) does not affect the first phase of wastewater treatment (WWTP). However, it addresses the second phase (line for sludge treatment), resulting in abandonment of the mechanical dewatering line and sludge thickener.

The sludge in the WWTP is produced during the microbial phase of wastewater purification in the nitrification and denitrification basins. Before treated effluents are released to the environment, suspended solids have to settle in the secondary clarifier. For the undisturbed wastewater purification, sludge must constantly recirculate between secondary clarifiers and purification basins (nitrification and denitrification). In each extreme case, when not enough sludge is recirculating or too much sludge is recirculating, the plant purification efficiency is at risk. Until RBs were put in operation in 2016, sludge generated in the WWTP Mojkovac was pumped and stored in a sludge thickener structure.

In Mojkovac, sludge drying reed beds were built with two off-ground reinforced concrete basins, identified as SDRB1 and SDRB2 (Table 5). The terrain characteristics (high level of groundwater due to the vicinity of Tara River) soil excavated basins and sealing with a waterproof membrane (EPDM, PEHD) were unfeasible. Reinforced concrete basins are resistant to wastewater corrosion, mechanical loads, UV light, air, and root growth. They are impermeable, long-lasting, and prevent leaking. Each of the beds has 450 m2 surface (10 m by 45 m), total 900 m2 (2 x 450 m2). The total height (filter layer + height for sludge depositing + freeboard) of the bed is 1,95 m.

[17] SDRB project documentation. Technological design. 2014. EcoSan Club.

Dimensions of the reed beds (RBs) are detailed in Table 5 the below.

Table 5: Dimensions of RBs

Reed bed	Width [m]	Length [m]	Area [m^2]	Height* [m]
SDRB 1	10	45	450	1,95
SDRB 2	10	45	450	1,95

* height of filter layer + height for sludge depositing and freeboard.

Reed beds are connected to the WWTP by a pipeline. Sludge from the secondary clarifier can be pumped to the reed beds or returned to the denitrification tank. Operators manually measure TSS content with a measuring cylinder, and when TSS content reaches one half of the cylinder, they send sludge to RBs. The operator chooses which bed (RB 1 or RB 2) is to be loaded with sludge. This is done manually by opening vents in the distribution manhole. There is no control system for operating, gathering and logging real-time data. Everything is done manually as the municipality asked for a robust system, which can be operated and maintained by local workers and using low tech.

Sludge distribution pipes are located on both sides of the concrete basin. The sludge is filled from the top down (*Figure 8*). Solids stay on the filter layer, while leachate percolates through the filter layer that consists of stones, gravel, and sand. Leachate is collected by drainage pipes placed on the bottom of beds and returned to a wastewater treatment plant. The beds are planted with common reed (*Phragmites australis*). This technology does not require any chemicals or flocculants.

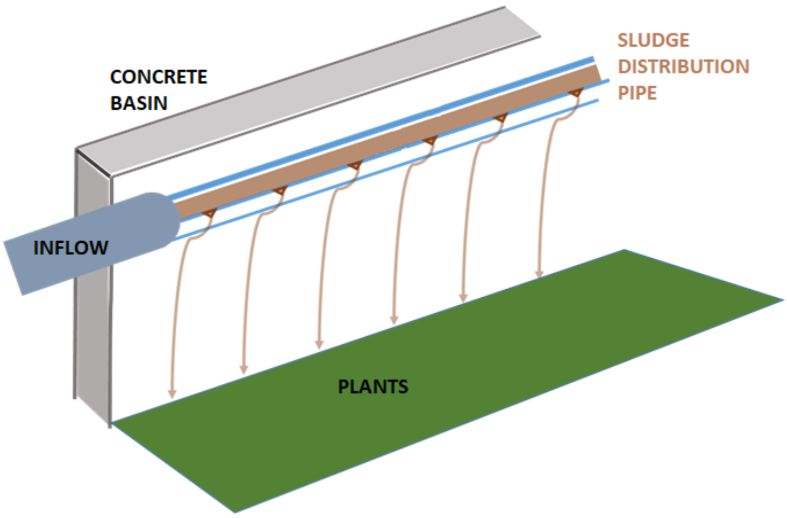

Figure 8: Sludge distribution pipe

The system of RBs comprises (Figure 9):

- **a sludge pumping station** for sludge pumping onto reed beds;
- **a sludge distribution manhole** for sludge distribution on which reed bed;
- **two sludge drying reed beds** with a surface area of 450 m each;
- **a leachate pumping station** to return drained water from RBs back to WWTP.

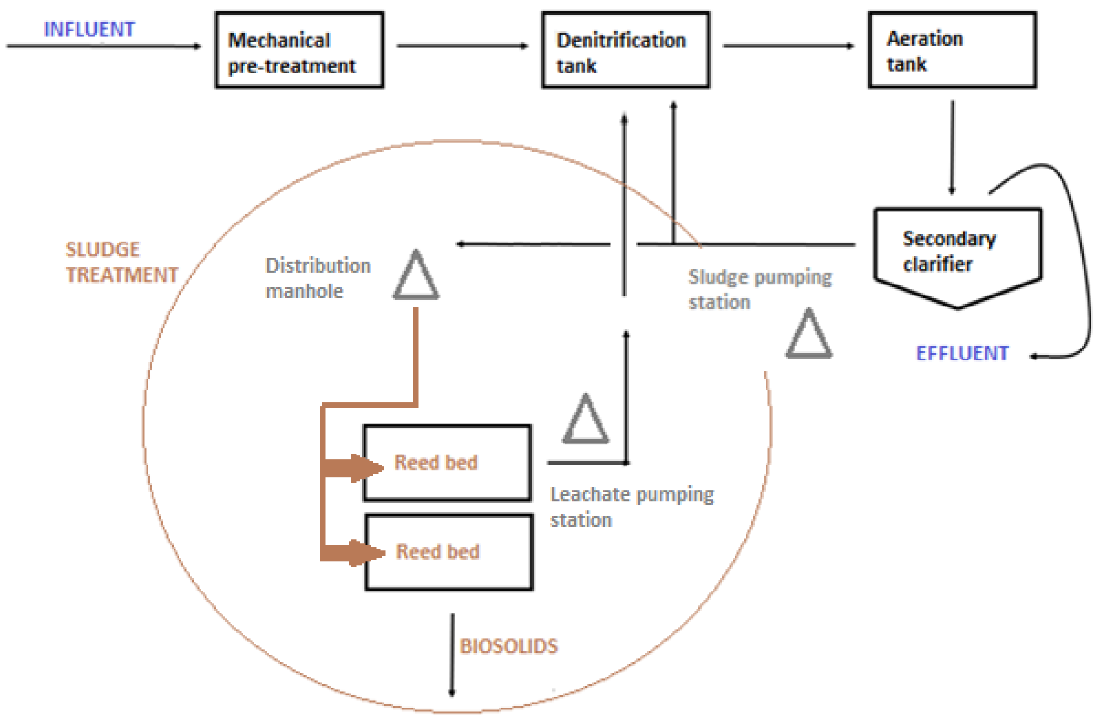

Figure 9: Flowchart diagram of operating sludge treatment in Mojkovac

3.1.4 Pictures and drawings

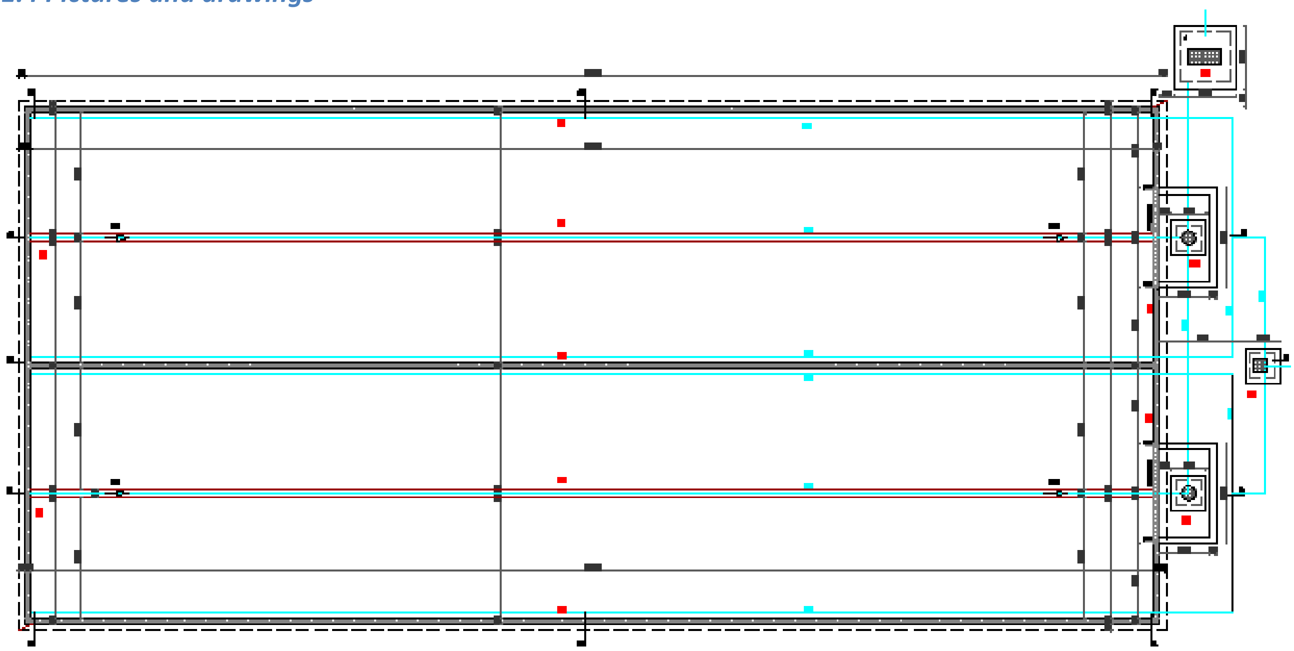
Figure 10: Floor plan of RBs in Mojkovac (Final project, 2015)[18]

[18] Final design project. Reed beds for sludge treatment from WWTP Mojkovac. 2015. D.O.O., Velmi-Yuvel. Bijelo Polje.

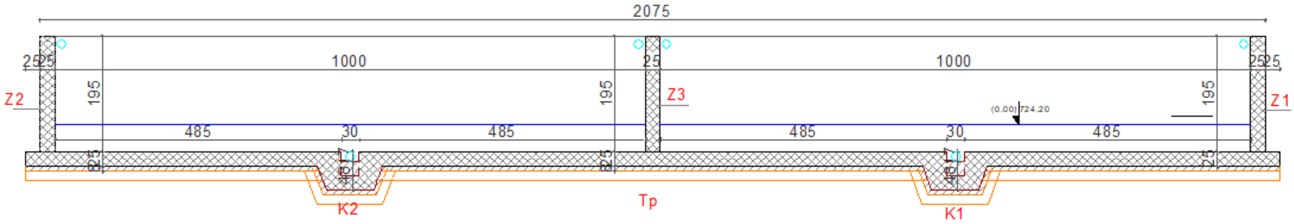

Figure 11: Cross section of RBs in Mojkovac (Final project, 2015)[19]

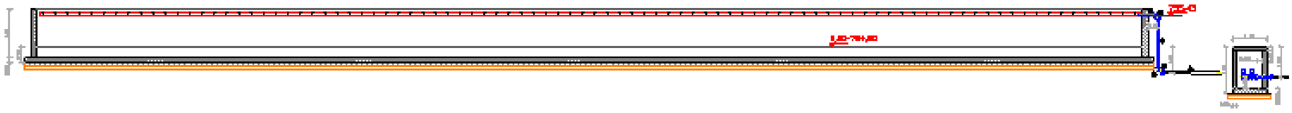
Figure 12: Longitudinal cross-section of Rbs in Mojkovac – sludge distribution (Final project, 2015)[20]

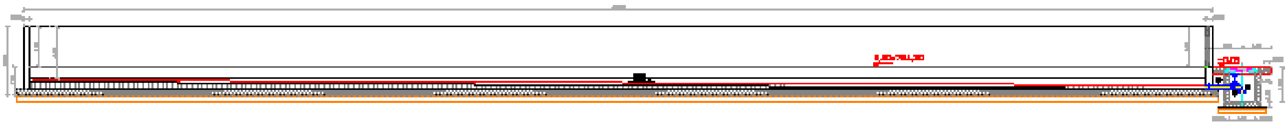
Figure 13: Longitudinal cross-section of Rbs in Mojkovac – sludge distribution (Final project, 2015)[21]

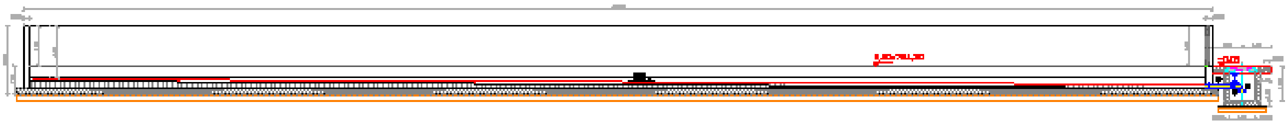
Figure 14: Longitudinal cross-section of Rbs in Mojkovac – leachate drainage (Final project, 2015)[22]

[19] Final design project. Reed beds for sludge treatment from WWTP Mojkovac. 2015. D.O.O., Velmi-Yuvel. Bijelo Polje.
[20] Final design project. Reed beds for sludge treatment from WWTP Mojkovac. 2015. D.O.O., Velmi-Yuvel. Bijelo Polje.
[21] Final design project. Reed beds for sludge treatment from WWTP Mojkovac. 2015. D.O.O., Velmi-Yuvel. Bijelo Polje.
[22] Final design project. Reed beds for sludge treatment from WWTP Mojkovac. 2015. D.O.O., Velmi-Yuvel. Bijelo Polje.


Figure 15: WWTP with RBs Mojkovac


Figure 16: Emergence of the reed after 1 month of planting

Figure 17: Reed beds in September 2019

3.1.5 Design parameters
Design parameters, which were input to the design process for RB in Mojkovac are presented below.

3.1.5.1 Design horizon parameters
Reed beds were constructed in 2016 with an adapted capacity of 2.500 PE. The time (investment) horizon is 30 years.

3.1.5.2 Sludge requirements for sludge reuse in Montenegro
A Regulation defines the management of sewage sludge in Montenegro on detailed conditions, which have to be met for municipal sewage sludge, quantities, volumes, frequency and methods of analyses of municipal sewage sludge for approved purposes, and conditions that have to be met for soil that will receive the sludge ("Official Gazette of Montenegro, No. 89/09 from 31.12.2009). The Regulation was adopted based on European sewage sludge Directive 86/278/EEC (for EU requirements for the use of sludge in agriculture see ANNEX 2).

The Regulation defines treated wastewater sludge as sludge processed by physical, chemical, biological or thermal treatment, long term storage, or other adequate treatment that enhances the reduction of its fermentation potential and threat to human health and environment during its usage. The Regulation also defines the limit values for treated sludge in heavy metals, organic matter, pathogens, and the percentage of dry matter. According to concentrations of pollutants, the sludge is classified into different quality classes that define further usage.

According to the dry matter content, the sludge can be used in agricultural land, green areas, and parks if it contains at least 50 % of dry matter. If the sludge contains at least 35 % of dry matter, it can be used as a covering material on landfills, re-cultivated landfills, degraded soils, and mining fields.

3.1.5.2.1 Limit values for soil to which sludge is applied

Table 6: Limit values for heavy metals concentration in soil to which treated sewage sludge is applied

Heavy metals	**Allowed heavy metal content in soil in mg/kg of dry matter of representative soil sample**		
pH of soil	5,0 <pH 6,0	6,0<pH<7,0	pH>7,0
Zn	100	150	200
Cu	40	50	100
Cr	50	75	100
Pb	50	70	100
Ni	30	50	70
Cd	0,5	1	1,5
Hg	0,2	0,5	1

3.1.5.2.2 Limit values for heavy metals in sludge

Table 7: Allowed heavy metal content in mg/kg of dry matter of the sample of treated sewage sludge of type A, B or C quality

Heavy metals	**Quality**		
	A	**B**	**C**
Zn	600	1200	2500
Cu	300	600	1000
Cr	100	250	1000
Pb	120	200	750
Ni	60	100	300
Cd	5	10	20
Hg	5	10	16

Quality of sludge determines possible use of biosolids:

- A and B: use in agriculture
- B: use on green areas and parks
- C: use for land recultivation on landfills, tailings and mining areas

3.1.5.2.3 Limit values for organic compounds in sludge

Table 8: Allowed content of organic pollutants in treated sewage sludge of A and B quality

Organic pollutants	**Allowed concentrations (mg/kg of dry matter)**
PAH (Polycyclic Aromatic Hydrocarbons)	*6*
PCBs (polychlorinated biphenyls)	*0,2 – 0,8**

* 0,2 for agriculture; 0,2-0,8 for park greening

3.1.5.2.4 Limit values for pathogens in sludge

Treated sewage sludge of A and B quality does not contain pathogen organisms.

The analysis of organic pollutants and pathogens content is performed only when treated municipal sewage sludge is produced at a WWTP with a capacity of more than 100 000 PE.

3.1.5.2.5 Limit values for dry matter in sludge
Wastewater treatment plant produce treated sewage sludge of min. 25 % of dry matter (DM) suitable for further treatment to achieve:

- 50 % DM for use in agriculture, park green areas;
- 35 % DM for landfill cover or landfill recultivation, less fertile land or mining areas.

Sewage sludge of 25 % DM can be applied to soil only if the sludge can be distributed mechanically (i.e. using fertilizer spreader or in case of soil remediation using bulldozer or similar) and be immediately cultivated into the soil.

3.1.5.2.6 Maximum annual load of heavy metals to land, on a ten years basis
Table 9: Limit values of heavy metal concentrations that can be annually added to soil where treated sewage sludge of A and B quality is applied, on the basis of 10-year average (kg/ha/y)

Heavy metals	Limit values
Zinc (Zn)	30
Copper (Cu)	12
Chromium (Cr)	-
Lead (Pb)	15
Nickel (Ni)	3
Cadmium (Cd)	0,15
Mercury (Hg)	0,1

Maximum allowed quantities of treated sewage sludge that can be applied to soil depend on the following parameters: percentage of available nitrogen in sludge, concentration of heavy metals in sludge and soil, percentage of dry matter in sludge, type of sludge and type of soil.

3.1.5.2.7 Maximum annual load of nitrogen in agriculture
Total nitrogen content introduced through mineralised sewage sludge should not exceed 250 kg/ha/y or 170 kg/ha/y where mineralised sewage sludge is applied to the nitrate-sensitive land that meets the optimal needs of crops.

3.1.5.3 Wastewater characteristics

3.1.5.3.1 Wastewater origin
The household wastewater consumption impacts sewer and WWTP design significantly. In the Municipality of Mojkovac, separate sewer systems are being built, while old urban areas have a combined sewer system. Mojkovac used to be an environmental hot spot – due to a considerable mining waste dump in the very center of the town[23]. However, nowadays there is no heavy industry, which could significantly affect wastewater quality. Wastewater has typical domestic characteristics.

3.1.5.3.2 Hydraulic parameters
The WWTP has started to operate in November 2008 and since than 1.290.450 m^3 of wastewater have been treated (data collected 02.10.2019). On this basis, we conclude that the average daily flow is 324 m^3/day (1.290.450 m^3/3.987 days).

[23] https://un.org.me/call-me-crazy-from-environmental-hotspot-to-eco-tourism/?page=call-me-crazy-from-environmental-hotspot-to-eco-tourism/

Figure 18: Flow on 02.10.2019 afternoon.

3.1.5.3.3 Influent wastewater loads

Constituents present in the domestic wastewater can be divided in main groups, but their presence and share in wastewater vary significantly:

- Microorganisms (Pathogenic bacteria, virus and worms' eggs);
- Biodegradable organic materials (Detergents, pesticides, fat, oil and grease, colouring, solvents, phenols, cyanide);
- Other organic materials;
- Nutrients (Nitrogen, phosphorus, ammonium);
- Metals (Hg, Pb, Cd, Cr, Cu, Ni);
- Other inorganic materials (Acids);
- Odor (Hydrogen sulphide);
- Radioactivity.

When discussing sludge treatment, the focus is often only on organic loading and nutrients, while other constituents that may be present in the domestic wastewater are neglected. Before deciding on technology, the analyses of wastewater are recommended, but in reality are not often implemented in practice. Thus, theoretical values are being used for designing.

The person loads vary from country to country. Influent specific mass loads of raw wastewater[24] taking into the account specific regional characterizes are expressed in g/PE*d.:

- Biochemical Oxygen Demand BOD_5 = 60 g/PE*d
- Chemical Oxygen Demand COD = 120 g/PE*d
- Total Suspended Solids TSS = 60 g/PE*d
- Total Phosphorus TP = 1,8 g/PE*d
- Total Nitrogen TN = 11 g/PE*d

[24] From Standard ATV-DVWK-A 198:2003

3.1.5.4 Sludge characteristics

All biological treatment processes generate sludge. Sludge production depends on the treatment processes, which generates sludge. Besides, sludge characteristics impact the efficiency of sludge treatment.

Sludge removal intervals have a significant influence on the sludge characteristics and treatment. WWTP Mojkovac main treatment processes are enabled by activated sludge. The result of this process is a constant increase in activated sludge biomass, which has to be removed from the treatment process to prevent degradation of dead biomass and the release of nutrients and organic matter back to the treated water. In the biological treatment process, part of the organic matter is metabolized and converted to microbial biomass (biological or secondary sludge).[25]The excess sludge presents biomass and microorganisms that contain organic matter, nutrients, and persistent pollutants that originate from wastewater. For example, sludge removed in intervals of weeks, months, years, or decades are usually thicker and already digested. RBs Mojkovac treats primary and secondary sludge from WWTP.

Table 10: TSS Influent specific loads

Parameter	**Unit**	***Value***
Influent Specific Loads of TSS	g/PE*d	70
	kg/d	175
	kg/y	63.875

Sludge characteristics before dosing sludge to reed beds Mojkovac:

- Sludge type: primary and secondary mixed together
- Aerobic biological sludge – stabilized
- Mechanical properties of sludge: fluid sludge
- Water content: 98-99 %
- Dry matter content: 0,5-2 %
- Suspended solids load concentration: 588 mg/l
- Total volatile solids (TVS) content: 85 – 90 %
- Sludge density very close to water: 1,02 kg/m^3 (1 m^3 of sludge ≈ 1000 kg or 1 ton of sludge)

3.1.6 Process Parameters

3.1.6.1 Sludge loading rate

An essential process parameter to affect sludge drying is the loading rate of dry matter. The sludge loading rate (SLR) is expressed in kg TSS/ m2/year. It represents the mass of solids dried on one m2 of bed in one year.[26] The loading rate depends on climate (temperature, precipitation, humidity), and thus optimal local operating conditions need to be determined during the design phase.

The maximum calculated loading rate in Mojkovac is 60 kg TSS/m^2 y.

3.1.6.2 Filtration rate

Drainage of the system is just as important as loading the system. Efficient filter layer and drainage piping enables drying of the sludge.

[25] http://site.iugaza.edu.ps/rkhatib/files/2015/02/Sludge-Managemant-Chapters-1-and-2.pdf
[26] https://www.un-ihe.org/sites/default/files/fsm_book_lr.pdf

In Mojkovac, fine sand is at the top of the layer and coarse gravel at the bottom of the filter layer, enabling the efficient removal of solids from water. The height of the filter layer determines the sufficient volume of RBs (cc. 81 m3). Water percolates through the filter layer by gravity. The filtration rate is expressed in m3 of water percolating through the filter layer in one hour, divided by the filter surface area. In case fine particles of suspended solids enter the filter layer, clogging can occur.

The filtration rates through filter media are in Mojkovac rated at 0,04 m/h (very slow filtration).

3.1.6.3 Sludge loading height

A sludge loading height is defined by the sludge loading volume per surface area of the bed. Higher loading volume can lead to a higher number of suspended solids in sludge, which can cause filter layer clogging and decrease of the drainage/filtration efficiency.

A loading volume of around 20 m^3 of sludge per one dosing is applied.

3.1.6.4 Sludge loading pattern

The operation stage started from the first day the RBs were, meaning that there was not and start-up phase with reduced loading. The sludge loading pattern depends on the season. Loading in Mojkovac can be grouped into three groups:

- **Usual loading**
  - Loading periods from February to September
  - Long loading periods of one week
  - One-week drying period
  - One bed filled two times per month

Table 11: Loading pattern from February to September

Month	BED 1	BED 2
Week 1	Filling once per week	*Resting*
Week 2	Filling once per week	*Resting*
Week 3	*Resting*	Filling once per week
Week 4	*Resting*	Filling once per week

- **Winter preparation loading**
  - Loading periods from October to November
  - Goal: to remove as much sludge as possible from the aeration/anaeration tanks
  - Short loading periods of one day
  - One day drying period
  - One bed filled every two days

Table 12: Loading pattern from October to November

Month	BED 1	BED 2
Day 1	Filling once per day	*Resting*
Day 2	*Resting*	Filling once per day
Day 3	Filling once per day	*Resting*
Day 4	*Resting*	Filling once per day
Day 5	Filling once per day	*Resting*

Month	BED 1	BED 2
Day 6	*Resting*	Filling once per day
Day 7	Filling once per day	*Resting*

- **Winter off-loading**
  - Off-loading period from December to January due to freezing of drainage water from RBs (when temperature drops below zero)
  - Sludge accumulates in Secondary Clarifier
  - No filling of beds

3.1.7 Visual examination of RBs in Mojkovac, Montenegro

The sludge drying reed beds in Mojkovac were evaluated in October 2019.

3.1.7.1 Sludge height

Sludge drying reed beds in Mojkovac are in operation since May 2016. A sludge height of 10 cm was achieved in three years. The samples obtained in October 2019 revealed good dewatering capability of reed beds in Mojkovac. The total suspended solids (TSS) content varied from 13 – 22 % (average 16 %). Average total volatile solids (TVS) content of sludge was 67 %.

Figure 19: Sludge height in RBs Mojkovac.

3.1.7.2 Sludge distribution

The sludge distribution is uniform. There are no dead zones or uneven plant growth. Water efficiently drains from the system and there are no signs of filter clogging.

Figure 20: Sludge sample from RB Mojkovac.

3.1.7.3 Plant growth

The chosen plant common reed (*Phragmites australis*) has proven to grow above the sludge. The plant is native and stands along marsh edges in Montenegro. There is no visible sign of a nematode attack. Plant is invasive, but cannot spread outside the reed bed system because the primary method of reproduction is vegetative via a vast underground rhizome network. The spreading of the reeds is disabled physically by the concrete basin and will not propagate to the adjacent zones.

Figure 21: Uniform growth of common reed in Mojkovac

Plants in Mojkovac are almost 3 m high. The growth is uniform. Plants reach their maximum height and density during summer (July, August), dry after the first frost in the fall (October, November), and start growing in the spring (April, May). They are not harvested.

Figure 22: Common reed height.

3.1.7.4 Odor

Sludge stabilization reduces the odor of sludge, while sludge spreading has an odor potential. The system in Mojkovac has no odor problems. The system is placed far from the urban city area, but the first houses are from 100 to 400 m away. So far, no one has complained about the odor. The Municipality is also constructing recreational area right next to the WWTP (see Figure 23).

Figure 23: WWTP Mojkovac location

Clogging of the system creates anaerobic conditions, limit air supply to the system, and causes odor emissions. Therefore, odor is one of the main alarming signs of the system malfunctioning and it has not happened at the site.

3.1.7.5 Water drainage

The drying process is done by drainage of leachate through the filter layer and evapotranspiration of plants. A sludge drying reed bed in Mojkovac consists of drainage piping and leachate collection, a manhole outside of the beds for temporary storage, and pumping leachate back to the WWTP for further treatment. Water efficiently exits the system at the bottom of the bed, and aerobic conditions for sludge drying are established. Heavy rain events do not negatively affect hydraulic of the RBs. Rainwater enters and exits the system.

3.2 Sludge treatment in Dellach am Drautal, Austria

In order to fully reflect the RBs operation and efficiency in the Alpine biogeographical region, another RBs in the territorial setting comparable with that of Mojkovac, were examined. The selected case for comparison is located in the Dellach am Drautal in Austria and presented in detail below. Gathered data from both cases (Mojkovac and Dellach am Drautal) will demonstrate the technical suitability and its potential for upscaling to the entire Alpine region. It is also worth comparing the sites due to their country origin and showing suitability and application regardless of the country's development level. The data availability of the Dellach site is much higher and, therefore, useful for the study.

3.2.1 Basic data on WWTP

The WWTP with sludge drying reed beds is located north-east from the urban area of Dellach and next to the Drau River. First houses are only about 500 m away from the WWTP facilities.

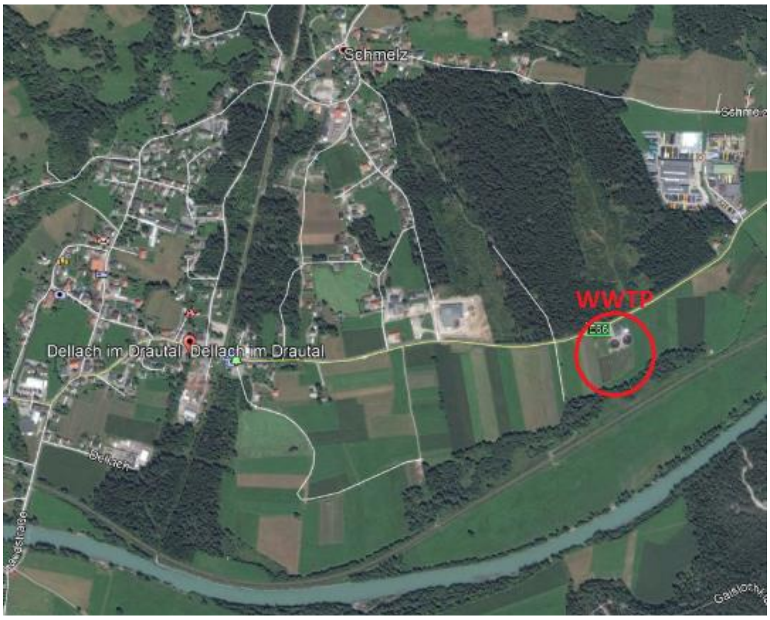

Figure 24: WWTP Dellach, Austria

WWTP design capacity is 7.800 PE Load of the WWTP is much lower during the winter (3.000-4.000 PE) and increases in the summer (7.800 PE). The reason for this is in a flourishing summer tourist season from May to September. The WWTP was built and started to run in 2008. The biological treatment process includes mechanical pre-treatment, nitrification, denitrification, phosphate removal, and aerobic sludge stabilization.

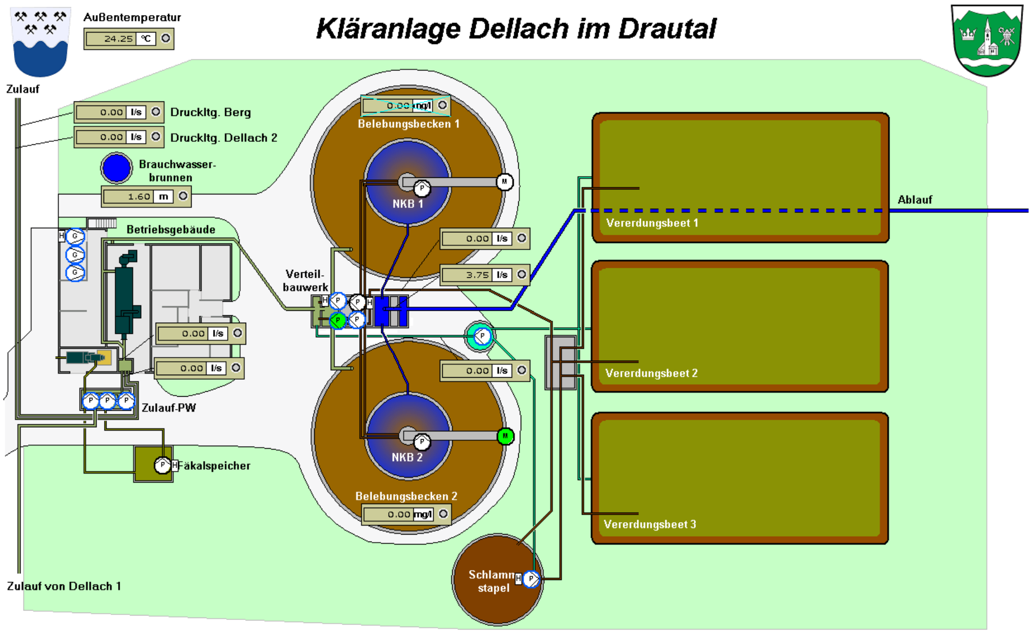

Figure 25: WWTP Dellach process scheme[27]

The main WWTP units are[28]:

- Mechanical treatment: sand and grease trap, screening line
- Biological treatment: two activated sludge reactors; each of them perform nitrification and denitrification. During high season (summer), both reactors are used, while during low season (winter), only one reactor is in operation.
- Phosphate removal: chemical precipitation with ferric chloride.
- Sludge line and treatment: sludge from secondary clarifier, where the flocks of microorganisms settle down is pumped directly to reed beds.

3.2.2 Sludge drying reed beds in Dellach am Drautal

The sludge drying reed technology was chosen as the sludge treatment option from economic and operational aspects. The system consists of three reed beds; each of them has a surface of 2.080 m^2, in total 6.240 m^2. Out of three parallel beds, only two are in operation since 2008. The third bed is awaiting the completion of the first filling cycle of app. 15 years. The bed depth is 2 m. Dimensions of the RBs are detailed in Table 13.

Table 13: Dimensions of RBs in Dellach

Reed bed	Width [m]	Length [m]	Area [m^2]	Height* [m]
RB 1	32	65	2.080	2
RB 2	32	65	2.080	2
RB 2	32	65	2.080	2

** height of filter layer + height for sludge depositing and freeboard*

[27] http://www.wv-oberesdrautal.at/home.html

[28]

Sludge drying reed beds were built as excavated basins. The beds are impermeabilized with high-density polyethylene film. The filter layer is 50 cm deep. The media used for the filter are layers of gravel, sand, and soil. The beds were planted with common reeds (*Phragmites australis*) and were acclimated to sludge. There is a 3 m wide maintenance path between the beds. Reed beds are connected to the wastewater treatment line with dosing and drainage piping. The uniform sludge distribution is assured through 6 distribution points from the side of the reed beds. Drainage pipes, at the bottom of the beds, are connected to the ventilation pipes to allow the passive flow of air to the bed to maintain aerobic conditions. Once water trickles down, two drainage pipes at the bottom collect water, while ventilation pipes provide unlimited air convective to the sludge layer. The WWTP has automatic control, except for manual valves, to determine which bed out of three will be fed with sludge.

3.2.3 Pictures and drawings

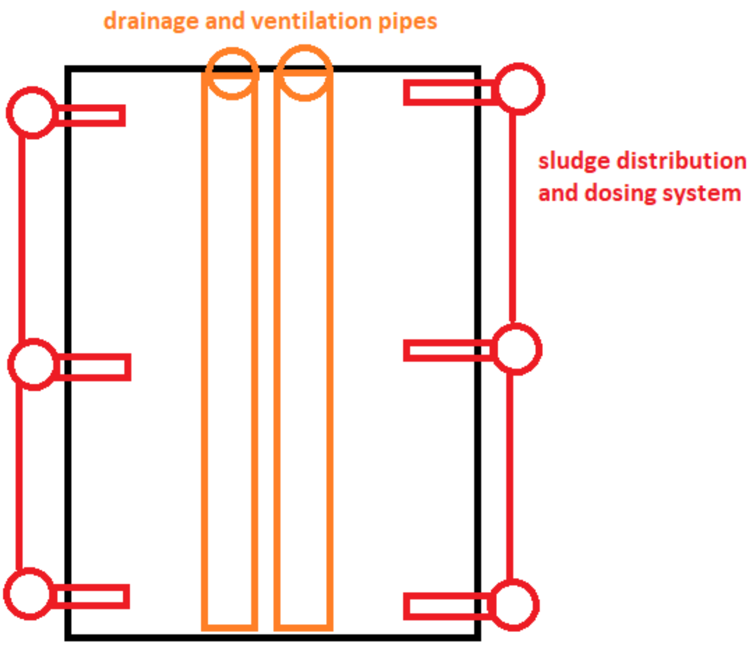

Figure 26: Sludge dosing system (red) and leachate collection system (orange)

Figure 27: Aeration/anaeration tank and RBs behind in Dellach am Drautal[29]

Figure 28: Reed beds in Dellach in May 2015 – beginning of vegetation season

Figure 29: Sludge distribution point

[29] http://www.wv-oberesdrautal.at/home.html

Figure 30: Sludge drying in Dellach

Figure 31: Reed beds in October 2019 – end of vegetation season

3.2.4 Sludge loading volume

Applied sludge volume per day is from 20 to 30 m^3 per bed.

Table 14: Sludge log data from Dellach am Drautal

Sludge loading	2015	2016	2017
Total excess sludge applied to RBs (m^3/y)	6.612	5.494	8.253
Maximum excess sludge (m^3/d)	18	15	24
Return sludge (m^3/y)	58.423	86.488	97.885

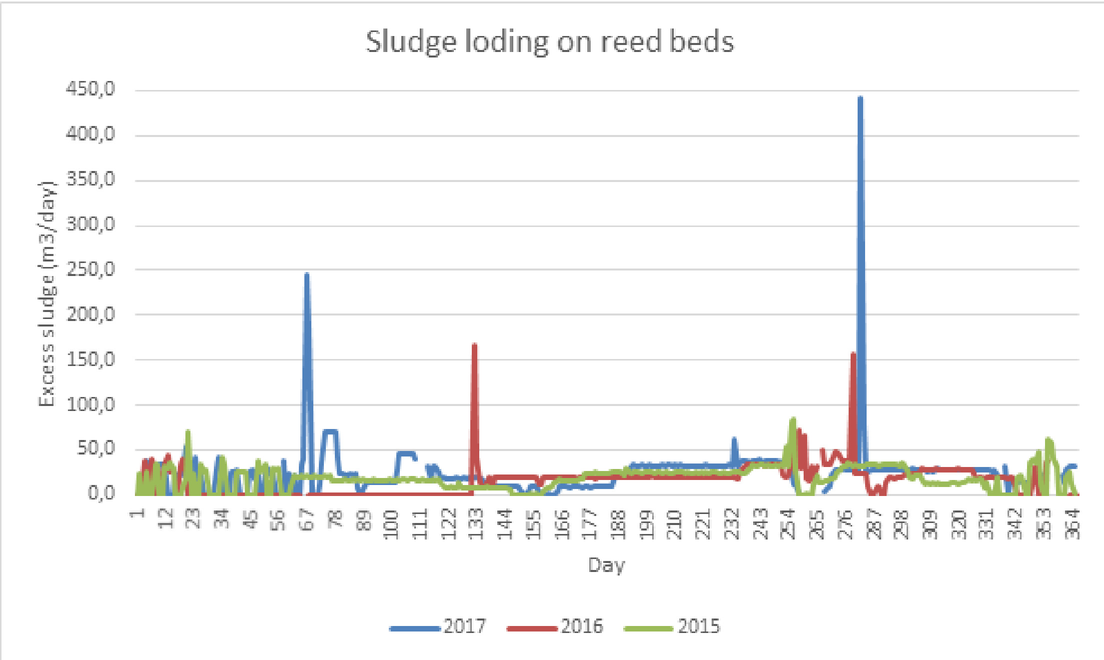

Figure 32: Daily sludge loading on reed beds in Dellach

It is assumed that sludge loading peaks occurred due to maintenance works and yearly emptying of the second tank, which is used only in the main tourist season.

Table 15: Tourist season (both tanks in operation)

Year/Month	**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**12**
2015						-	-	-			
2016				-	-	-	-	-			
2017						-	-	-	-		

Sludge loading in Dellach depends on the loading of WWTP, which is seasonal. The highest loadings are during summer, while loading is less frequent when temperatures are below zero (January, February).

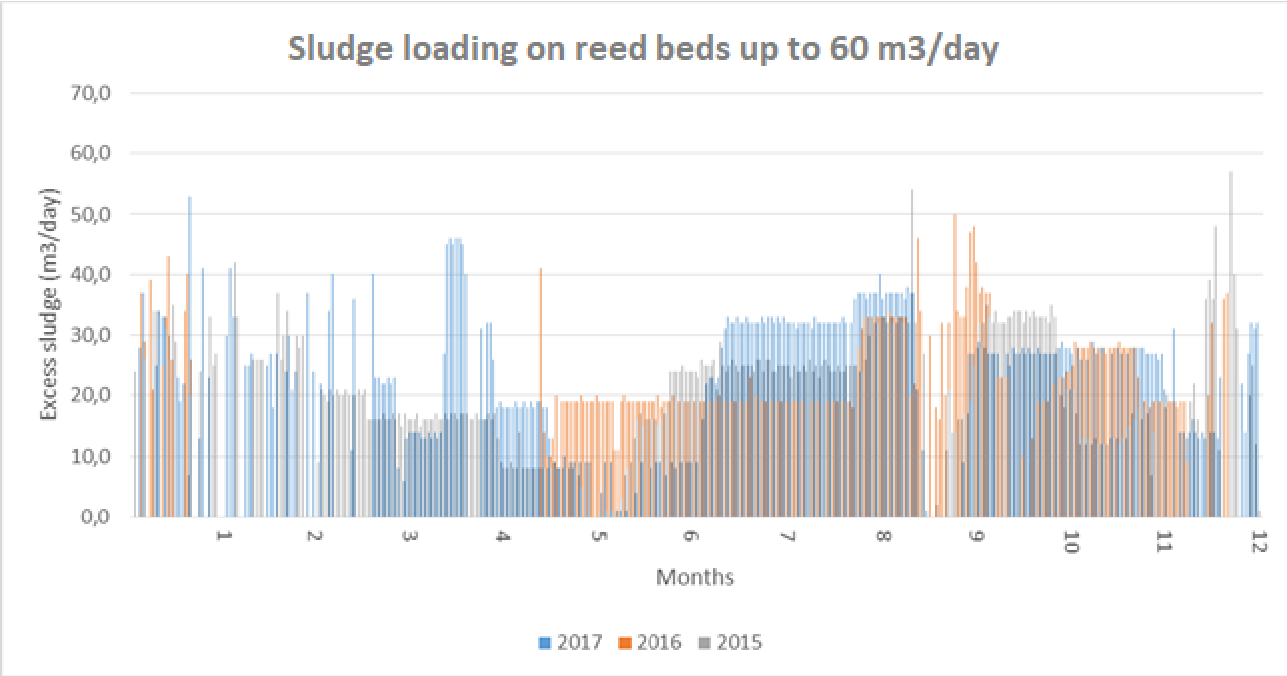

Figure 33: Sludge loading on reed beds up to 60 m^3/day

Table 16: No. of loadings per month during winter months (temperatures below zero)

Winter months	2015	2016	2017
January	13	11	13
February	16	0	13

3.2.5 Sludge loading pattern

Sludge loading can be grouped into usual (summer) and winter loading.

- Summer loading
  - Loading period from – March to October
  - Daily loading – sludge feeding every hour
  - The operating cycle per bed lasts three weeks – one bed filled every day for three weeks
- Winter loading
  - Loading period from November to February
  - Daily loading – sludge feeding once per day or less
  - The operating cycle per bed lasts three weeks – one bed filled every day for three weeks

Table 17: Loading pattern

Month	**BED 1**	**BED 2**
Week 1	Filling	*Resting*
Week 2	Filling	*Resting*
Week 3	Filling	*Resting*
Week 4	*Resting*	Filling
Week 5	*Resting*	Filling
Week 6	*Resting*	Filling

Loading during winter is much lower, and the system does not work at full capacity (more than half of the system is not in operation). Therefore, it is dosed less frequently per day. Also, winter conditions require the removal of a flexible tube to prevent freezing. This means that every time the operator pumps the sludge onto the reed beds, they have to install the flexible tube manually, and after sludge pumping is done, remove it again. The process is time-consuming, and since usually operators are present only one hour per day, wintertime sludge is pumped only once per day to save time.

3.2.6 Visual examination of RBs in Dellach, Austria

3.2.6.1 Sludge height

Sludge drying reed beds in Dellach are in operation since 2008. A sludge height of 50-60 cm was achieved in 10 years.

3.2.6.2 Sludge distribution

Feeding system enables uniform sludge distribution. There are no dead zones or uneven plant growth. Water efficiently drains from the system and there are no signs of filter clogging.

3.2.6.3 Plant growth

Plants in Dellach have grown to 2 m high. The growth is uniform. Plants reach their maximum height and density during summer (July, August), wilt after the first frost in the fall (October, November), and start growing in the spring (April, May). During field visit in October 2019, the plants were wilting because of the end of the vegetative period. They do not harvest the plants.

Figure 34: Plants at the beginning of growing season (May 2015, left) and at the end of growing season (October 2019, right)

RB technology does not predict harvesting. Harvesting of reed beds would be a quite challenging (it is difficult to walk on sludge, health issues). Plant uptake can contribute to the removals of nutrients, primarily through subsequent harvesting of biomass. However, because RBs are not being harvested, nutrients are being stored into mineralized sludge through decomposition processes on RBs surface. In terms of sludge reuse, nitrogen, phosphorus, and potassium are the most valuable nutrients in sewage sludge.

3.2.6.4 Odor

WWTPs tend to be more problematic during the winter because of the reduced activity of the bacteria. The system in Dellach has odor problems between winter loading cycles, but only when snow melts on reed beds. Odor is not related to system malfunctioning but the effect of the snow. During field visit in October 2019, there was no odor.

3.3 Other experiences with sludge drying reed beds in Alpine region

The third identified site of RBs in Alpine Region is situated in Stallhofen der Möll, south-west from Obervellach town in Austria. The location was included in the study because it was assumed, they have experience with the final disposal of biosolids. Even though the RBs are operating for more than ten years, the full capacity has not been reached yet. Thus, it is expected that the first operational cycle will last at least 20 years long and not ten years as assumed at first.

The WWTP was built in 2007 and had a capacity of 15.000 PE. Sludge treatment consists of 4 beds with a total surface area of 16.000 m2. The annual amount of fresh sludge is 16.250 m³. The fresh sludge is aerobic stabilized and contains around 2 % of total suspended solids.

Figure 35: WWTP Stallhofen der Möll[30]

According to the operator feedback[31] on RB technology, RBs are efficiently reducing sludge volume by 97 %. Annual results of sludge analysis showed that biosolids could be used in agriculture as fertilizer or for the production of humus, planting substrates, soil for flowers, landscaping, the greening of sports facilities (football fields), parks, reclamation, and landscaping after construction works.

The gained feedback on RB operation was used to confirm efficiency assumptions in Alpine climate. It also confirmed the life expectancy of reed beds as also that the filter layer should not clog after ten or more years.

[30] https://www.rhv-moelltal.at/schlammbehandlung

[31] Geschäftsführer: Herr Ing. Martin Thorer

In addition, two more cases were investigated, Mrkopalj (1.400 PE) and Ravna Gora (2.000 PE) in Croatia. The two WWTP with reed beds were constructed parallel, and trial operation of one year was launched in September 2019.

The technology applied consists of two reed beds on each location.

Figure 36: Two reed beds in Mrkopalj, after construction in 2017[32]

During the first year of operation, vegetation established on both locations. Even though locations are close by and both under the Alpine climate, the precipitation levels differ considerably. Thus, the drainage system on one location had to be adapted to micro conditions during trial operation. The sludge analysis was not done yet.

The experience from newly constructed reed beds in Croatia confirmed the importance of trial operation and that microclimate conditions impact operation of reed beds. Pilot cases before the construction of large systems (more than 10.000 PE) are highly recommended.

[32] https://www.limnos.si/projekti/mrkopalj-hrvaska/

3.4 Efficiency

RBs efficiency of RBs Mojkovac and RBs Dellach is determined by sludge analysis.

3.4.1 Sludge analysis from WWTP Mojkovac

Sludge analysis was performed to assess the sludge quality produced at Mojkovac. On-site sampling was done in October 2019. Grab samples were taken from 6 sampling points. The created sample assures homogeneity, and best represents the physical and chemical quality of sludge treated on reed beds in Mojkovac.

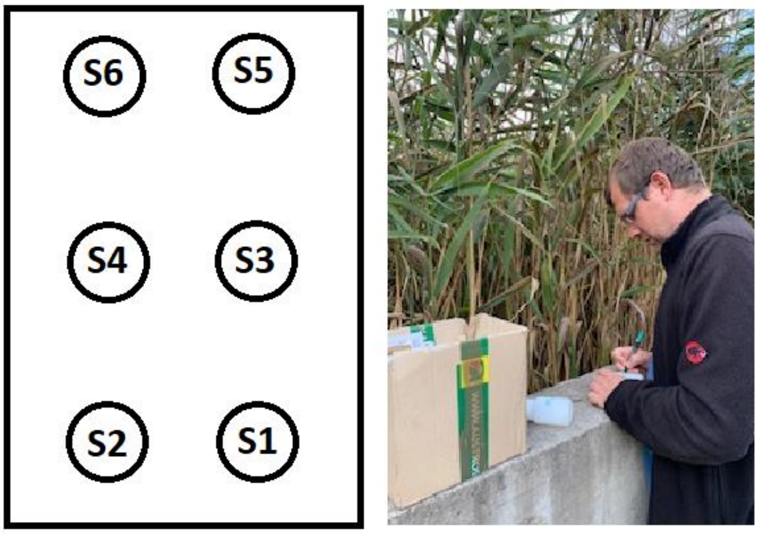

Figure 37: Sampling plan (left) and preparation for sampling (right) in Mojkovac

The analysis was performed for dry matter, total volatile solids, heavy metals, TP and TN, and pathogens. The analyses were done by a laboratory that is certified / accredited (Biotechnical University of the University of Ljubljana). Standard methods were used. The results from the analysis are presented in the table below.

Table 18: Dry matter, total volatile solids, heavy metals, TP and TN results

Parameter	Unit	Measured values		Limit for A and B class
		(S1, S2, S3, S4, S5, S6)	(P1, P2)	
Dry matter	mass %	16	16	
Total volatile solids	mass %	67	67,5	
Total nitrogen	mass %	4,9	4,6	
Total phosphorous	mass %	1,4	1,4	
Total carbon	mass %	33,5	32,5	
pH		5,8	5,9	
Cadmium (Cd)	mg/kg TS	1,8	1,7	5-10
Copper (Cu)	mg/kg TS	154	154	300 – 600
Nickel (Ni)	mg/kg TS	38	37	60 – 100
Lead (Pb)	mg/kg TS	98	94	120 – 200
Zinc (Zn)	mg/kg TS	983	995	600 – 1.200
Mercury (Hg)	mg/kg TS	2,7	2,1	5 – 10
Chromium (Cr)	mg/kg TS	55	51	100-250

* A and B: possible use of biosolids in agriculture

The disposal or intended end use of biosolids is considered as pathogen risk. Pathogen die-off in RBs is assured with a resting period 4 to 6 months of before biosolids extraction. Resting period is a period without sludge loading. Based on this, we set up the pathogen test in Mojkovac to simulate the resting period. With the test, we mimic the similar conditions to the one happening under a resting period. A part of the system was isolated to stop sludge loading onto the system in this particular area. Sludge samples were taken, and Pathogen content was determined:

- during RBs operation and
- after 10 months of resting period.

Figure 38: Set up of the pathogen test in Mojkovac

The analyses were done by a laboratory that is certified / accredited (Faculty of Health Sciences of the University of Ljubljana and Univerzitet Crne Gore, Institut za biologiju). Standard methods were used.

Table 19: Pathogens results before simulated resting period (period without sludge loading)

Homogenous sample from following sampling points	***Escherichia coli*** **CFU/g**	**Coliform bacteria CFU/g**	**Enterococci CFU/g**	***Salmonella*** **spp. in 50 g**
P1, P2	2,9*10^3	3,2*10^5	5,1*10^3	Present*

* Salmonella in 50 g sample after pre-enrichment is present but in very small numbers.

Table 20: Pathogens results after 7 months of simulated resting period (period without sludge loading)

Homogenous sample from following sampling points	***Escherichia coli*** **CFU/g**	**Coliform bacteria CFU/g**	**Enterococci CFU/g**	***Salmonella*** **spp. in 50 g**
P1, P2	1*10^2	7*10^2	1*10^3	-

In Montenegro the regulations for treated sewage sludge of A and B quality for the use in agriculture must not contain pathogen organisms.

3.4.2 Sludge analysis from WWTP Dellach am Drautal

Analyses of sludge from RBs in Dellach are done every year. The results from September 2018 are presented in the table below. All the results are within allowed limit values. Pathogen microbial content in treated sludge on reed beds is not part of the required yearly analysis.

Table 21: Dry matter, total volatile solids, heavy metals, TP and TN results from RBs in Dellach am Drautal[33]

Parameter	Unit	Measured value	Limit
Dry matter	mass %	22	
Total volatile solids	mass %	61	
Total nitrogen	%	3,4	
Total phosphorous	kg/t TS	37	
Cadmium	mg/kg TS	0,9	2
Copper	mg/kg TS	278	300
Nickel	mg/kg TS	30	60
Lead	mg/kg TS	35	150
Zinc	mg/kg TS	871	1.200
Mercury	mg/kg TS	1,1	2
Chromium	mg/kg TS	38	70

Same public utility “Wartungsverband Abwasserenstsorgung Oberes Drautal-Weissensee” that operates WWTP Dellach (7.800 PE) also operates WWTP Steinfeld (13.300 PE) and WWTP Irschen (4.950 PE), which are all in the same Region. WWTP Steinfeld composts 670 tons of sludge per year and use it in agriculture. The results of sludge from composting system in WWTP Steinfeld from February 2019 are presented below.

Table 22: Dry matter, total volatile solids, heavy metals, TP and TN results from composting system in Steinfeld[34]

Parameter	Unit	Measured value	Limit
Dry matter	mass %	22	
Total volatile solids	mass %	/	
Total nitrogen	kg/t TS	5,6	
Total phosphorous	kg/t TS	31	
Cadmium	mg/kg TS	0,5	2
Copper	mg/kg TS	222	300
Nickel	mg/kg TS	21	60
Lead	mg/kg TS	26	150
Zinc	mg/kg TS	659	1.200
Mercury	mg/kg TS	0,5	2
Chromium	mg/kg TS	21	70

The sludge analysis showed that characteristics of sludge treated on reed beds or sludge treated by composting are similar and comparable. However, sludge treated on the composting system can be used in agriculture, while sludge treated on reed beds is not allowed. The operator expects that once the reed beds are filled with sludge to the top, the bed will rest for at least one to two years. This is how they will assure pathogen day-off and gain time to decide for the final disposal of biosolids. They are also considering mixing biosolids with lime to avoid

[33] Technisches Büro für Kulturtechnik und Wasserwirtschaft, Entsorgungs- und Umwelttechnik Chemisches Laboratorium für Umwelt und Gesundheit. Prüfbericht Nr. U 18/1363 A. Untersuchung einer lärschlammprobe (Vererdungsbecken) für Wartungsverband Abwasserentsorgung Oberes Drautal-Weißensee 9772 Dellach im Drautal 197 LARA DELLACH.

[34] Technisches Büro für Kulturtechnik und Wasserwirtschaft, Entsorgungs- und Umwelttechnik Chemisches Laboratorium für Umwelt und Gesundheit. Prüfbericht Nr. U 19/0128. Untersuchung eine klarshamprobe auf basis der Kartner Klarschlamm-und Kompost-VO für Wartungsverband Abwasserentsorgung Oberes Drautal-Weißensee 9772 Dellach im Drautal 197 ARA STEINFELD.

incineration costs and loss of nutrients. The final decision will be taken by the municipality and will mainly depend on the legislation at that time.

3.4.3 RBs efficiency

There are relatively few academic articles on the effectiveness of reed beds on the content of various pollutants, as the topic is new. In reviewing the literature, one can rely on a small group of experts. Most experts are primarily concerned with heavy metals and their content in the final product (biosolids) and the quality of the final product in general - whether it meets the standards for agricultural land disposal. TS and TVS were also reviewed in terms of dry matter volume, hazardous substances, biodegradability and mineralization, micropollutants, and pathogenic organisms. Reed beds have proven effective in removing, decomposing, and accumulating different types of pollutants, which is gathered in ANNEX 5.

3.4.3.1 Heavy metals

Analysis of sludge in Mojkovac (Montenegro) and Dellach (Austria) showed that heavy metals in sludge are within allowed limits for biosolids use in agriculture. The obtained results are in line with several other studies, which show that in general heavy metal concentrations in biosolids are within the limits for unrestricted land application[35,36,37], and remain quite unchanged over time[38] or their values are slightly higher due to accumulation through years[39].

3.4.3.2 Nutrients

In Mojkovac, total nitrogen varies from 4,5 to 4,9% of mass while in Dellach measured value is 3,4%. These TN contents are similar to the TN contents of three other plants (2,9-3,2%).[40] In Polish RBs[41] the average nutrient contents were for nitrogen from 1.0 to 10% dry matter and for phosphorus from 0.2 to 1.0% dry matter. In Mojkovac, total phosphorus content is 1,4% mass and in Dellach 3,1 % mass.

Another study[42] detected a certain decrease in nutrient concentration (TN and TP) along the vertical profile of sludge treated in RBs, probably due to plant uptake during the growing season. The same pattern was detected by Pempkowiak and Obarsza-Pempkowiak[43] in sludge systems in Poland.

The results confirm that the long-term stabilization of sewage sludge causes an increase of phosphorus concentration, which is caused by the decomposition of organic matter while retaining the phosphorus. The

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[35] Uggetti, E., Llorens, E., Pedescoll, A., Ferrer, I., Castellnou, R., García, J. (2009a). Sludge dewatering and stabilisation in drying reed beds: characterisation of three full-scale systems in Catalonia, Spain. Bioresource Technology 100 (17), 3882-3890.
[36] Nielsen, S., & Willoughby, N. (2005). Sludge treatment and drying reed bed systems in Denmark. Water and Environment Journal, 19(4), 296–305. https://doi.org/10.1111/j.1747-6593.2005.tb00566.x
[37] Nielsen, S. (2007). Sludge treatment and drying reed bed systems. Ecohydrology and Hydrobiology, 7(3–4), 223–234. https://doi.org/10.1016/S1642-3593(07)70105-2
[38] Peruzzi, E., Macci, C., Doni, S., Masciandaro, G., Peruzzi, P., Aiello, M., & Ceccanti, B. (2009). Phragmites australis for sewage sludge stabilization. Desalination, 246(1–3), 110–119. https://doi.org/10.1016/j.desal.2008.02.039
[39] Nielsen, S., & Bruun, E. W. (2015). Sludge quality after 10–20 years of treatment in reed bed systems. Environmental Science and Pollution Research, 22(17), 12885–12891. https://doi.org/10.1007/s11356-014-3815-6
[40] B. Gómez-Muñoz, J.D. Larsen, G. Bekiaris, C. Scheutz, S. Bruun, S. Nielsen, L.S. Jensen,
Nitrogen mineralisation and greenhouse gas emission from the soil application of sludge from reed bed mineralisation systems, Journal of Environmental Management, Volume 203, Part 1, 2017, Pages 59-67,
ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2017.07.042.
[41] Obarska-Pempkowiak, H., Tuszynska, A., Sobocinski, Z. (2003). Polish experience with sewage sludge dewatering in reed systems. Water Science & Technology 48(5), 111-117.
[42] Yubo, C., Tieheng, S., Lihui, Z., Tingliang, J., Liping, Z. (2008). Performance of wastewater sludge ecological stabilization. Journal of Environmental Sciences 20, 385-389.
[43] Obarska-Pempkowiak, H., Tuszynska, A., Sobocinski, Z. (2003). Polish experience with sewage sludge dewatering in reed systems. Water Science & Technology 48(5), 111-117.

presence of nutrients N and P indicates that the stabilized sludge in the RBs can be a valuable fertilizer[44]. The results of nutrients suggest that the final product from the treatment, because of its stabilization, may be used as a fertilizer in agriculture.

3.4.3.3 Dry matter

In Mojkovac, dry matter is 16% while in Dellach is 22%. These are just intermediate results and samples taken during the winter. Due to climate conditions, additional solar drying is recommended before biosolids use. Dry matter in Mojkovac is lower because sludge was analysed during the period when dosing sludge on reed beds appeared every day. The reason was to empty secondary clarifier before winter so the operators can store sludge within the system for a more extended period.

RBs can increase the dry matter content of sludge by up to 40%[45] and can be comparatively better than products from mechanical dewatering[46]. A maximum content of dry matter (40%) has been obtained due to long time operation – dry matter content increases with depth[47].

3.4.3.4 Total volatile solids

In Mojkovac TVS are 67% and in Dellach are 61 %.

During sludge treatment within the reed beds, a VS reduction of 25–30 % can be achieved, reaching final VS concentrations of between 40 and 50 %. VS removal yields depend on influent sludge VS concentration. For instance, sludge from extended aeration activated sludge systems has lower VS content than that from other treatments (i.e., conventional activated sludge); hence VS removal within the wetlands is lower when this type of sludge is treated. Consequently, the efficiency in terms of VS removal of the wetlands might be slightly lower than that of aerobic digestion (40–55 %) or anaerobic digestion (35–50 %)[48,49] . On the other hand, VS contents in compost are considerably higher (60–70 %) than in sludge from other treatments, including wetlands.[50].

3.4.3.5 Pathogens

The pathogen experiment was set up in Mojkovac reed bed. It contained two isolated parts that were not exposed to the sludge. Each part was designed to mimic the resting period. We collected samples before the resting period and after 10 months of the resting period. The results showed 1 log (96,55%) reduction of E. coli, 5 log (99,78%) reduction of Coliform bacteria and 0 log reduction (80,39%) of enterococci. The reduction efficiency is lower than in Galten Sludge Reed Bed Plant[51] where pathogen content was reduced by approximately 6 log units after 6 -9 months after the last loadings, based on a dry solids basis to a level corresponding to the requirements for controlled sanitation (Salmonella-not detected, Faecal Streptococci less than 100/g and E.coli-

[44] Kominko, H., Gorazda, K., & Wzorek, Z. (2019). Potentiality of sewage sludge-based organo-mineral fertilizer production in Poland considering nutrient value, heavy metal content and phytotoxicity for rapeseed crops. *Journal of Environmental Management*, *248*(February), 109283. https://doi.org/10.1016/j.jenvman.2019.109283

[45] S. Nielsen. Sludge drying reed beds. Water Sci. Technol., 48 (5) (2003), pp. 101-109

[46] Plestenjak, Eler, K. Mihelič, R. Ferlan, M. Ogrinc, N. Krajnc, B. Vodnik, Can additional air supply enhance decomposition processes in sludge treatment reed beds? 2020. Not yet published.

[47] Obarska-Pempkowiak, H., Tuszynska, A., Sobocinski, Z. (2003). Polish experience with sewage sludge dewatering in reed systems. Water Science & Technology 48(5), 111-117.

[48] Metcalf and Eddy (2003). Wastewater Engineering: Treatment, Disposal and Reuse. McGrawHill. New York.

[49] Von Sperling and Gonçalves (2007). Sludge characteristics and production. In: Sludge Treatment and Disposal. Cleverson, Von Sperling & Fernandes Eds. IWA Publishing, London, UK, 2007.

[50] Uggetti, E., Ferrer, I., Llorens, E., & García, J. (2010). Sludge treatment wetlands: A review on the state of the art. *Bioresource Technology*, *101*(9), 2905–2912. https://doi.org/10.1016/j.biortech.2009.11.102

[51] Nielsen, S., & Willoughby, N. (2005). Sludge treatment and drying reed bed systems in Denmark. *Water and Environment Journal*, *19*(4), 296–305. https://doi.org/10.1111/j.1747-6593.2005.tb00566.x

less than 20/g). Their results correspond to the ones reported by the Danish EPA for the storage of sludge (Environmental project number 351 regarding sanitation aspects during handing and recycling of organic waste).

Another study[52] indicated that the pathogen content in the sludge residue through a period of 3–4 months after the last loading was reduced down to 2/100 g (Salmonella), 10 CFU/g (enterococci) and, 200 number/100 g (E. coli). For enterococci and E. coli the reduction was approximately log 5 and log 6–7, respectively. In the same period the sludge residue achieved a dry solids content of approximately 20–35%.

Based on the results of the pathogen experiment consultant concluded that the pathogen content was not reduced as expected (at least log 5 should be achieved). The most likely reason for that is that isolation of the area within RBs wasn't 100% and fresh sludge has infiltrated into the isolated area. The operator was asked for details, but due to overgrown vegetation, he was not able to see the isolated parts.

3.4.3.6 Generalization

Presented pilot cases showed efficient work of reed beds in the Alpine biogeographical region and potential use of biosolids in agriculture. Principal findings for reed beds in Alpine region are summarised below:

- Sludge loadings during winter are lower compared to summer loadings because of winter conditions;
- Seasonal loading changes (e.g., tourist season[53]) does not impact RBs efficiency;
- Snow melting can cause odor problems;
- Sludge analysis (intermediate results) showed that:
  - Heavy metals in sludge are within limits for biosolids use in agriculture;
  - Valuable nutrients are present in the sludge;
  - To improve dry matter content, additional solar drying is suggested before biosolids application.

[52] Nielsen, S. (2007). Helsinge sludge reed bed system: Reduction of pathogenic microorganisms. *Water Science and Technology*, *56*(3), 175–182. https://doi.org/10.2166/wst.2007.491

[53] Alps are the world's second most important tourist region after the Mediterranean coast: http://www.iscar-alpineresearch.org/documents/Factsheet_Mountains_English_000.pdf

4 COST ANALYSIS

4.1 Investment costs

Investment costs present an initial investment that includes all the fixed and non-fixed assets. Total investment costs can be divided into the following groups:

- Costs of project documentation;
- Costs of construction;
- Costs of staff training;
- Costs of dissemination.

The detailed investment cost breakdown is presented in Table 23

Table 23: Project investment cost breakdown

*Project investment cost	% of investment	Total cost (EUR)
Project documentation	13%	25.000,00
Construction	72%	138.525,00
Operation staff training	8%	14.475,00
Dissemination	8%	15.000,00
**VAT:	-	0
TOTAL (EUR):	**100%**	**193.000**

* Costs of project management fee are not included.
** Donation income is not a business activity thus falls outside the scope of VAT (VAT=O%).

The project was built with financial support provided by the government of the Republic of Slovenia to the United Nations Industrial Development Organization (UNIDO). Donor country pledged 243.221,00 EUR to the UNIDO in support of Montenegro (developing country) efforts to prevent degradation of the environment in Mojkovac. The grant was a non-refundable donation (100 %). The source of financing was not a loan and no-cofinancing from Municipality was needed.

The land for RBs construction was available and accessible. All infrastructure was already there. RBs were constructed within the WWTP Mojkovac property. Municipality of Mojkovac owned the land, thus there were no costs of land purchasing or renting through an acquisition process. Land was free of charge.

Investment costs do not include process optimization during defect liability period (trial operation) including monitoring, support for RBs operating staff, and optimization of RBs operation. These activities were not foreseen as part of the project. Although they were identified as needed during the implementation of the project, they were never carried out due to financial constraints.

Capital expenditures (CAPEX) related to investment in assets that will last for many years are expressed in EUR/PE (P.E: Person equivalent) and amount to:

- 55 EUR/PE for only construction costs,
- 77 EUR/PE for project documentation, construction, staff training and dissemination;
- *97 EUR/PE for project documentation, construction, staff training, and dissemination; including donor management fee.

***Comment**: The observed management fee is higher than a formulated price of project management by the market (higher than the market price of project management).

The following sections illustrate, in detail, the investment costs of RBs implementation in Mojkovac.

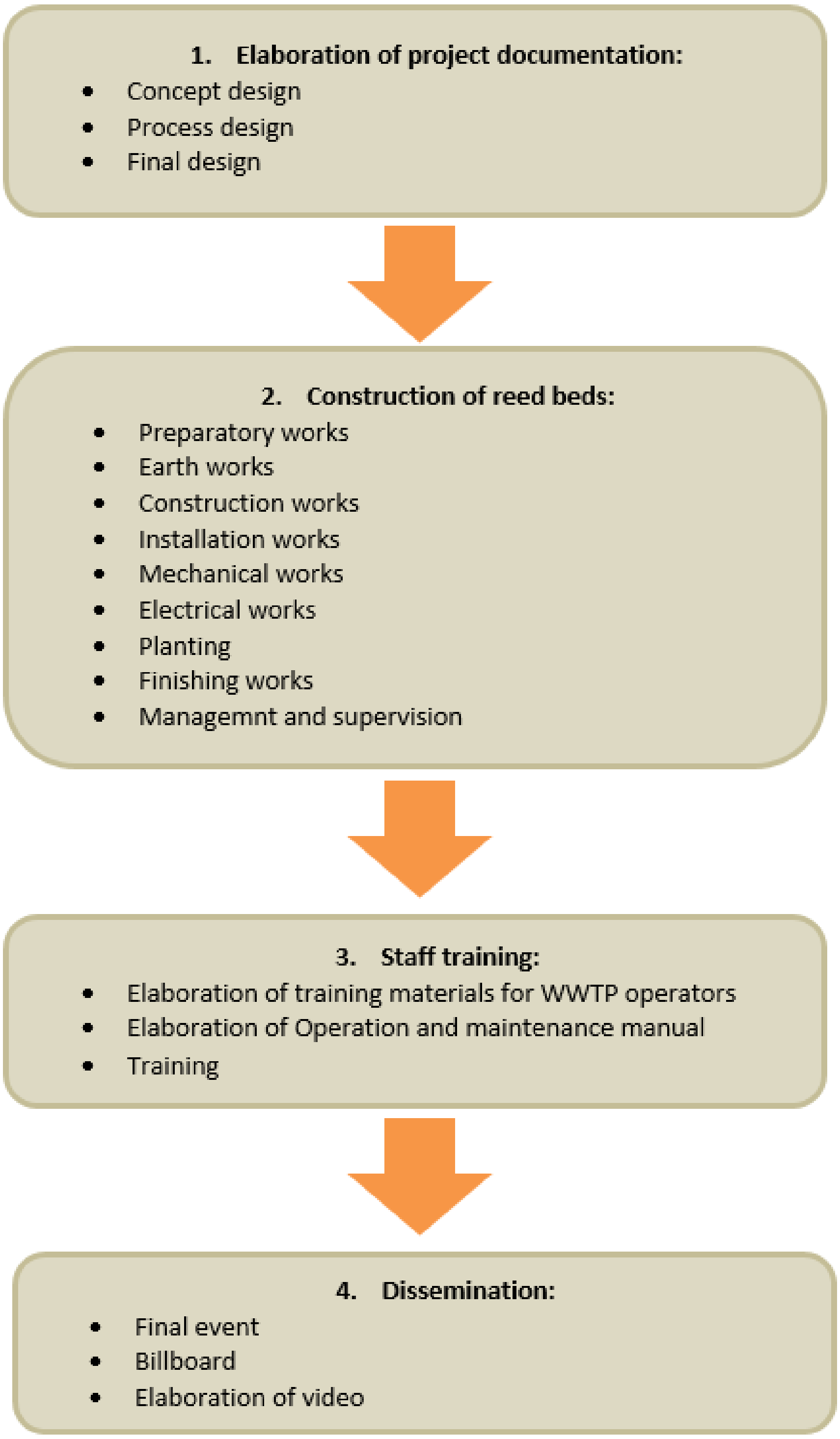

Figure 39: The steps of implementation of RBs in Mojkovac

4.2 O&M costs

Operating costs include all the costs to operate and maintain (O&M) sludge drying reed beds in Mojkovac. Analysis was carried out based on historical unit costs with the help of WWTP Mojkovac operators. Patterns of expenditures on operations and maintenance were taken into account. Forecasted costs are experienced-based and validated with current regional prices. O&M costs are project-specific and cannot be transferred to another location without detailed insight.

Typical O&M costs of RBs include regular and periodic maintenance. **Regular maintenance** is a set of measures and actions that have to be carried out regularly throughout the year, to maintain the effective sludge treatment and technology / technical correctness of RBs. **Periodic maintenance** includes a set of maintenance works necessary due to ongoing technology improvements and predicted lifetime of RBs parts. Periodic investment works ensure sustainability and increase the effectiveness of the treatment plant.

Regular operation and maintenance works of RBs consists of:

- Daily check of plants (color and growth);
- Daily check if the sludge is drying out (no water on the surface);
- Weekly control of the water level in the filter layer;
- Weekly check of external parts of drainage pipes and manholes;
- Cleaning od pipes and manholes as needed;
- RBs management and operation (loading dosing/patterns);
- Service costs of mechanical equipment (service of the pumps on a yearly basis or on number of operating hours);
- Monitoring;
- Landscaping;
- Final disposal costs.

Year after year, RBs degrade due to age and many other factors. Periodic investment maintenance consists of carrying significant repairs to restore the system optimum operational conditions. Periodic investment operation and maintenance works of RBs consists of:

- Replacement costs at the end of the warranty;
- Repairs.

An indicative list of typical O&M costs is provided in the figure below.

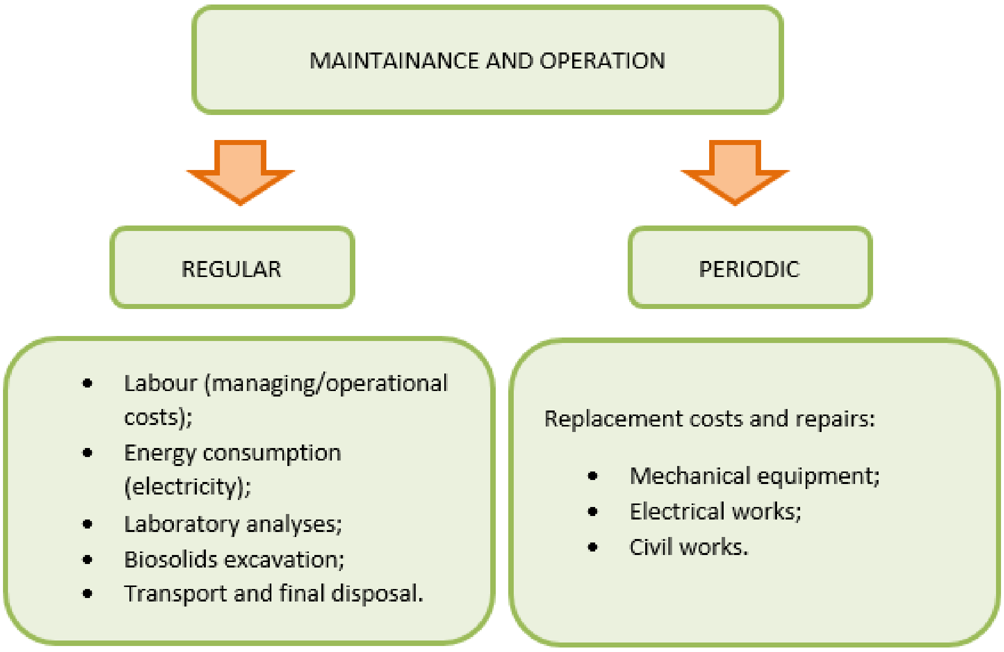

Figure 40: Typical O&M costs.

THE PUBLIC UTILITY ESTIMATED THAT ALL OPERATING COSTS FOR THE ENTIRE WWTP, NOT JUST RB, ARISE TO 2.000 EUROS PER MONTH. Their estimation does not include labor costs nor final sludge disposal costs. They perform only urgent maintenance and replacement costs and repairs. Savings for future repairs are also not included. Below a consultant estimation for all O&M works related to RBs is presented.

4.2.1 Labor costs

Labor costs are the costs of the employer working on the WWTP Mojkovac. WWTP Mojkovac operates 24 hours, seven days per week; thus, 5 people are employed taking into the account paid vacation and possible sick leave. One person must always be present at the treatment plant. In case WWTP was more automated, fewer workers would be necessary. The Municipality requested robust WWTP due to socio-economic reasons.

Table 24: Labor costs for O&M of WWTP Mojkovac

Labor costs	1 x WWTP employer	5 x WWTP employers
Hourly gross rate (EUR/h)	3,53	-
Average monthly gross salary costs (EUR/month)	519	2.595
Average gross yearly salary costs (EUR/year)	6.228	31.140

Comment: None of the employees is wastewater technical expert (higher education), which is common practised in developing countries.

In Table 24 labor costs for entire WWTP Mojkovac, including O&M costs for RBs are presented. The salary rate is the actual wage for the staff working on WWTP Mojkovac. Data was provided by public utility and not observed from the national statistical office. Gross payment includes paid holidays, sick leave, taxes, and all other contributions.

To estimate O&M costs for RBs, we had to define O&M activities related to RBs and how many working hours they require.

Table 25: O&M activities of RBs Mojkovac expressed in working hours

Labor costs	No. days	Working hours per year	Gross value (EUR/year)
Visual examination of all units of RBs (max 0,5 h/day)	365	183h	644 EUR
Sludge dosing on RBs (0,5 h/day)	69	46 h	162 EUR
Cleaning of pipes and manholes (2 x 2 days)	2	16 h	56 EUR
*Other work (10 %)		24 h	86 EUR
	TOTAL:	**257 h**	**949 EUR**

* Other work: e.g. landscaping.

Estimated working hours for O&M activities of RBs Mojkovac present 3 % of total working hours (32 days) operating the WWTP Mojkovac.

4.2.2 Electricity consumption

Energy consumption of RBs in Mojkovac is expressed in the costs of electric power required for its functioning. The pumps do not log operation hours, so an estimation of the working hours per year based on the pumped sludge on RBs (estimated value: 1.840 m^3 of pumped sludge/year) is performed.

System contains of two pumping stations:

- PUMP 1: for sludge dozing on reed beds;
- PUMP 2: for return of drained water from reed beds return back to the WWTP to be treated.

Table 26: Electricity consumption of RBs per year

Labor costs	Power	Working hours per year (hours)	Electricity (kWh/year)	Electricity consumption costs (EUR/year)
PUMP 1 – dosing	4 kW	31	132	10
PUMP 2 - collecting	1 kW	57	57	4,60
		TOTAL:	**180 h**	**14,47 EUR**

Electricity consumption of pumps considers water balance:

- an average yearly precipitation (1.197 mm/day * 900 m^2 = 1077 m^3/year)
- an estimated average yearly evapotranspiration (ET) (1.25[54] mm/day * 900 m^2 = 411 m^3/year)

[54] https://www.atlas.impact2c.eu/en/climate/evapotranspiration/

Comment on ET value: The evapotranspiration rate was observed for common reed (*Phragmites australis*) in several studies. It ranged between 0.5 and 5.5 mm/d in Kent, UK[55]. Herbst and Kappen[56] indicated exceptional values of evapotranspiration up to 20 mm/d for reed beds in northern Germany. Evapotranspiration rates in the Czech Republic from wetland dominated by *Phragmites australis* was reported to be between 6.9–11.4 mm/d[57]. Overall evapotranspiration ranges from 0 to 1,75 mm/day in Europe[58]. ET rate is influenced by the micro-location, availability of water, and changes throughout the year. The value of 1.25[59] mm/d throughout the whole year for the Alpine Region was used.

In the calculation of electricity consumption (Table 26) variable market unit cost for electricity of 0,0805 (non-household consumers, the second half of 2018)[60] €/kWh is applied. The electricity consumption is low because pumps are, on average, working only once per week for no more than half an hour. There is no other electrical consumption because the system does not have any automatic control system (monitoring, sensors).

4.2.3 Monitoring costs

WWTP Mojkovac does not perform sludge analysis every year, unlike WWTP Dellach am Drautal in Austria. The plan is to carry out sludge sampling and analysis only before the final disposal decision. Below the costs for sludge analysis for dry matter, total volatile solids, heavy metals, TP, TN, and pathogens and of heavy metals concentration analysis in soil are estimated.

Table 27: Estimated monitoring costs

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

* Soil analysis are required only if biosolids will be deposited on soil owned by the Municipality.

4.2.4 Maintenance costs of mechanical equipment

Maintenance of mechanical equipment and installations is estimated with the percentage of the CAPEX expenditure: 1,5 %. Activities include service of the pumps every year or the number of operating hours. From 2016 to 2019, the service of the pumps in Mojkovac was not carried out. Pumping station for sludge dosing is not only used for sludge dosing to RBs, but also re-circulate sludge within the WWTP system.

Table 28: Forecasted maintenance of mechanical equipment

Maintenance of mechanical equipment	**Reed beds in Mojkovac**
1, 5 % of the CAPEX for mechanical equipment	270 EUR
TOTAL:	**270**

[55] Peacock CE, Hess TM(2004) Estimating evapotranspiration from a reed bed using the Bowen ratio energy balance method. Hydrol Processes 18:247–260
[56] Herbst M, Kappen L (1999) The ratio of transpiration versus evaporation in a reed belt as influenced by weather conditions. Aquatic Bot 63:113–125
[57] Květ J (1973) Transpiration of South Moravian Phragmites communis littoral of the Nesyt Fishpond. Studies Cz Acad Sci 15:143–146
[58] https://www.atlas.impact2c.eu/en/climate/evapotranspiration/
[59] https://www.atlas.impact2c.eu/en/climate/evapotranspiration/
[60] Eurostat. 2018.

4.2.6 Replacement costs and repairs

Periodic investments present periodic maintenance and include all activities intended to restore the original condition[61] of the RBs in Mojkovac. Replacement costs and repairs of RBs are estimated based on the expected schedule of periodic maintenance works. Periodic investment maintenance tasks are organized, defined, and scheduled on regular inspection tours. Periodic investment maintenance must meet all technical specifications from project documentation (e.g., bill of quantities elaborated for the final design).

Periodic investment maintenance works of WWTP are carried out:

- due to age and consequently poor performance;
- due to bad operation;
- at the end of warranty.

Periodic investment includes:

- **Pumping station investment maintenance:**
  - Life expectancy: 10 years
  - Reasons for interventions: pump failure and wear out
  - Solution: replacement of the pump after the end of the life cycle.

- **Concrete basins investment maintenance:**
  - Life expectancy: 50 years
  - Reasons for interventions: major cracks, fractures, deformation, collapse of the system, mechanical damage (system leaking)
  - Solution: civil/building works (major repairs).

- **Piping and manholes investment maintenance:**
  - Life expectancy: 30 years
  - Reasons for interventions: cracks, fractures, deformations of the piping and manholes
  - Solution: replacement of the piping and manholes

- **Filter layer investment maintenance:**
  - Life expectancy: 30 years
  - Reasons for interventions: clogging of the filter layer
  - Solution: replacement of the substrate

- **Piping and manholes investment maintenance:**
  - Life expectancy: 30 years
  - Reasons for interventions: cracks, fractures, deformations of the piping and manholes
  - Solution: replacement of the piping and manholes

- **Access road investment maintenance:**
  - Life expectancy: min 20 years
  - Reasons for interventions: difficult to drive
  - Solution: civil/building works (major repairs)

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

Table 29: Forecasted periodic investment costs of RBs in Mojkovac

Periodic maintenance activities	Cost
Replacement of pumps	1.200 EUR/year
Major repairs of concrete basin (1 % of concrete works)	600 EUR/year
Replacement costs repairs of piping and manholes (1 % investment works)	110 EUR/year
Replacement of filter layer: 540 m^3 (excavation of existing layer, transport, deposition. Installation of a new layer and re-planting)	720 EUR/year
Repairs of access road (1 % of investment costs)	51 EUR/year
TOTAL:	**2.681 EUR/year**

In Table 32 the main periodic activities with estimated yearly costs are shown. Since RBs in Mojkovac are in operation, no periodic maintenance works were carried out. In Table 32 periodic maintenance works are estimated.

4.2.7 Final disposal or reuse costs

Cost analysis considers two options for sludge final disposal:

- Option 1: Reuse of biosolids
- Option 2: Incineration

Used variable unit costs, which are market-based:

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

In 2017 price for sludge collection and export to Albania was 65,95[62] EUR/ton for ex. WWTP Budva along the Montenegrin coast. Export to Albania is still the cheapest option, while export to Hungary is much more costly, totalling 180[63] EUR/ton. However, from January 2020 export to Hungary is no longer an option due to the Hungarian ban on imports of foreign sludge.

Table 30: Final disposal costs (based on design data)

Optimal scenario	Regular scenario
40% dry matter 40% mineralization	25% dry matter 40% mineralization
94 ton/year	151 ton/year
5.667 EUR/year for incineration **1.417 EUR/year biosolids reuse**	**9.067 EUR/year for incineration** **2.267 EUR/year biosolids reuse**
Operational cycle: 11 years	Operational cycle: 7 years

*Reuse of dehydrated sludge is not feasible.

Since the start of reed bed operation, around 10 cm of sludge is accumulated in both beds. According to the project calculation, the sludge layer should be thicker. This is an indicator that in the WWTP system is producing less suspended solids (e.g., less sewage connections) than predicted during the design phase. According to calculations, during the current period, the sludge height should be at least 25 cm. The height of residual sludge

[62] http://www.cin-cg.me/primorske-opstine-ekoloske-probleme-sele-komsijama-mulj-ide-u-albaniju-ponekad-i-u-more/
[63] https://www.vijesti.me/vijesti/drustvo/lose-planiranje-stvorilo-tone-kanalizacionog-otpada-dobre-namjere-potonule-u-mulj

over time affects the annual cost estimation. Below a scenario of sludge removal after the completion of the first filling cycle of cc. 20 years is presented.

The RBs basins will be excavated to a depth of 1.0 meter and 10 meters wide by 45 meters long. The sludge removal from both beds will not take place at the same time. One bed will be emptied first, then the second after a year or two.

Table 31: Final disposal costs taking into the account filling cycle of 20 years (forecasted sludge production based on real time data)

Final disposal costs	**Reed beds**
Sludge excavation • SDRB 1 (sludge production in m^3) • SDRB 2 (sludge production in m^3)	 450 450
Sludge excavation total (m^3):	900
Sludge production per year with existing loading (m^3/year):	45
Forecasted sludge production per year (ton/year):	51,75
****Disposal – incineration (EUR/year):**	**3.105**
Disposal – biosolids reuse (EUR/year):	**776**

*Incineration plant in Montenegro is not yet constructed. The nearest planned incineration plant will be in Podgorica (Mojkovac-Podgorica = 91 km). It is also not known whether sludge from WWTP Mojkovac would be accepted.

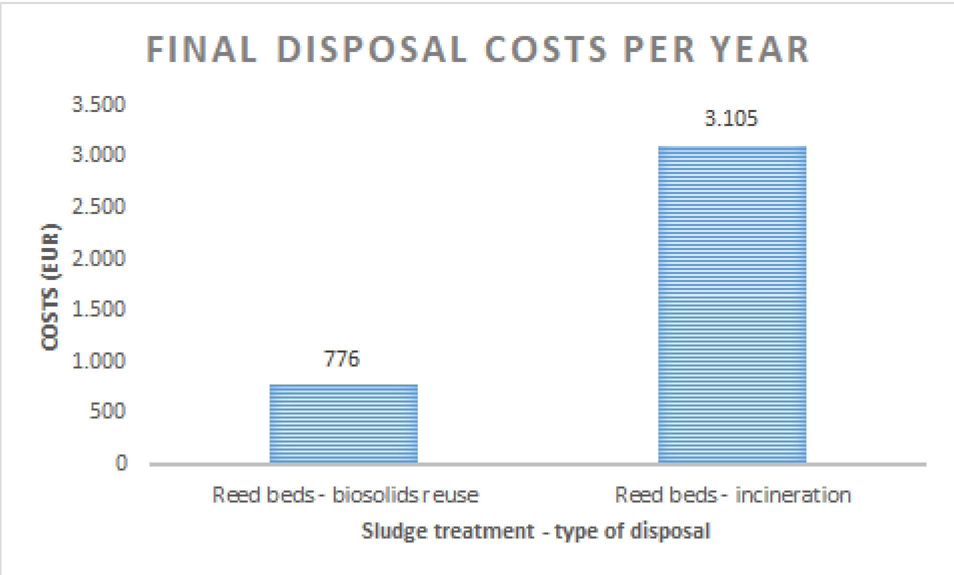

Figure 41: Final disposal costs taking into the account filling cycle of 20 years (forecasted sludge production).

4.2.8 Overview of O&M costs

Table 32: Cost analysis of RBs in Mojkovac

O&M costs	Reed beds
Labor costs (EUR/year)	949
Electricity consumption (EUR/year)	15
Monitoring (EUR/year)	72
Reagents (EUR/year)	0
Maintenance (EUR/year)	2.951
TOTAL (without disposal) in EUR/year:	**3.987**
TOTAL (without disposal) in EUR/PE/year:	**1,59**
Disposal – incineration (EUR/year)	5.667
TOTAL with incineration in EUR/year:	**9.654**
TOTAL with incineration in EUR/PE/year:	**3,86**
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**

* For disposal are used design values for RB capacity with 2.500 PE

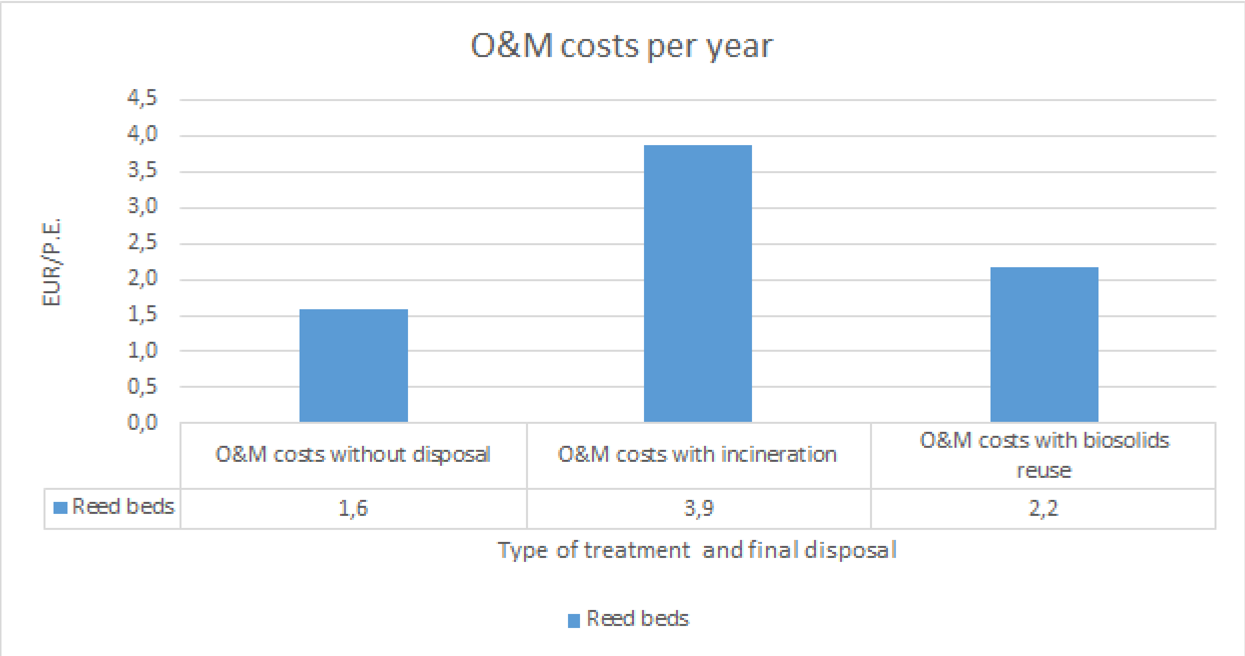

Figure 42: O&M costs for sludge treatment per year

4.3 Tariff revenues

4.3.1 Water tariff

Source of financial revenues comes from the application of charges to users of services (tariffs). In Mojkovac, water services include drinking water supply, wastewater collection, and treatment. The methodology for price setting is set by governmental decree. The tariff is proposed by the public water service provider and approved by Municipality. Tariff correction happened only once in ten years, and they are not planning to change it soon.

Table 33: Water tariffs paid by users

Municipality	Cost of delivery of water and wastewater treatment services for persons with VAT (€ / m³)	Cost of water delivery and wastewater disposal services for legal entities including VAT (€ / m³)
Mojkovac	0,56	2,01

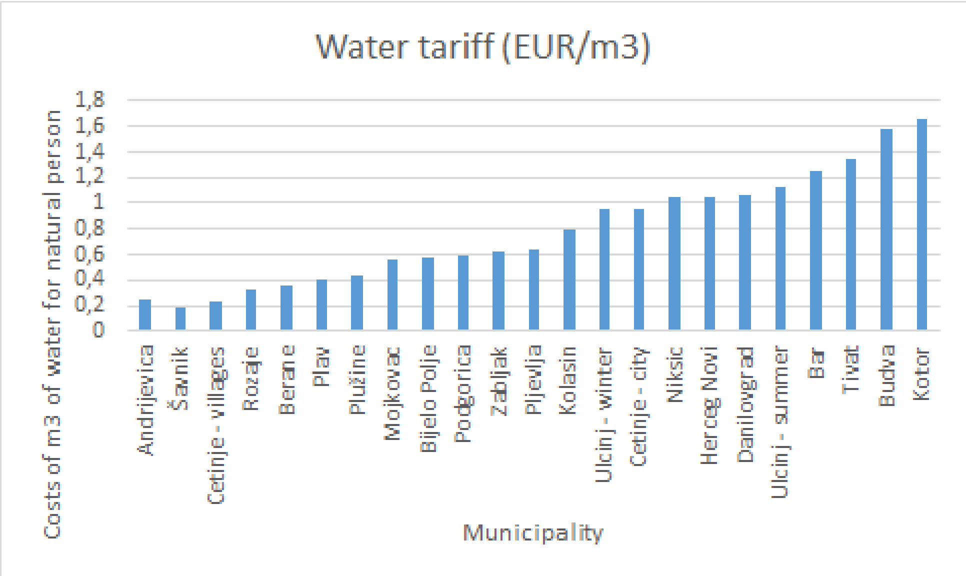

Figure 43: Cost of water in Montenegro in EUR/m³ [64]

4.3.2 Cash flow analysis

4.3.2.1 Grant

The assumptions made for the cash flow analysis of RBs in Mojkovac:

- Cash in-flows
  - **Non-refundable donation (grant)**
  - The application of charges to users (revenues)
    - water tariff per cubic meter (monthly charges) – paid to public utility
    - public utility charges – paid to Municipality
- Cash out-flows
  - Investment costs
  - O&M costs

[64] Udruzenjevodovoda.me

Different entities own and operate the infrastructure. The body responsible for project implementation is Municipality of Mojkovac, while WWTP is operated by the public utility "Komunalne usluge Gradac" Mojkovac (concession contract). Financial analysis excludes cash flows between the owner and the operator and does not depend on the internal payments.

The financial discount rate adopted is 4 %. Project cash-flow forecasts 30 years of RBs operating life. Within this period, project impacts are long-term. The projections of flow cash are based on the following assumptions:

- Revenues are calculated from design capacity (m^3 x 0,56 EUR/m^3); only purchased water was taken into account (without infiltration rate).
- The calculation is verified only if the current water tariff can cover NPV O&M costs; other costs derived from water tariffs are excluded.

Table 34: Projections of flow-cash with grant

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

Existing water tariffs can cover RBs operation, and its share is presented in the graph below. Initial investment was covered with a 100 % grant; thus, we assessed only the price of the tariff required for O&M activities.

Table 35: Assessment of water tariff rates to cover operation and maintenance of sludge treatment

Type of sludge treatment and final disposal	Water tariff for O&M (EUR/m^3) of RBs	% of existing water tariff (0,56 EUR/m^3) for persons
Reed beds + incineration	0,13	23%
Reed beds + biosolids use	0,07	13%

The cash-flow for the best option (reed beds + biosolids use) is detailed below.

Table 36: Detailed projection of cash-flow with grant for reed beds with biosolids reuse

Year	INFLOW		OUTFLOW	
	Grant	NPV Revenue	Investment	NPV O&M costs
0	193.000	0	-193.000	0
1	0	40.117	0	-5.196
2	0	38.574	0	-4.996
3	0	37.091	0	-4.804
4	0	35.664	0	-4.619
5	0	34.293	0	-4.441
6	0	32.974	0	-4.271
7	0	31.705	0	-4.106
8	0	30.486	0	-3.948

Year	INFLOW		OUTFLOW	
	Grant	NPV Revenue	Investment	NPV O&M costs
9	0	29.313	0	-3.797
10	0	28.186	0	-3.651
11	0	27.102	0	-3.510
12	0	26.060	0	-3.375
13	0	25.057	0	-3.245
14	0	24.093	0	-3.120
15	0	23.167	0	-3.000
16	0	22.276	0	-2.885
17	0	21.419	0	-2.774
18	0	20.595	0	-2.667
19	0	19.803	0	-2.565
20	0	19.041	0	-2.466
21	0	18.309	0	-2.371
22	0	17.605	0	-2.280
23	0	16.928	0	-2.192
24	0	16.277	0	-2.108
25	0	15.651	0	-2.027
26	0	15.049	0	-1.949
27	0	14.470	0	-1.874
28	0	13.913	0	-1.802
29	0	13.378	0	-1.733
30	0	12.864	0	-1.666
SUM	193.000	721.460	-193.000	-93.440
Cash flows:	**Cash in-flow**		**Cash out-flow**	
	914.460		**-286.440**	

4.3.2.2 Loan

A 100 % grant is not always the case, so a scenario of providing financial resources through loans was created. Long-term financial services pursued by national or global development banks include the financing of public infrastructure. In the case of Mojkovac, initial investment costs (193.000 EUR) are small compared to major infrastructure estimated at millions of euros, thus financing through national banks is more realistic. The loan is predicted as an outflow. It is assumed to be paid back in 30 years.

Assumptions for cash analysis scenarios:

- Long-term loan: 30 years;
- Fixed interest rate (0,7 %);
- Euribor interest rate is not included, because it is below zero since November 2015;
- Revenues derived from water tariff (0,56 EUR/m^3);
- NPV of O&M costs;
- Investment costs incl. also project documentation, staff training, and dissemination.

Cash-flow projections with loans are presented in the table below.

Table 37: Projections of flow-cash with loan

Scenario	In-flow/out-flow	Flow	EUR
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**

Existing water tariff can cover RBs investment costs through loan and operation costs (Table 38). It is necessary to note that no other costs on water and wastewater infrastructure in Mojkovac paid from water tariff revenues are considered; thus we are not in a position to evaluate whether water tariff is or is not appropriate. We can only conclude that the tariff of 0,28 EUR/m^3 is sufficient to cover RBs investment costs through loan and 0&M costs with incineration. Other wastewater services (e.g., O&M costs of WWTP) should also be added to this tariff, which is not within the scope of this project.

Table 38: 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 loan + O&M (EUR/m^3) of RBs	% of existing water tariff (0,56 EUR/m^3) for persons
Reed beds + incineration	0,30	53%
Reed beds + biosolids reuse	0,24	43%

Below detailed cash-flow projection for the highest-ranked option from a financial point of view is presented – sludge treatment on reed beds and final disposal of sludge with biosolids reuse.

Table 39: Detailed projection of cash-flow with loan for reed beds with biosolids reuse

Year	INFLOW	OUTFLOW			INFLOW-OUTFLOW	REMAINING DEBT
	Revenue	Loan repayments	Fix interest rate (0,70%)	O&M costs		
0	0			0	0	
1	40.117	-5.803	-1.333	-5.196	27.786	-206.932
2	38.574	-5.843	-1.293	-4.996	26.442	-199.796
3	37.091	-5.884	-1.251	-4.804	25.152	-192.660
4	35.664	-5.926	-1.210	-4.619	23.909	-185.524
5	34.293	-5.967	-1.168	-4.441	22.716	-178.389
6	32.974	-6.009	-1.127	-4.271	21.567	-171.253
7	31.705	-6.051	-1.084	-4.106	20.464	-164.118
8	30.486	-6.093	-1.042	-3.948	19.402	-156.983
9	29.313	-6.137	-999	-3.797	18.381	-149.847
10	28.186	-6.180	-956	-3.651	17.400	-142.712
11	27.102	-6.223	-912	-3.510	16.456	-135.576
12	26.060	-6.266	-868	-3.375	15.550	-128.442

Year	INFLOW	OUTFLOW			INFLOW-OUTFLOW	REMAINING DEBT
	Revenue	Loan repayments	Fix interest rate (0,70%)	O&M costs		
13	25.057	-6.311	-825	-3.245	14.676	-121.306
14	24.093	-6.355	-780	-3.120	13.838	-114.171
15	23.167	-6.399	-736	-3.000	13.032	-107.036
16	22.276	-6.444	-691	-2.885	12.256	-99.902
17	21.419	-6.490	-645	-2.774	11.510	-92.766
18	20.595	-6.535	-600	-2.667	10.793	-85.631
19	19.803	-6.581	-554	-2.565	10.104	-78.497
20	19.041	-6.628	-509	-2.466	9.439	-71.360
21	18.309	-6.674	-461	-2.371	8.803	-64.225
22	17.605	-6.720	-414	-2.280	8.191	-57.091
23	16.928	-6.768	-369	-2.192	7.598	-49.954
24	16.277	-6.817	-320	-2.108	7.032	-42.817
25	15.651	-6.866	-271	-2.027	6.486	-35.680
26	15.049	-6.913	-225	-1.949	5.962	-28.542
27	14.470	-6.960	-177	-1.874	5.459	-21.405
28	13.913	-7.009	-126	-1.802	4.977	-14.271
29	13.378	-7.058	-77	-1.733	4.511	-7.136
30	12.864	-7.108	-28	-1.666	4.062	0
SUM	**721.460**	**-193.018**	**-21.050**	**-93.440**	**392.885**	

4.3.3 Tariff and affordability analysis

For the provision of water services, a single entity is engaged as an operator. It can estimate tariff affordability to ensure tariffs are maintained within consumers' ability to pay. It determines the required annual revenues to ensure that the cumulative cash flow would meet cash operating costs, depreciation and debt service.

Under the Law on Public Utilities ("Official Gazette of Montenegro", No. 055/16 of 17.08.2016, 074/16 of 01.12.2016) financing of communal activities and maintenance of communal infrastructure, equipment and assets, as well as investment maintenance of communal infrastructure in Montenegro is provided from:

- funds collected from the provided utility services;
- local government budget;
- other sources.

According to Art. 53 of the Law, utility prices are determined based on the following elements:

- cost of hiring the necessary workforce;
- energy consumed;
- maintenance costs of utility infrastructure and associated equipment;
- loan repayment costs for the construction of utility infrastructure and the acquisition of related equipment;
- supplies of consumables;
- other costs incurred in providing the service.

The funds collected from the utility services provide for the provision of utilities, investment maintenance of the utility infrastructure, equipment, and resources needed to perform the services.

Existing water tariffs in Mojkovac are applied for the analysis. Tariff analysis includes assessment of affordability for project beneficiaries. It should ensure that all community members have access to these services without placing a significant burden on their household expenditures.

In Montenegro, a national regulatory body[65] has been established that defines and validates the methodology for tariff setting. Previously the municipalities could set the tariffs themselves. The procedure begins with the operating public utility suggesting the level of a tariff, regulatory body approves it and, lastly, the municipality accepts it. According to the regulatory body rules, the tariff should not exceed 3% of the household income (price ceiling).

The average household income is based on socio-economic data. In Montenegro, there are 192.242 households. On average, a household has 3.2 members[66]. Mojkovac has 1.385 households with three to five members, 637 members with two members, 533 households with one member[67]. In September 2019, the average net wage payment was 516 EUR and the average gross payment was 775[68].

Figure 44: Average net and gross[69] earnings taxes in EUR from September 2018 to September 2019[70]

According to national statistics[71], the structure of personal consumption reveals household costs of 14,6% for water, electricity, and housing (combined) for urban areas outside the capital of Podgorica in 2015. The following table provides expenditure ratios calculated from personal consumption for Montenegro. Affordability ratio tells us the ratio between the expenditure on a given utility service and the household's total income[72].

[65] Regulatorna agencija za energetiku je organizacija osnovana u skladu sa zakonom kojim se određuju energetske djelatnosti i uređuju uslovi i način njihovog obavljanja (u daljem tekstu: Agencija);
[66] https://www.monstat.org/eng/page.php?id=57&pageid=57
[67] https://www.monstat.org/userfiles/file/popis2011/saopstenje/Saop%20%20struktura%20domacinstava%2004_11_.pdf
[68] http://monstat.org/userfiles/file/zarade/2019/9/zarade%20saopstenje%20septembar%202019.pdf
[69] Gross earnings include taxes and contributions.
[70] http://monstat.org/userfiles/file/zarade/2019/9/zarade%20saopstenje%20septembar%202019.pdf
[71] https://www.monstat.org/eng/page.php?id=72&pageid=72
[72] https://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

Table 40: Affordability ratio for water, electricity and housing, 2015

	Montenegro	Urban area	Other area	Podgorica
Water, electricity and housing (%)	13,66	13,90	13,26	12,61

Household income in Montenegro varies between capital, urbanized, and other areas and is presented in the table below. Mojkovac falls under the urban area.

Table 41: Household income in Montenegro (2015)[73]

	Montenegro	Urban area	Other area	Podgorica
Total available assets (EUR)	644	669	596	714

Affordability analysis has been carried out and its affordability limit has been set. The projected tariff represents 0,68 % of average monthly household income.

Table 42: Affordability analysis (2015)

Average monthly consumption (m^3)	Average water bill (EUR)	Average household income in 2015 (EUR)[74]	Affordability ratio (%)	Affordability limit (EUR)
8	5	669	0,68	20,07

* Data for urbanised areas outside capital of Podgorica.

The share of expected income spent on wastewater bill is less than 3 % of average household income and therefore affordable.

4.4.4 Sources of financing

Mojkovac municipality benefitted from being a small but active municipality and was able to receive an international grant. The action was part of the efforts of the landscape reclamation program of a larger mining area in the city. It was necessary due to the proximity of the environmentally relevant and protected area of the Tara river.

While it is normal for developing countries to maximize the uptake of grants before seeking repayable sources of finance, it is rarely an option for most of the remaining communities. Mainly a 100 % grant is rare; thus, investors can use different financial instruments, as elaborated in ANNEX 6.

The decision on sources of financing varies and is site-specific. Mostly it depends on the following factors:

- urgency to act (health, environmental causes) that hinders development potential of a site/location
- legislation as an ultimate driver of change (and its threat of penalization with negative financial impact for the community);
- general purchasing power of the users of the community (and availability of subsidies);
- identification and pressure on the polluters in the community and their tariff payment potential.

[73] https://www.monstat.org/eng/page.php?id=72&pageid=72
[74] https://www.monstat.org/eng/page.php?id=72&pageid=72

4.4 Net present value

Calculated net present value (NPV) takes into account:

- The average economic life of the project assets (time horizon) is assumed to be 30 years;
- Initial investment costs (capital costs);
- Operational and maintenance costs;
- The real discount rate applied is 4%.

Table 43: Net present value of sludge treatment in EUR

Sludge treatment + disposal	NPV O&M	NPV Investment	NPV Total	Ranking
Reed beds + incineration	-166.931	-193.000	**-359.931**	**2**
Reed beds + biosolids reuse	-93.440	-193.000	**-286.440**	**1**

The results showed that biosolids reuse have a higher ranking compared to incineration. More about the NPV and how can be used is summarized in ANNEX 7.

4.5 Return on investment

Estimating of annual cost savings (avoided costs) deriving from changed sludge disposal (incineration or biosolids use) are presented in Table 44. Results showed that the Municipality of Mojkovac could save up 93.440 EUR in case of biosolids reuse.

Table 44: O&M savings if we select biosolids reuse over incineration

Year	O&M costs for reed beds + incineration (EUR/year)	O&M costs for reed beds + biosolids use (EUR/year)	Annual savings (EUR/year)	Total savings – Net revenue (EUR)
0	0	0		
1	9.282	5.196	5.196	
2	8.925	4.996	4.996	10.192
3	8.582	4.804	4.804	14.996
4	8.252	4.619	4.619	19.615
5	7.935	4.441	4.441	24.056
6	7.629	4.271	4.271	28.327
7	7.336	4.106	4.106	32.433
8	7.054	3.948	3.948	36.381
9	6.783	3.797	3.797	40.178
10	6.522	3.651	3.651	43.828
11	6.271	3.510	3.510	47.339
12	6.030	3.375	3.375	50.714
13	5.798	3.245	3.245	53.959
14	5.575	3.120	3.120	57.079
15	5.360	3.000	3.000	60.080
16	5.154	2.885	2.885	62.965
17	4.956	2.774	2.774	65.739
18	4.765	2.667	2.667	68.406
19	4.582	2.565	2.565	70.971

Year	O&M costs for reed beds + incineration (EUR/year)	O&M costs for reed beds + biosolids use (EUR/year)	Annual savings (EUR/year)	Total savings – Net revenue (EUR)
20	4.406	2.466	2.466	73.437
21	4.236	2.371	2.371	75.809
22	4.073	2.280	2.280	78.089
23	3.917	2.192	2.192	80.281
24	3.766	2.108	2.108	82.389
25	3.621	2.027	2.027	84.416
26	3.482	1.949	1.949	86.365
27	3.348	1.874	1.874	88.239
28	3.219	1.802	1.802	90.041
29	3.095	1.733	1.733	91.774
30	2.976	1.666	1.666	93.440
SUM:	166.931	93.440	93.440	

4.6 Cost comparison analysis (RBs vs mechanical dewatering)

Chapter compares the expenditures, tariff revenues, net present value and return on investment of RBs to mechanical dewatering. A more detailed cost comparison analysis is presented in ANNEX 7.

While there is substantial uncertainty in the precise cost analysis on RBs in Mojkovac, a strong case can be developed on RBs as a cost-effective solution in terms of sludge management. For the leading group of analysed costs, a summary of cost comparison analysis is presented in Table 45.

Table 45: Summary of cost analysis (based on design values)

Cost analysis	Reed beds	Mechanical dewatering
INVESTMENT COSTS		
Construction costs (EUR)	138.525	80.000
Initial investment costs (EUR)	193.000	134.475
O&M COSTS		
O&M costs without final disposal (EUR/year)	3.987	8.826
Final disposal – incineration (EUR/year)	5.667	18.900
Final disposal – biosolids reuse (EUR/year)	1.417	-
Total O&M costs with incineration (EUR/year)	9.654	27.726
Total O&M costs with biosolids reuse (EUR/year)	5.404	-
NPV		
NPV total with incineration (EUR)	-359.931	-613.914
NPV total With biosolids reuse (EUR)	-286.440	-
TARIFF REVENUE (grant considered)		
Cash inflow-outflow – with incineration (EUR)	554.529	242.021
Cash inflow-outflow – with biosolids reuse (EUR)	628.020	-
TARIFF REVENUE (loan considered)		

Cost analysis	Reed beds	Mechanical dewatering
Cash inflow-outflow – with incineration (EUR)	340.461	92.880
Cash inflow-outflow – with biosolids reuse (EUR)	414.062	-
REQUIRED WATER TARIFF		
Tariff for O&M - with incineration (EUR/m^3)	0,13	0,38
Tariff for O&M - with biosolids reuse (EUR/m^3)	0,07	-
Tariff for investment costs with loan and 0&M costs - with incineration (EUR/m^3)	0,30	0,49
Tariff for investment costs with loan and 0&M costs - with biosolids reuse (EUR/m^3)	0,24	-
POTENTIAL COST SAVINGS FROM CHANGED PRACTICE (MECHANICAL DEWATERING CHANGED TO REED BEDS)		
Potential of cost savings – incineration (EUR/30 years)	312.507	0
Potential of cost savings – biosolids reuse (EUR/30 years)	385.999	0
POTENTIAL INVESTMENT RETURN FROM COST SAVINGS (MECHANICAL DEWATERING CHANGED TO REED BEDS)		
Potential investment return for construction costs of RBs - incineration	10 years	
Potential investment return for construction costs of RBs – biosolids use	8 years	

4.7 Generalization

Presented cost analysis is case-specific, and all prices apply to Montenegro and not for other Alpine countries. The presented cost methodology is transferable, but with use of case-specific prices. Below a regional diversity of prices around the Alpine region is shown.

Labor costs

Presented labor costs based on the pilot case in Montenegro are among lower in the Alpine region. When transferring this data to the Alpine region, it must be considered that hourly earnings can vary from 2,03 EUR/hour in Romania to 29,46 EUR/hour in Switzerland (Table 46).

Table 46: Median gross hourly earnings in countries of Alpine Region.

Country	Median gross hourly earnings in EUR/hours, all employees (excluding apprentices), 2014[75]
Albania	2,19[76]
Andorra	16,60[77]
Austria	14,02
BiH	4,54[78]

[75] https://ec.europa.eu/eurostat/statistics-explained/index.php/Wages_and_labor_costs#Gross_wages.2Fearnings
[76] https://balkaneu.com/salaries-albania-drastic-gap-minimum-maximum-pay/
[77] http://www.salaryexplorer.com/salary-survey.php?loc=6&loctype=1
[78] https://tradingeconomics.com/bosnia-and-herzegovina/wages

Country	Median gross hourly earnings in EUR/hours, all employees (excluding apprentices), 2014[75]
Bulgaria	1,67
Croatia	4,90
Czechia	4,56
Finland	17,24
France	14,94
Germany	15,67
Greece	8,00
Hungary	3,59
Italy	12,49
Kosovo	3,15[79]
Liechtenstein	30,44[80]
North Macedonia	2,20
Montenegro	3,42
Norway	27,99
Poland	4,29
Romania	2,03
Russia	4,04[81]
Serbia	2,63
Slovakia	4,40
Slovenia	7,32
Spain	9,83
Sweden	18,46
Switzerland	29,46
Ukraine	2,53[82]

Water tariff

Water tariffing is a complex topic as it depends on multiple local parameters like tax level, water sources, length of network per inhabitant, receiving water, etc. It is generally regulated through a public body, either an official regulator or the local government. [83] Below a snapshot of the current situation in the EU member countries with average prices of water per m^3 is presented. Prices are useful in evaluating the global diversity of prices across Europe; however, a direct comparison of water bills or the price per cubic meter between countries is not possible. [84]

[79] https://tradingeconomics.com/kosovo/wages
[80] http://www.salaryexplorer.com/salary-survey.php?loc=123&loctype=1
[81] https://tradingeconomics.com/russia/wages
[82] https://tradingeconomics.com/ukraine/wages
[83] http://www.eureau.org/resources/publications/1460-eureau-data-report-2017-1/file
[84] http://www.eureau.org/resources/publications/1460-eureau-data-report-2017-1/file

Table 47: Average price of water tariffs around the Europe[85] (countries in Alpine region)

Country	Drinking water network length per capita (m)	Average residential consumption (l/cap/d)	Wastewater network length per capita (m)	Average price of water tariff (€/m3)
Austria	9,37	135	11,28	3,67
Bulgaria	/	/	/	/
Croatia	7,8	150	14	1,98
Czech Republic	7,38	8,55	4,48	3,27
Finland	19,4	119	11,0	5,89
France	15	143	6	3,92
Germany	6,94	122	7,37	/
Greece	6,61	150	4,46	1,40
Hungary	6,74	95	5,01	2,65
Italy	5,8	245	4,7	1,5
Norway	8,43	140	12,2	5,7
Poland	7,59	94,17	5,4	2,15
Romania	3,5	136	1,3	1,42
Serbia	/	/	/	/
Slovakia	5,5	79	2,4	2,4
Slovenia	15,09	102,34	4,33	2,17
Spain	4,8	139	3,54	1,78
Sweden	9,2	140	8,9	4,44
Switzerland	7,2	307	15,4	2,1

4.8 Conclusions of the cost analysis

Cost analysis conclusions based on pilot case in Mojkovac:

- Construction costs of RBs amounted to 55 EUR/PE without project documentation and dissemination;
- Estimated operational and maintenance costs (labor, energy consumption, monitoring, regular and periodic maintenance) of RBs are 2,16 EUR/PE/year with biosolids reuse and 3,86 EUR/PE/year with incineration. At the moment, all operating costs for the entire WWTP, not just RB, arise to 0,8 EUR/PE without labor costs and final sludge disposal costs. Public utility performs only urgent maintenance works, hence the difference in price;
- Ranking options (RBs with incineration and RBs with biosolids use) by NPV showed that biosolids reuse is considered a more financially acceptable option;
- Comparing reed beds to mechanical dewatering showed that investment in mechanical dewatering (32 EUR/PE) is cheaper for 42%, but RBs has lower operational costs and are in cheaper in the long term. Operational costs of RBs in Mojkovac with biosolids (2,16 EUR/PE/year) use are every year for more than 80 % cheaper than mechanical dewatering with incineration (11,09 EUR/PE/year). Cost savings from O&M costs are from 312.507 EUR (with sludge incineration) to 385.999 (with biosolids reuse) for a period of 30 years. In 8 to 10 years, cost savings could repay construction costs in RBs;

[85] http://www.eureau.org/resources/publications/150-report-on-the-governance-of-water-services-in-europe/file

- The existing water tariff (0,56 €/m^3) supposedly covers around 80 % of water and wastewater costs because they want to keep water affordable. In this Study, calculated water tariff needed for RBs should be set at 0,07 €/m^3 to cover OPEX of RBs with biosolids use and 0,13 €/m^3 to cover OPEX of RBs with incineration. In case Municipality of Mojkovac would not get the 100% non-refundable grant and should take the loan to finance implementation of RBs, the needed water tariff would be higher for 0,17 €/m^3 (0,24 €/m^3 to cover CAPEX and OPEX of RBs with biosolids use and 0,30 €/m^3 to cover CAPEX and OPEX of RBs with incineration);
- Cost analysis of the pilot case in Mojkovac showed how important is to adapt a long-term perspective. It should be a basis for local authorities to make related sludge decisions and plans;
- The obtained results are case-specific and do not reflect the situation of the whole Alpine region.
- The approach used for cost analysis is transferrable, but not the used units and prices. Cost assessment also demonstrated vulnerability related to specific conditions and expert judgment.

5 DIRECT AND INDIRECT BENEFITS

The growing demand for using benefit analysis to assess prospective policies, their implementation potential, and advantages of benefit transfer methods (BTM) have triggered an increased interest in the benefit transfer technique. Time and money are saved when economically valuing ecosystem goods or services.

The main objective of this chapter is to make a quantification and valuation of the direct and indirect benefits (recreation, landscape improvement and value of land, flood protection, biodiversity, etc.) through appropriate value transfer methods as well. The methodological approach to choose the best appropriate value transfer methods is presented in ANNEX 8.

Following the best available techniques and information, the next main groups of direct and indirect benefits were defined, measured and estimated by quantified parameters:

DIRECT BENEFITS:

- Avoided capital expenditures - quantified in EUR/PE;
- O&M cost-saving - quantified in EUR/year;
- Efficiency of WWTP with RBs in operation - quantified in kW/m3, kWh/kgBOD/d, kWh/kgCOD/d, kWh/kgN/d, kWh/kgP/d.

INDIRECT BENEFITS[86] in:

- **Scenic Views**
  - *How many people benefit from seeing RBs from homes, roads or trails*
    - Number of homes within 150 m of the site
    - Number of homes within 100 m of the site
    - Weighted number who benefit
    - Are there roads or trails within 100 m of the site?
  - *Service Quality*
    - Aesthetic features or characteristics?
  - *Scarcity*
    - NBS or water within 200 m (number or %)
  - *Complements that people can benefit*
    - Number and types of natural land use within 200 m – impacting what is attractive about the landscape
  - *Preferences*
    - Will people find it aesthetically pleasing?
- **Environmental Education**
  - *How Many Benefits*
    - Education institutions within 800 m of the site
  - *Service Quality*
    - Features/habitat/wildlife of education interest?
  - *Scarcity*
    - Wetlands within 800 m of the site
  - *Complements*
    - Educational facilities or infrastructure on-site?
  - *Preferences*
    - Will people prefer the characteristics of the site?
- **Recreation**

[86] Assessing the Benefits of Wetland Restoration: A Rapid Benefit Indicators Approach for Decision Makers, US EPA/600/R-16/084, July, 2016

- *How Many Benefits*
  - Number of homes within 530 m of the site
  - Are there bike paths within 530 m of the site?
  - Are there bus stops within 530 m of the site?
  - Number of homes within 0 to 800 m of the site
  - Number of homes within 0,80 to 10 km of the site
- *Service Quality*
  - Total area of green space around the site, ha
- *Scarcity*
  - green space in ha within 1 km of the site
  - green space in ha within 1,6 km of the site
  - green space in ha within 20 km of the site
  - green space in ha within 20 km of the site
- *Complements*
  - Infrastructure supporting recreational activities?
- *Preferences*
  - Are there additional features on the site?

- **Bird Watching**
  - *How Many Benefits*
    - Number of homes within 500 m of the site
  - *Service Quality*
    - Will the site support rare or unique species?
  - *Scarcity*
  - *Complements*
    - Supporting habitat on the site?
  - *Preferences*
    - Will people be interested in birds at the site?
- **Biosolids reuse**
  - *How Many Benefits*
    - Number/area of agricultural land within 5 km of the site
  - *Service Quality*
    - What is the service quality?
  - *Scarcity*
    - Is there a need for a soil amendment?
  - *Complements*
    - Is there willingness to pay for biosolids?
  - *Preferences*

5.1 Direct benefits

RBs Mojkovac are designed and installed to provide direct benefits (reduce sludge volume and pollutants). These are demonstrated through O&M costs savings and avoided capital expenditures. They result from design and operation and can be measured or estimated.

5.1.1 Avoided expenditures

5.1.1.1 Capital costs

The capital costs (CAPEX), for reed beds dewatering, are presented in detail in chapter 4 COST ANALYSIS. The capital expenditures for RBs were 193.000 EUR (77 EUR/PE), including project documentation, construction, operation staff training, and dissemination. The Municipality of Mojkovac received a 100 % grant, FROM WHICH

Municipality of Mojkovac directly benefited. It has to be emphasised that the Municipality received the grant due to shown advantages of RBs over other technologies.

5.1.1.2 O&M costs

For direct benefits by using RBs solution in Mojkovac, the typical expenditures are taken into account, which are in detail presented in chapter 4 COST ANALYSIS.

Functioning reed beds are operated continuously for several years without harvesting sludge, it is estimated that in Mojkovac, sludge residue will be removed after the completion of the first filling cycle of ca. 20 years due to lower loadings. Except for the initial reed establishment and the excavation process on average at every ten or more years, the only routine operation is visual inspection and operation (sludge dosing). There is no need for annual harvesting or frequent weeding.

Transport and disposal costs are lower for sludge disposal with biosolids reuse. Also, reed beds require less labor, energy consumption, replacement, and repairs of mechanical and electrical equipment than mechanical dewatering. The annual costs of using RBs are presented in the table below.

Table 48: Annual cost of using reeds

O&M costs	Reed beds
TOTAL O&M costs without final disposal (EUR/year)	**3.987**
TOTAL O&M costs with incineration (EUR/year):	**9.654**
TOTAL O&M costs with biosolids reuse (EUR/year)	**5.404**

The analysis of cash flows that water that reed beds and biosolids reuse represents the lowest share of existing water tariff per person for covering the initial and O&M costs. It can be concluded that the most affordable type of sludge treatment in WWTP Mojkovac is using RBs aiming at biosolids reuse. The cost savings in RBs for sludge treatment were the main reason to implement technology in Mojkovac.

5.1.1.3 Comparison of RBs to mechanical dewatering

To quantify the financial benefits of RBs, it is necessary to compare them with an alternative – for the Municipality of Mojkovac that was mechanical dewatering. The cost comparison is presented in the Table *45* and shows that OPEX of RBs with biosolids reuse (5.404 €/year) is cheaper for 22.322 EUR/year than OPEX of mechanical dewatering with incineration (27.726 €/year).

Table 49: Cost savings

Cost analysis	Cost savings
CAPEX (EUR)	-58.525
OPEX - with biosolids reuse (EUR/year)	22.322

Detail calculation and presentation of avoided expenditures through comparison between RBs and mechanical dewatering is presented in ANNEX 9.

5.1.2 Energy efficiency of WWTP with RBs

5.1.2.1 Efficiency of WWTP with RBs in Dellach, Austria

RBs in Mojkovac does not log operational data, so we couldn't make conclusions on the relation between energy and treatment efficiency. Thus, we used data from RBs in Dellach, Austria.

An overview of the total efficiency during the operation process expressed through the consumed energy for the treatment of the main parameters: BOD, COD, Total N, and Total P is given in the table below.

Table 50: Energy efficiency indicators for WWTP with RBs in a three-year period

WWTP	Year	Type	Electricity consumption				
			kWh/m³	kWh/KgBOD/d	kWh/KgCOD/d	kWh/KgN/d	kWh/KgP/d
WWTP with RBs[87]	2015-2017	I	0,148	0,248	0,157	1,822	11.452

The observed electricity consumption for COD removal is lower than the ones Lango et. al[88] reports (1,54 kWh/kg COD-removed) for 2.000 PE<WWTP<10.000 PE and also lower than set benchmark values in the document Benchmarking Energy Use for Wastewater Treatment Plants[89]: 1,4 kWh/kg COD-removed, 3,0 kWh/kg BOD-removed, 14,8 kWh/kg N-removed. It can be concluded that reed beds for dewatering of excess sludge increase WWTP energy-efficiency.

5.1.2.1.2 Comparison of efficiency of WWTP with RBs to WWTP with mechanical dewatering

Efficiency in WWTP using RBs in Dellach (Austria) and WWTP in Sillistra (Bulgaria) using mechanical dewatering of sludge was compared. The results are presented in the table below (for more information see ANNEX 9).

Table 51: Energy efficiency indicators for WWTP with and without RBs

WWTP	Electricity consumption				
	kWh/m³	kWh/KgBOD/d	kWh/KgCOD/d	kWh/KgN/d	kWh/KgP/d
Better efficiency of WWTP with RBs for (%)	2,63	76, 84	46,05	69,75	64,68

5.2 Indirect benefits

The indirect benefits from RBs could be based on:

- Social
- Environmental
- Economic (outcomes emerging from enhancing environmental services).

More general information about the indirect benefits of RBs can be found in ANNEX 10.

5.2.1 Social

From a social point of view, reed beds as NBS enable:

- Social cohesion
- Cultural values
- Stakeholders' collaboration as:

[87] WWTP Dellach, Austria. Designed for 7.800 PE

[88] Longo, S., d'Antoni, B. M., Bongards, M., Chaparro, A., Cronrath, A., Fatone, F., … Hospido, A. (2016, October 1). Monitoring and diagnosis of energy consumption in wastewater treatment plants. A state of the art and proposals for improvement. Applied Energy, Vol. 179, pp. 1251–1268. https://doi.org/10.1016/j.apenergy.2016.07.043

[89] Benchmarking Energy Use for Wastewater Treatment Plants. (N.D.). https://doi.org/10.21139/wej.2018.023

- Civil engagement;
- Reuse opportunities.

5.2.1.1 Social cohesion

RBs in Mojkovac could foster collaboration across the full spectrum of stakeholders such as farmers, utility operators, municipal officials, and residents to ensure cross-sectoral buy-in and commitment for nature-based solution policies and planning guidelines.

Based on stakeholder engagement in Mojkovac several categories of social values, which have indirect benefits, were defined as follows:

- Educational [90] - estimated as low;
- Well-being[91] - estimated as high;
- Life sustaining[92] - estimated as medium;
- Social inclusion[93] - estimated as low;
- Safety[94] - estimated as medium.

The overall social cohesion is estimated as low to medium.

5.2.1.2 Cultural values

As for cultural values, several categories were recognized for Mojkovac, which have indirect benefits for the current study, as follow:

- ***Aesthetic***[95] - estimated as high:

RBs in Mojkovac merge harmoniously with green nature and the surrounding mountains, rich in reeds, which had recounted in the acceptance of WWTPs, which is in the vicinity of the city center. Reed beds present green area, thus enhance aesthetic qualities. Solution contributes to the overall improvement of the:

- scenic attributes and preferences;
- nature's beauty;
- enjoyment of sights, sound and smells;
- aesthetical experiences;
- naturalistic styles of landscape design;[96].

- ***Recreation / Tourism sustainability and development, taking into account the value of Tara river natural assets*** [97] - estimated as high***:***

Using RBs as nature-based solution for the excess sludge treatment in WWTP Mojkovac, reduces:

- Daily / weekly transportation of mechanically dewatered sludge;

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[90] (Özgüner, Kendle and Bisgrove, 2007) (Sherrouse, Clement and Semmens, 2011) (Plieninger et al., 2013) (Vierikko and Niemela, 2016) (Langemeyer et al., 2015)

[91] (Sherrouse, Clement and Semmens, 2011) (Graham et al., 2013) (Bieling et al., 2014) (Camps-Calvet et al., 2015) (Kenter et al., 2015) (Bryce et al., 2016)

[92] (Sherrouse, Clement and Semmens, 2011) (van Riper et al., 2012) (Graham et al., 2013) (Karrasch, Klenke and Woltjer, 2014) (Uren, Dzidic and Bishop, 2015) (Vierikko and Niemela, 2016)

[93] (Özgüner, Kendle and Bisgrove, 2007) (Graham et al., 2013) (Dieleman, 2015) (Kenter et al., 2015)(Vollmer et al., 2015) (Fish, Church and Winter, 2016) (Matthew Dennis and James, 2016) (Vierikko and Niemela, 2016)

[94] (Özgüner and Kendle, 2006) (Graham et al., 2013) (Demuzere et al., 2014) (Karrasch, Klenke and Woltjer, 2014)

[95] (Özgüner and Kendle, 2006) (Özgüner, Kendle and Bisgrove, 2007) (Bryan et al., 2010) (Sherrouse, Clement and Semmens, 2011) (van Riper et al., 2012) (Plieninger et al., 2013) (Bieling et al., 2014) (Langemeyer et al., 2015) (Cooper et al., 2016) (Fish et al., 2016) (Vierikko and Niemela, 2016)

[96] (Weber, Kowarik and Säumel, 2014) (Vierikko and Niemela, 2016) (Ives et al., 2017)

[97] (Bryan et al., 2010) (Sherrouse, Clement and Semmens, 2011) (van Riper et al., 2012) (Vollmer et al., 2015) (Fish et al., 2016) (Matthew Dennis and James, 2016) (Vierikko and Niemela, 2016)

- Greenhouse gas emissions produced during transport to further management phase of mechanical dewatering sludge;
- Reduces the risk of untreated sludge being discharged to the Tara River. The sustainable sludge treatment, based on RBs, ensures that the Tara River will not be polluted during the extreme load operation of WWTP because of unpredicted peak loads caused by water quantity and the inflow contamination.

This, in turn, leads to a decrease of several environmental factors, based on reduction of the frequent transportation of dewatered sludge:

- Noise stress;
- Air pollution;
- Gas emissions

The indirect effect would be related to the tourism sustainability and development in Mojkovac district area.

The overall cultural values are estimated as high.

5.2.2.3 Stakeholders' collaboration

Stakeholder engagement and collaboration during RBs planning can help local dialogue and promote community involvement through the site revitalization process. Reed beds deployment in Mojkovac did not have considerable stakeholder participation (only public utility, municipality, and environmental ministry). Montenegro is a centralised country (capital Podgorica and coast benefiting from the majority of government measures and economic impact). Municipality of Mojkovac is considered remote and poorly connected (bad roads) to the capital. It takes more than two hours to travel less than 100 km. That is one of the reasons why more stakeholders did not directly and personally participate in the meetings and final event.
The following stakeholders' collaboration possibilities (civil engagement based on institutional and individual stakeholders' collaboration) are presented below:

- Using stabilized biosolids in agriculture, consequently reducing the quantity of commercial fertilizer (limited global resources of mineral phosphate).
- Use on green areas and parks;
- Use for land re-cultivation on landfills, tailings and mining areas and site recovery;
- The low cost/environmental-friendly technology enables improvement of soil conditions (nutrients beneficial as a soil amendment for crop production, organic matter improves soil physical properties for microbial activity, increased water retention capacity, and plant growth support).

The unwillingness of farmers to use or pay for biosolids impacts all involved stakeholders and a final decision regarding final disposal. Currently, the only possibility to use biosolids is to use them in non-food agricultural areas, degraded areas restoration, forest regrowth, etc. Negative opinions towards biosolids use could be improved with stakeholders` collaboration. At the moment, zero activities are addressing this negative attitude and low awareness of circular economy decisions/opportunities.

The overall stakeholder`s collaboration is estimated as medium.

5.2.2 Environmental

RBs enhanced the aesthetics of WWTP and probably contributed to higher acceptance of WW treatment in Mojkovac. In general, people are against having a WWTP in their backyard. However, RBs could make people less contrary due to aesthetic reasons, and if they were told that due to RBs, their monthly water bill would not increase. In Mojkovac this statement is supported by the:

- lower costs compared to mechanical dewatering - water tariff did not increase,
- less traffic - less emissions because technology does not require sludge transport, and
- environmental protection of the Tara river - preserved environment since RBs were constructed (and sludge was not deposited in nature).

Development due to RBs is possible in the future (possible biosolids use – mineralised sludge is not a waste but a resource, environmental degradation is prevented, and new area/river preserved from sewage sludge deposition –).

RBs enabling sludge treatment in Mojkovac and provide green area with additional functions as:

- Habitats;
- GHG emissions;
- Use of biosolids;
- Contribute to wastewater retention capacity.

5.2.2.1 Habitats

Maintaining the biological diversity in alpine NBS/RBs areas, such as Mojkovac's RBs could impact the quality of life of inhabitants by bringing and enriching[98]:

- biodiversity;
- fauna and flora;
- personal and community values ecosystems
- wildlife conservation.

RBs Mojkovac supports a diverse range of invertebrate species. Many species[99] can be found; operators noticed the existence of earthworms (a sign of soil health), frogs, and birds. This suggests that RBs may be at least as biodiverse as naturally occurring reed-beds and add to the overall biodiversity. No bird type could be named by the operator being present in significant numbers.

The indirect habitat benefits are estimated with medium impact.

5.2.2.2 Greenhouse gas emissions

The study provides CO_2 and N_2O emissions (Table 52) derived from the transport of dewatered sludge from Mojkovac to Podgorica for incineration. Methodology and calculations are presented in the ANNEX 10.

Table 52: CO2 and N2O emission footprint emissions over the period of 1 and 20 years as a function of the type of sludge dewatering (RB=reed beds, MD=mechanical dewatering) and disposal methods (incineration or land application)

[98] (Özgüner, Kendle and Bisgrove, 2007) (Sherrouse, Clement and Semmens, 2011) (van Riper et al., 2012) (Laurila-Pant et al., 2015)
[99] https://www.hindawi.com/journals/ijecol/2012/324295/

C02 and N2O emission footprint over the life cycle of the project as a function of the type of sludge dewatering and disposal					
TYPE OF SLUDGE DEWATERING AND DISPOSAL		**RB with inceneration**	**RB with land application**	**MD with inceneration**	**MD with land application**
CALCULATION OF THE C02, CH4 and N2O FOOTRPINT		value	value	value	value
Load capacity of trailer of four-axle dump truck (Scania p420)	м3	17	17	17	17
Load capacity of trailer of four-axle dump truck (Scania p420)	tons	20	20	20	20
Own weight of four-axle dump truck (Scania p420)	tons	9	9	9	9
Total weight of four-axle dump truck (Scania p420) with load capacity of trailer	tons	29	29	29	29
CO2 emission rate of full load four-axle dump truck with trailer	gCO2 / km	800	800	800	800
Transported material distance from WWTP Mojkovac to WWTP Podgorica, Montenegro	km	95	5	95	5
Dewatered sludge	t / year	94	94	315	315
Period of years	years	20	20	20	20
Dewatered sludge	t / 20 years	1.880	1.880	6.300	6.300
Number of trucks	number / year	5	5	16	16
Transported material distance from WWTP Mojkovac to WWTP Podgorica, Montenegro	km / year	893	47	2.993	158
Carbon footprint of material transportation for 1 year	kgCO2 / year	714	38	2.394	126
Transported material distance from WWTP Mojkovac to WWTP Podgorica, Montenegro	km / 20 years	17.860	940	59.850	3.150
Number of trucks	number / 20 years	94	94	315	315
Carbon footprint of material transportation for 20 years	kgCO2 / year	14.288	752	47.880	2.520
Average annual wastewater treatment at the outlet	m3/year	118.250	118.250	118.250	118.250
Electricity consumption for WWTP	kWh/m3	0,15	0,15	0,15	0,15

C02 and N2O emission footprint over the life cycle of the project as a function of the type of sludge dewatering and disposal					
TYPE OF SLUDGE DEWATERING AND DISPOSAL		**RB with inceneration**	**RB with land application**	**MD with inceneration**	**MD with land application**
CALCULATION OF THE C02, CH4 and N2O FOOTRPINT		value	value	value	value
Average annual electricity consumption	kWh/year	17 501	17 501	17 974	17 974
Electricity emission factor	Kg/kWh	0,09	0,09	0,09	0,09
Average annual electricity carbon footprint	***Kg/year***	1.558	1.558	1.600	1.600
Average electricity carbon footprint for 20 years	***Kg/ 20 years***	31.152	31.152	31.994	31.994
Total C02 footprint for 1 year	**Kg/year**	**2.272**	**1.596**	**3.994**	**1.726**
Total C02 footprint for 20 years	**Kg/ 20 years**	**45.448**	**31.912**	**79.880**	**34.520**
Land application (Composted sludge) N20 emission factor	kg/ton		0,05		
Land application (Dry sludge) N20 emission factor	kg/ton				0,29
Incineration N20 emission factor	kg/ton	1,64		1,64	
Average annual N20 emission	**Kg/year**	**154**	**5**	**517**	**91**
Average N20 emission for 20 years	**Kg/ 20 years**	**3.083**	**94**	**10.332**	**1.811**

CO_2 and N_2O emission footprint emissions as a function of the sludge dewatering technology and disposal methods are presented in the table below. The table is designed based on the disposal routes of excess sludge as well as the sludge treatments, produce greenhouse gases (GHG).

- Each process generates direct emissions:
    - Storage;
    - Thickening;
    - Anaerobic digestion;
    - Composting;
    - Land applications;
    - Incineration;
- Indirect emissions are due to:
    - Energy and chemical consumptions (combustible or electricity) to operate each process.
    - Transport emissions (for consumables, sludges and ashes), and
    - Electricity emissions.

Taking into account the emission calculations, we can rank the best available techniques for reducing C02 and N20 footprints (1 – best alternative; 4 worst alternative) produced by sludge handling, which is suitable for WWTP Mojkovac:

1. RB, with land application emitting emission footprint of 31,91 tons $C0_2$ and 0,09 tons N_20 for 20 years;
2. MD, with land application emitting emission footprint of 34,52 tons $C0_2$ and 1,81 tons N_20 for 20 years;
3. RB, with incineration emitting emission footprint of 45,45 tons $C0_2$ and 3,08 tons N_20 for 20 years;
4. MD, with incineration emitting emission footprint of 79,88 $C0_2$ and 10,33 tons N_20 for 20 years.

The RBs have lower emissions than mechanical dewatering; thus their indirect benefits related to GHG emissions are high. It can be concluded that using RBs for sludge dewatering and subsequent biosolids use for land application seems to be the best alternative to reduce emissions footprint.

5.2.2.3 Use of biosolids

The required agricultural land for biosolids use in Mojkovac is shown below (for more information regarding calculation see ANNEX 10).

Table 52: Existing and theoretical potential of biosolids use in agriculture

Biosolids in agriculture		
1 Scenario: Extensive agriculture		
Required agricultural land	ha (min)	332
	ha (max)	553
2 Scenario: Intensive agriculture		
Required agricultural land	ha (min)	71
	ha (max)	118

In Mojkovac, there are 4.580 ha of agricultural land, 31.802 ha of pastures, forest, grasslands, and shrubs and 71 ha of mineral extraction sites. Therefore, the Municipality of Mojkovac has enough area and possibilities for final biosolids disposal. Municipality of Mojkovac would like to sanitate forest erosion with the use of biosolids. The material can also improve the characteristics of non-agricultural land.

The benefits of biosolid application on agricultural land is estimated as low due to low quantities of biosolids. However, the benefits of the use of biosolids for local forest erosion are estimated as high.

5.2.3 Economic

Economic indirect benefits of using RBs in the Municipality of Mojkovac are:

- Cost savings for the water community
    - achieving better energy efficiency by reducing the use of electric equipment;
    - reducing costs for final sludge disposal;
    - reducing overall O&M costs;
    - rising the willingness to pay for WWT service;
- Lower demand for commercial fertilizer (limited global resources of mineral phosphate). Every ten or more years, around 1.000 tons of biosolids will be available, which could complement the use of commercial fertilizer.

The cost analysis of RBs in Mojkovac showed that sludge services cost less than conventional dewatering, disposal, or incineration. In the case of mechanical dewatering and disposal, the municipality of Mojkovac needs to increase water tariffs. Thus, RBs are a more financially sustainable solution. Since RBs implementation, the water tariff stayed the same.

The indirect economic benefits are estimated as high.

5.2.4 Rapid indirect benefit indicators assessment

The current chapter assesses the quantitative information, qualitative information, and narrative information for measuring indirect indicators.

Table 57 presents quantitative information summarized based on the mean value of all the data collected. Values indicating higher benefits relative to the mean, are color-coded in blue, and values indicating lower benefits relative to the mean, are coded in red. Quantitative information that does not vary across the sites is informative but presented in grey as not very relevant.

Qualitative information, such as yes/no indicators, is also summarized using color-coding. In most cases, a yes value indicates higher benefits and appears in blue, while a no value indicates lower benefits, and appears in red.

A 'no' indicates higher benefits and appears in blue, and a 'yes' indicates lower benefits and appears in red.

Table 53: Quantitative, qualitative and narrative indirect benefit indicators[100]

Indirect	Summarize the Indicators		Site
Benefit	**Indicators**		**Mojkovac WWTP with RBs**
Scenic Views	3.2 How Many Benefit?	Number of homes within 150 m of site	0
		Number of homes within 100 m of site	0
		Weighted number who benefit	0
		Are there roads or trails within 100 m of site?	Yes
	3.3.A Service Quality	Aesthetic features or characteristics?	Yes
	3.3.B Scarcity	NBS or water within 200 m (number or %)	1
	3.3.C Complements	Natural land use types within 200 m (types)	6
	3.3.D Preferences	Will people find it aesthetically pleasing?	Yes
Environmental Education	3.2 How Many Benefit?	Education institutions within 800 m of site	0
	3.3.A Service Quality	Features/habitat/wildlife of education interest?	Yes
	3.3.B Scarcity	Wetlands within 800 m of the site	No
	3.3.C Complements	Educational facilities or infrastructure on site?	Yes
	3.3.D Preferences	Will people prefer characteristics of the site?	Yes
Recreatio n	3.2 How Many Benefit?	Number of homes within 530 m of the site	122
		Are there bike paths within 530 m of site?	Yes
		Are there bus stops within 530 m of site?	Yes

[100] Assessing the Benefits of Wetland Restoration: A Rapid Benefit Indicators Approach for Decision Makers, US EPA/600/R-16/084, July, 2016

Indirect	Summarize the Indicators		Site
Benefit	**Indicators**		**Mojkovac WWTP with RBs**
		Number of homes within 0 to 800 m of site	164
		Number of homes within 0,80 to 10 km of site	376
	3.3.A Service Quality	Total area of green space around site, ha	150
	3.3.B Scarcity	green space in ha within 1 km of site	315
		green space in ha within 1,6 km of site	800
		green space in ha within 20 km of site	100.480
	3.3.C Complements	Infrastructure supporting recreational activities?	No
	3.3.D Preferences	Are there additional features on the site?	No
Bird Watching	3.2 How Many Benefit?	Number of homes within 500 m of site	104
		Are there roads or trails within 500 m of site?	Yes
	3.3.A Service Quality	Will the site support rare or unique species?	Yes
	3.3.B Scarcity	NA	NA
	3.3.C Complements	Supporting habitat on site?	Yes
	3.3.D Preferences	Will people be interested in birds at the site?	No
Biosolids reuse	3.2 How Many Benefit?	Number of agriculture lands within 5 km of site	30
	3.3.A Service Quality	What is the service quality	NA
	3.3.B Scarcity	Is there need for soil amendment?	Yes
	3.3.C Complements	Are they willingness to pay for biosolids?	No
	3.3.D Preferences		NA
Legend: BLACK = No entry; **GREY** = NA; **BLUE** = Above Average/YES*; **RED** = Below Average/No* (*reverse for scarcity)[101]			

The numbers and answers in the above table were compared with the values collected and analysed in "Assessing the Benefits of Wetland Restoration: A Rapid Benefit Indicators Approach for Decision Makers"[102] made by Environmental Protection Agency of United States.

The indicators, part of indirect benefits groups, illustrates the results summary and color-coding:

- Site WWTP Mojkovac is not fully visible to people, so most of the scenic view indicators are coloured in red;
- Environmental education indicators show high potential;
- Recreation indicators are high, but the site does not support recreational activities. However, next to the RBs there is recreational park;

- The number of people who benefit from bird watching is 104, which is above the mean and shaded in blue. The WWTP cannot be used for bird-watching even though the site is accessible and close to the city;
- Biosolids indicators are high, but willingness to use or pay for biosolids is very low.

It can be summarized that the table above shows that the local city population has indirect benefits by the usage of RBs for the WWTP sludge treatment process. The main indirect benefits, other than C02 and N20 emissions reduction, are aesthetic, educational, habitat, and biosolids use. Although, there seems to be little demand for these at the Mojkovac site, and the number of people benefiting is low. Because we are talking about the WWTP site, which is not open for the public, people cannot benefit from benefits such as recreation or bird watching.

5.3 Conclusions of the benefits

Direct benefits conclusions based on pilot case in Mojkovac:

- Municipality of Mojkovac avoided capital costs (193.000 EUR) by successfully applying for 100% non-refundable donation from UNIDO, which covered elaboration of project documentation, construction costs, and dissemination activities.
- The solution replaced mechanical dewatering aiming at biosolids reuse. The potential O&M cost savings (8,93 EUR/PE) were the main reason for the implementation of RB technology in Mojkovac.
- The most affordable sludge disposal method is biosolids reuse. The disposal method with biosolids reuse instead of incineration reduces the annual O&M costs for 29% or 2.329 EUR/year.
- Analysis of efficiency indicators of two WWTP with different types of sludge treatment (RBs and mechanical dewatering) showed that RBs increase overall efficiency results. The electricity consumption for production of 1 kg of BOD is reduced by 77% per day, and by 46% in case of COD.

Indirect benefits conclusions based on pilot case in Mojkovac:

- SOCIAL
    - Social cohesion – estimated as low to medium
        - Social cohesion was estimated using five categories of social indicators: educational, well-being, life-sustaining, social inclusion, and safety. Even though RBs in Mojkovac could be used as “classroom in nature”, its potential is not exploited. Its aesthetic value probably positively affects the sense of well-being of residents (physical, mental, and social) and is a step toward ecological lifestyle. RBs are life-sustaining solutions because RBs are producing, preserving, purifying, and renewing air, soil, and water. Project could enhance social inclusion, but the community was not actively involved in the project nor takes care or is connected to O&M of RBs. However, dissemination activities reached inhabitants; thus, their general feeling of safety probably improved due to environmental and health protection.
    - Cultural values – estimated as high
        - Cultural benefits were estimated using two social indicators: aesthetic and tourism. RBs in Mojkovac merge harmoniously with green nature and the surrounding mountains contributing to the overall protection of nature’s beauty. The solution reduces the risk of untreated sludge being discharged to the Tara River Canyon, which is the second-longest in the world after Grand Canyon. It attracts tourists from all around the world. Compared to mechanical dewatering, RBs require much less transport and thus reduce noise stress, air pollution, and gas emissions, which is better for the development of tourism.

- Stakeholder`s engagement – estimated as medium
    - Stakeholder`s engagement was estimated by stakeholder participation in the project. Good collaboration is established among public utility, municipality, and environmental ministry. These are the stakeholders who were involved in the project since the beginning. Other institutions (research, education, and agriculture), local communities, and farmers were not actively involved, and collaboration is not established. Circular economy (biosolids use) will require long term collaboration among all stakeholders and especially engagement of the end-users. Municipality is at the beginning of these activities.

- ENVIRONMENTAL
    - Habitats – estimated as medium
        - RBs in Mojkovac support biodiversity. The identified invertebrates are earthworms, frogs, and birds. The operator could not identify the number and type of species.
    - GHG emissions – estimated as high.

      Using reed beds instead of mechanical dewatering seems to be the best alternative to reduce emissions footprint. RB, with biosolids land application, emit 60% less CO_2 and 84% less N_20.
    - Biosolids use – low for land application on agricultural land, high for local erosion
        - The amount of biosolids (1000 tons per operating cycle) could be applied on 10% (465ha[103]) of all agricultural land in the municipality every ten years or more. However, sanitation of local forest erosion with biosolids could have a higher local impact.
- ECONOMIC – estimated as high
    - The used indicator for economic benefits assessment is water tariff, which stayed the same since RBs were implemented. In the case of mechanical dewatering and disposal, the municipality of Mojkovac would need to increase water tariffs.

Gathered quantitative, qualitative, and narrative indirect benefit indicators showed that RBs have aesthetic value, but there are no homes within 150 m. People can benefit from the view only from the recreational trail near the site. High school in Mojkovac is less than 1 km away, and pupils could benefit RB site, but there is no established collaboration or that kind of demand at the moment. Recreation or bird watching is not possible on the WWTP site.

[103] extensive agriculture, 5 % of nitrogen in biosolids

6 IMPLEMENTATION CHALLENGES

Nature-based solutions are a reasonably new approach, not in terms of engineering feasibility, but in terms of the capacity to solve concrete problem areas and determining their multiple potential benefits. An apparent lack of awareness of the potential of NBS and RBs application for sludge treatment is not an exception. The main reason is a lack of pilot cases and a strong market position of competing solutions. One of the concerns from the authorities is that NBS technology is not sufficiently tested. Bottlenecks for implementation and barriers to innovation are discussed in this chapter.

6.1 Financing and funding

What is the specific problem?

Municipality of Mojkovac is experiencing limited resources and funds available for establishing infrastructure projects. Demand for infrastructural development is higher, and resources used in the provision of infrastructure are limited[104] in low- and middle-income countries as Montenegro[105]. Therefore, to implement NBS projects, local authorities have to find creative ways to fund these projects. Even with implemented RBs, a number of financial barriers to operate and maintain RBs in Mojkovac remain.

6.1.1 Lack of financial resources for initial investment

Ministry of Sustainable Development and Tourism of Montenegro, together with the Municipality of Mojkovac, had overcome this barrier by obtaining a grant (100% non-refundable donation from UNIDO).

Wastewater sludge related problems are a high priority because of the potentially detrimental impact on natural heritage (two National Parks, one of which is a world heritage site) and an excellent opportunity for green tourism.

The sludge problem at Mojkovac was so acute that it created political pressure on the Municipality (top-down approach). At the national level, the Municipality of Mojkovac was considered the black environmental spot on the map of Montenegro for a long time, which helped when asking for economic support, and the funding for the RBs was not the first donation they received. The actions taken to achieve desirable outcomes were derived from previous experiences with fundraising, effective management, and system knowledge.

Cost analysis showed that the existing water tariff (0,56 €/m3) could not cover initial investment costs in RBs. They could not include other related services (e.g., O&M costs of WWTP, O&M costs of WWTP sewerage system, O&M costs of drinking system, investment costs) to deliver both water and wastewater treatment services.

Tariffs* needed for reed beds (calculated in chapter Cost Analysis):

- 0,13 €/m^3 to cover OPEX of RBs with incineration
  The tariff covers NPV operational cost (3.987 €/year) of RBs with biosolids reuse (1.417 €/year) over period of 30 years (NPV total: 166.931 €/30 years).
- 0,07 €/m^3 to cover OPEX of RBs with biosolids use
  The tariff covers operational cost (3.987 €/year) of RBs with incineration (5.667 €/year) over period of 30 years (NPV total: 93.440 €/30 years).
- 0,30 €/m^3 to cover CAPEX through loan and OPEX of RBs with incineration

[104] https://www.researchgate.net/publication/305904424_INFRASTRUCTURE_PROBLEMS_OF_DEVELOPING_NATIONS_AND_SUSTAINABLE_DEVELOPMENT
[105] https://www.oecd-ilibrary.org/development/geographical-distribution-of-financial-flows-to-developing-countries-2019_fin_flows_dev-2019-en-fr and
https://www.worldbank.org/en/country/montenegro/overview

The tariff covers investment costs through loan (214.068 €) and operational costs with incineration (166.931 €/30 years) over period of 30 years (NPV total: 380.998 €/30 years).

- 0,24 €/m^3 to cover CAPEX through loan and OPEX of RBs with biosolids use
  The tariff covers investment costs through loan (214.068 €) and operational costs with biosolids use (93.440 €/30 years) over period of 30 years (NPV total: 307.508 €/30 years).

  ***Comment:** The calculated average tariffs take into account future stream of costs and convert them into equivalent values today. It must be noted that the tariff needed during 1st year of operation is higher as one needed in the last year of operation due to modelled net costs for each of the future years. This is done by discounting costs using an appropriate real discount rate.

The public utility stated that the existing water tariff (0,56 €/m3) covers cc. 80 % of water and wastewater costs because the local government wants to keep water affordable. Around ten percent of inhabitants cannot pay water tariff (social problems). The missing funds are earned on the market, primarily through the contractual arrangements for the landscaping of green areas for the Municipality.

What action is needed?
The question of how to raise funding arises. Steps derived from experience (from idea to project proposal) in Mojkovac are:

- Establishment of project office responsible for project preparation and fundraising;
- Elaboration of a conceptual solution, including presentation of the problem, the definition of objectives, project identification, technical feasibility, environmental sustainability, and financial analysis;
- Identification of relevant call for proposals/projects/grants;
- Elaboration of a project proposal (each call is unique) and project submission.

Some funding schemes have co-financing requirements, which have to be assured when applying. The level of required project documentation (building permit) prior proposal submission depends on the call.

A simplified process of how to apply for grants is presented in the following figure.

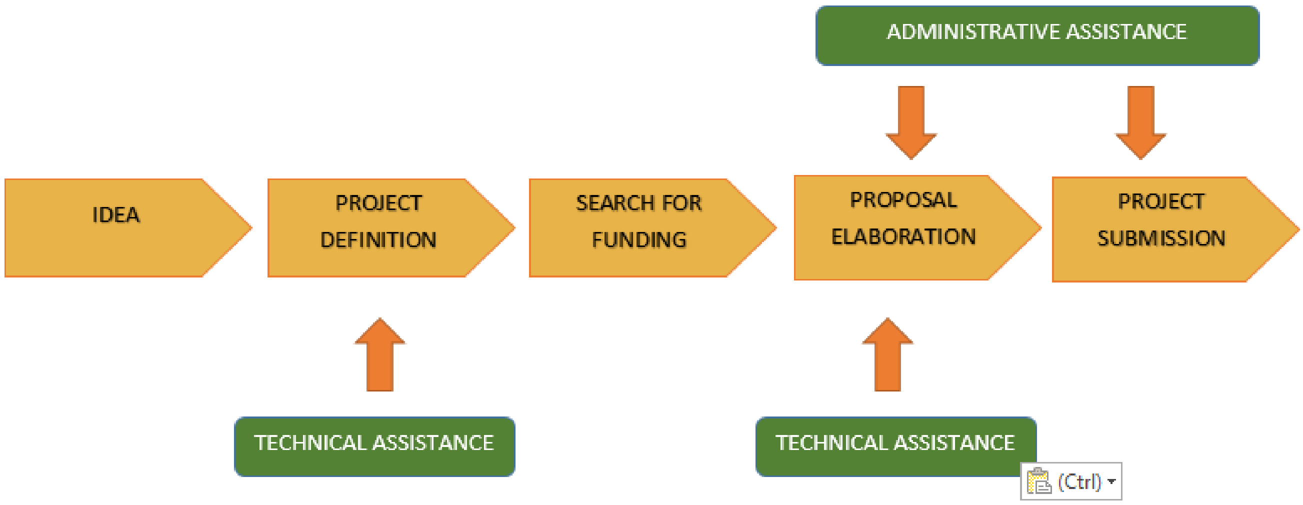

Figure 45: From idea to project proposal

6.1.2 Lack of financial resources for O&M activities

Regular O&M activities are being covered with water tariff. Analysis showed that water tariffs, which should include all RBs O&M activities, represent from 13 to 23 % of existing water tariff, which is a relatively high percentage, taking into account that other services have to be covered and financed from water tariff as well. For this reason, care should be adopted in financial planning, particularly in terms of the budgeting of all water and wastewater services so long term - goals are achieved.

What action is needed?

Sustainable cost recovery may be achieved with tariffs, taxes or transfers (3Ts) to finance recurrent and capital costs. Capital (investment) costs of RBs were covered by the transfer (grant) while O&M costs should be covered by the water tariff, to set in compliance with the full-cost recovery principles.

Municipality of Mojkovac should elaborate O&M plan as a mechanism for identifying and addressing specific priority issues. The planning should take into account specific expenditure challenges of RBs – e.g., excavation and final disposal of biosolids every ten or more years.

6.2 Capacity

The system in Mojkovac is first-ever constructed NBS for sludge treatment in the Western Balkan region. Understanding the pathways that led to this outcome, opportunities, and remaining challenges is crucial for the implementation and potential of RBs. Improved capacity of decision-makers and better institutional cooperation are essential elements to address this challenge.

6.2.1 Innovation

What is the specific problem?

Because RBs are a relatively new concept in biosolids management, it is necessary to find mechanisms to build capacity for the successful implementation of RBs on a larger scale. Ministry of Sustainable Development and Tourism of Montenegro supported NBS technologies and was introduced with RB technology through a project exploring nature-based possibilities for application in Montenegro. The presentation of technology and benefits raised the interest in the Municipality of Mojkovac for RBs. They were convinced by the ease of operation and low maintenance costs. The question of final biosolid disposal can be postponed for ten or more years (no incineration plant near Mojkovac). Support of the Municipality to the technology was crucial for the start of the project. A close collaboration between the municipality, ministry, public utility, and technology experts 'resulted in the successful construction of RBs. After the building was completed, and during the start-up, there was a strong emphasis on dissemination (video, project presentation) to promote RBs adoption. RBs in Mojkovac demonstrate good practice, which may also help in full implementation, but challenges remain.

Lessons learned can be summarized as follows:

- It is required much more than the transfer of RBs knowledge and skills to individuals;
- Authorities need financial, technical and operational resources to carry the idea into realization;
- Authorities need technical assistance on the technology (experts);
- It is required the coordinated effort of multiple levels of government to implement RBs;
- It is necessary to produce knowledge that can result in the broad implementation of RBs;
- Only a successful pilot project can lead to full application of RBs;
- Learning from pilot projects and dissemination activities are essential to build trust in technology and create behavioral change (change from mechanical dewatering to RBs);
- Country strategy on sludge management

What action is needed?

- Establish a sludge working group of experts, including expert for RBs, to address sludge problems on the national level (creation of knowledge hub) and support policy;
- Elaborate a study with baseline scenarios and future scenarios regarding sludge quantities, treatment, and disposal on a national level (ecological and economic aspects) – the basis for strategic decisions (incineration plant, disposal routes, reuse, etc.) taking into account specific geographical context;
- Workshops on sludge - expand knowledge on RBs and biosolids reuse among decision-makers;
- Inclusion of RB technology in the school curriculum (Biotechnical University and University of civil engineering);
- Enrichment of RBs in Mojkovac with teaching materials and learning paths for various interest groups (stakeholders, students, inhabitants).

6.2.2 Biosolids use in agriculture

What is the specific problem?

Municipality of Mojkovac is well aware of biosolids use problem, but decided not to explore options for use until the end of the operational cycle (when RBs will reach full capacity and excavation of biosolids will be necessary). Even though the idea of stabilized sludge use exists for some time and legislation enables biosolids use, the agricultural sector does not support this initiative. Directorate for agriculture and Directorate for plant production and inspection[106] believe biosolid use is not aligned with strategic agricultural documents and long-term goals. Reasons why biosolids, use in agriculture, should not be used according to the agricultural sector:

- Declaration of the 20th September 1991 in Žabljak, declared Montenegro as the first ecological state in the world and as such supports ecological and organic farming;
- Montenegro has a well-preserved environment, including high quality, well-preserved and fertile soil, and low level of pollution due to a moderate use of mineral fertilizers and pesticides[107];
- Montenegro does not have an intensive agriculture and farming is characterized by small-scale farms;
- Use of biosolids should be avoided due to sufficient quantities of natural fertilizer (manure);
- The agricultural sector wants to protect high-quality soil; thus, application of biosolids is not acceptable and will not get approval or support from the Ministry of Agriculture and Rural Development.

Quality of sludge determines the possible use of biosolids – agriculture is only one of the options. Other options include use on green areas and parks and use for land recultivation on landfills, tailings, and mining areas. Municipality of Mojkovac does not intend to use biosolids on agricultural land, but to sanitate forest erosion. However, this is just the idea, not a final decision. It all depends on the legislation and limit values that will apply in 10 or more years. In the meantime, steps required to apply biosolids use should be clarified on all levels.

Lessons learned:

- There is a need for better institutional and cross-sectoral cooperation with regards to biosolids use;
- Biosolids use must be placed in the broader context of country strategies and goals.

Experiment conducted in Czech demonstration site[108] studied possibilities of applying treatment sewage sludge from small municipal on agricultural land. They tried to verify the quality of the prepared materials (composts,

[106] http://www.minpolj.gov.me/kontakt/Direktorat_za_poljoprivredu/
[107] Government of Montenegro. Ministry of Agriculture and Rural Development. Strategy for the development of agriculture and rural areas 2015-2020.
[108] Holubík O., Šmejkal J., Štěpánová V., Kratina J., Rozkošný M., Hnátková T., Šereš M. 2019. POSSIBILITIES OF APPLYING TREATMENT SEWAGE SLUDGE FROM SMALL MUNICIPAL SOURCES - APPLICATIONS ON AGRICULTURAL LAND. Abstract proceedings of Pedological days 2019 conference, Srní, 11. – 13. September 2019 (in Czech)

dried sewage sludges from reed-bed technology, pure mineral forms of fertilizers (NPK), and developed pelleted organo-mineral fertilizers and evaluate their nutrient stability after the effect of simulated rainfall (30 min.; 1mm/min).

The field experiment measurement resulted in a positive effect of the reed-bed sludge application. The winter rye (Secale cereale) biomass shows from 1.5 to 2 times higher yield of biomass in the reed-bed variant than NPK standard (500kg/ha) and almost 3.5 times higher yield compared with a control (unfertilized option).

Figure 46: The growth vegetation with biosolids use

- Preparation of national sludge management document emphasizing sludge use as a resource. Such a paper should, at a minimum, discuss agricultural and non-agricultural land uses, sludge sales and giveaways, and the feasibility of technologies;
- Municipal sludge strategy document;
- Workshops on biosolids use (cross-sectoral).

6.2.3 Construction

What is the specific problem?

Construction of RBs is simple and not demanding, but the contractor must fully understand the system – functionally and structurally and have to be designed by engineers with knowledge. If they consider it only structurally as an elementary facility, they make several mistakes, which are the key to the function of RBs. The typical errors made by contractors and builders include incorrect levels of inlet and outlet pipes, wrong angle of bottom inclination, poor leveling of the filter layer, provision of the improper fraction of substrate (media) for plants, and inadequate sealing of impermeabilization layer. The need for very close construction supervision cannot be neglected.[109] In Mojkovac, a considerable time was spent so the contractor would understand the RBs

[109] https://www.constructedwetlands.net/IR2-Factors%20for%20Success%20and%20Failure_FIN.pdf

technology and system functioning. Construction mistakes were prevented with the implementation of technological supervision.

What action is needed?

- Local contractors can be easily trained to build RBs because a critical strength of this system is in its simplicity of operation and transferability of know-how. This also makes technology reliable and affordable;
- Where possible, give preference to the experienced local contractor (experience with NBS technology is conditioned by the size and complexity of the site);
- Establishment of a collaboration between contractor and RB technology expert to ensure proper technical execution of the project. Before construction starts, contractor, lead engineer and RBs technology expert should go through project (structurally and functionally);
- Construction supervision in compliance with national standards, including consultant supervision (technological supervisor);
- Supervision meetings during construction.

6.2.4 Trial operation, operation and maintenance

What is the specific problem?

The contractor has to put into operation and handover the complete RBs that comply fully with the functional and performance requirements. The contractor is responsible for taking all necessary measures to provide RBs that fulfill all requirements. The contractor must prove the fulfillment of the performance guarantees for final acceptance during trial operation (defect liability period). Testing usually includes the type of sampling, the frequency, number of sampling, and the allowed number of failing samples, etc. Municipality of Mojkovac started to operate RBs when the final condition of the completed work was verified with a conclusive acceptance. Training and know-how transfer were provided for the staff in charge of the O&M of the WWTP Mojkovac. One day training included theoretical and onsite practical training. During the first year of operation, the contractor stayed in close contact with operating staff to observe plant growth and optimize operation.

What action is needed?

- Conduction of guarantee tests and correction of deficiencies and malfunctions;
- Inclusion of the operating staff during trial operation;
- Elaboration of training and knowhow transfer activities for strengthening the technical and operational capacities;
- Elaboration of training and knowhow transfer concept according to prior discussion with local authorities (e.g., municipalities and public utilities);
- Preparation of user-friendly project documentation in the local language;
- Elaboration of O&M manual;
- Provision of adequate training of RBs operating staff and other relevant staff from the municipality/public utility;
- Transfer of key messages - poor maintenance and wrong operation can result in poor performance; thus, it is essential to recognize first signs of problems early;
- The training should include but not be limited to theoretical training and onsite practical training of the staff;
- Identification of challenges and further training needs and knowhow exchange after the end of the project;
- Optimization of RBs operation to achieve/increase efficiency and minimize operational costs;
- Optional support hotline for RBs operating staff.

6.2.5 Competing technologies

What is the specific problem?

Anyone from the wastewater business is aware that since mechanical dewatering emerged, its application has been widely used. Co-natural technologies like RBs have been on the market for decades, but they have not gained widespread establishment except in Denmark. So, for policy-makers, decision-makers, businesses and users of technologies, the critical question is: What is the differentiating factor between the competing technologies, fast winners and slow progressive technologies?

We can say that RBs technology has been ready for years (in Denmark since the early 1990s), but the system has not been prepared for it to reach mainstream adoption. Forecasting technological changes is a challenging task, and a complex environment makes it even harder. Below key challenges for RBs are listed:

- RBs often do not come into consideration because of a rather large footprint requirement. They require much larger area than mechanical dewatering, which means that RB technology appears most practical for smaller and medium-sized wastewater treatment plants (WWTPs)[110];
- Costs that make mechanical dewatering attractive to the investor are low initial costs, which are lower than initial investment costs in RBs. Thus, it is crucial to show investors that RBs are a cheaper solution compared to mechanical dewatering due to much lower O&M costs. RBs in Mojkovac with biosolids use are every year for more than 70 % less expensive than mechanical dewatering with incineration;
- Mechanical dewatering has a more significant market share, and it`s keeping it even though RBs create added value (cost savings and sludge reuse) and are a much cheaper solution in the long run;
- Lower operational costs are often neglected when deciding for the technology, due to lack of information in the market or unfamiliarity with technology;
- As a consultant evaluates different sludge treatment technologies, mechanical dewatering is perceived as more established and proven technology.
- RBs opponents often claim technical limitations (odor, insects, unsuccessful performance) are a significant set-back; but are not a risk since well designed and constructed RBs should not promote the drawbacks;
- Lack of confidence in technology prevents mainstream adoption;
- Another significant barrier to the deployment of RBs is the insufficient understanding amongst stakeholders of the way NBS function, which often results in an underused potential for RBs development. Design engineers should also point out other aspects, such as landscaping of WWTPs. RBs may enhance the attractiveness of the plant site in harmony with the environment;
- Lack of a clear regulatory framework for sludge reuse and transfer into practice;
- In engineering culture, traditionally conventional approaches (technical solutions) have been more favored and respected throughout history.

In Mojkovac, RBs competed with mechanical dewatering, but won the support of decision-makers due to low operational costs and as a long-term solution for sludge storage. We cannot say with certainty what would happen if there was an incineration plant in Montenegro – they might choose to use mechanical dewatering anyway. However, the successful implementation of the first RBs in Montenegro broke the ice for technology recognition and appreciation. RBs in Mojkovac has the potential to become a turning point for technology adoption in broader applications in the region.

What action is needed?

[110] Mennerich A., Niebuhr L., Ezzo H. Full Scale Sludge Treatment in Reed Beds in Moderate Climate—A Case Study. September 2017Water 9(10):741. DOI: 10.3390/w9100741
https://www.researchgate.net/publication/320090699_Full_Scale_Sludge_Treatment_in_Reed_Beds_in_Moderate_Climate-A_Case_Study

Action needed to overcome above listed key challenges:

- **Land requirements**
  - River deltas, seashores, and other lowland areas have been favored sites for cities. Increasing competition for land for agriculture production, forestry, urbanization, and water retention, together with engineering and economic criteria, influence the decision of WWTP location. Rather large land requirement is the most significant limitation factor constraining RBs broader application.
  - Spatial requirements also integrate flood-risk management. Building in flood areas often requires mitigation measures to mitigate the loss of the flood area. RBs occupy a more substantial space in comparison to mechanical dewatering and require more extensive mitigation measures.
  - RB experts are working on improvements affecting land requirements, but so far, there has been no breakthrough in this direction.
  - Land costs are highly relevant to the entire investment of RBs and should be included in cost analysis. The price of land may vary greatly depending on its use, productivity, potential alternative uses, and availability.
  - Land cost is a typical administrative risk (land cost higher than predicted) and can cause procedural delays. The availability of land is a crucial aspect when selecting the location for a WWTP. Land acquisition is usually part of the pre-construction phase (pre-tendering phase). When it comes to large WWTP projects, the municipal (detailed) spatial plan approvals take up most of the time, and this has to be done before submission of the final design for building permits. WWTPs are often placed on municipal land, thus avoiding land costs and lengthy procedures. Otherwise, the municipality has pre-emptive rights. Only up to 10 % of land acquisition costs are eligible costs for the EU cohesion funding scheme, which must be taken into account when preparing the project proposal. In principle, land requirements should be included in the planning process and calculated on a project-by-project basis.
  - Framework with realistic expectations should be set when offering RB technology for the Alpine region. Generally, technology is more likely to be adopted and implemented by smaller settlements where the price of land is low or land is already owned by the state or municipality.

To sum up, RBs are suitable for rural areas and small WWTPs, where there may be less competition for land and more demand for biosolids. Since sludge management of small and medium WWTP is not anymore limited to sludge storage, landfilling, and transport to central WWTP, the low cost of preparation of the material for final disposal is one of the primary decision drivers for technology selection as RBs. The solutions with lower numbers of beds, as RBs in Mojkovac are designed, can only be used for small local wastewater treatment plants serving several hundred people. It is indicated that this technology could be an economical and useful solution to the sewage sludge problem in small and medium-sized wastewater treatment plants. For economic and environmental reasons, it is an attractive solution, especially in rural areas where there are no appropriate facilities[111].

- **Lack of confidence in technology and recognition of benefits[112]**
  - Many of the technical and physical barriers at the local level are the result of limited outreach and education, limited resources, competing interests, and a lack of confidence in local government. To overcome these barriers, local governments and municipalities (WW decision makers) need to develop training programs and increase training opportunities for staff;

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[111] Obarska-Pempkowiak, H., Tuszynska, A., Sobocinski, Z. (2003). Polish experience with sewage sludge dewatering in reed systems. Water Science & Technology 48(5), 111-117.
[112] https://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/FactSheet%20-%20OvercomingBarriers%20PRINT.pdf

- Local governments need to consider multiple benefits and avoided costs associated with RBs. Incentives that encourage the use of RBs should be developed;
- The characteristics and values of a community significantly influence a community's acceptance and may represent critical barriers (resistance to change, development plans, political commitment) to its implementation. Overcoming these barriers require local governments to generate public understanding and potential support, conduct education and outreach, and ensure broad stakeholder participation;
- Development of regional demonstration projects with application of sludge reuse and long-term monitoring of pollutants and impact on land/land use in collaboration with research institutions;
- Promotion of RB technology among the engineering society related to wastewaters (engineering conferences, events, and publications).

6.3 Governance

What is the specific problem?

Decision-making about new wastewater infrastructure typically occurs at the local level. Although we have regional and national planning and developing instruments that identify preferred goals related to future wastewater solutions, decision-making often occurs based on local preferences and suggestions by external parties or even costs. Municipalities are left alone to select the most appropriate sludge treatment technology and decide how and where to dispose of treated sludge. However, in some cases, this question is neglected at the WWT investment phase and is forcibly tackled later, when sewage sludge occurs. Lack of integrated sludge management becomes evident through the implementation of expensive and sometimes inefficient sludge systems all over the region. The holistic approach is missing, while operational programs for WWT and investment programming are ongoing. Alternative solutions, such as RBs, do not get enough attention from local/implementing authorities. Implementation process of RBs (and potential other solutions) require institutional support for placement and biosolids reuse, which is currently weak in the Western Balkan countries. However, this problem is not just limited to region, because operators of RBs in Dellach (Austria) are having the same problem – final decision for biosolids disposal has not yet been adopted despite the quality of the material. Sludge treatment and reuse should not be regulated by the operators and market only but state-led as a strategic area due to its economic, environmental, health, and nutrient potential. One can learn from experience in Slovenia, which found itself in the middle of an ecological crisis due to the Hungarian ban on imports of foreign sludge. For years, municipalities have chosen the cheapest sludge disposal option – export to Hungary, and therefore they were not open to any other suggestions or innovation. All this time, national authorities had not been working on strategic sludge questions. Poor governance resulted in a lack of reliable and unified data, treatment options knowledge, decision-making powers, and leadership.

Many strategic documents support biosolids reuse, but implementation on a local level is not widespread. Poor collaboration between the environmental and agricultural sectors indicates different views on biosolids reuse that eventually influence the behavior of the user. Therefore, biosolids are nor perceived as increasingly valuable resources from which stakeholders can benefit, but as the apple of a cross-sectoral discord. Different options for sludge reuse and competing interests make wastewater governance even more complicated.

Identified governance gaps include:

- lack of coordination of responsible sectoral authorities,
- limited technical know-how, and
- limited financial resources for planning and implementation/evaluation.

What action is needed?

The following steps are required to shape the adequate response and holistic sludge management approach:

- Sludge treatment and disposal agenda building with all relevant stakeholders (competent authorities and engaged sectors) involved and agreed;
- Definition and description of possible alternative solutions (expert aided);
- Selection and support to acceptable/recommended options (legal, organizational, awareness, planning); key authorities responsible;
- Implementation (stimulated with public funds);
- Evaluation/monitoring of implemented solutions (responsible authorities).

The process of establishment of a holistic sludge management approach is presented in Figure 47.

Figure 47: Establishing of adequate response and holistic sludge management approach

Understanding the governance of wastewater at the different levels, responsibilities, and information flows is a basis for sustainable and high-quality wastewater services. A display of different actors must be involved, to provide an efficient and high-quality sewage sludge agenda:

- responsible national/regional/sector authorities,
- public officials involved in related sectors to sewage sludge question,
- public utilities/operators,
- private sector entities related to communal services,
- civil society organizations,
- experts, and
- media.

Figure 48 shows actors and mechanisms to provide an efficient and high-quality sewage sludge agenda.

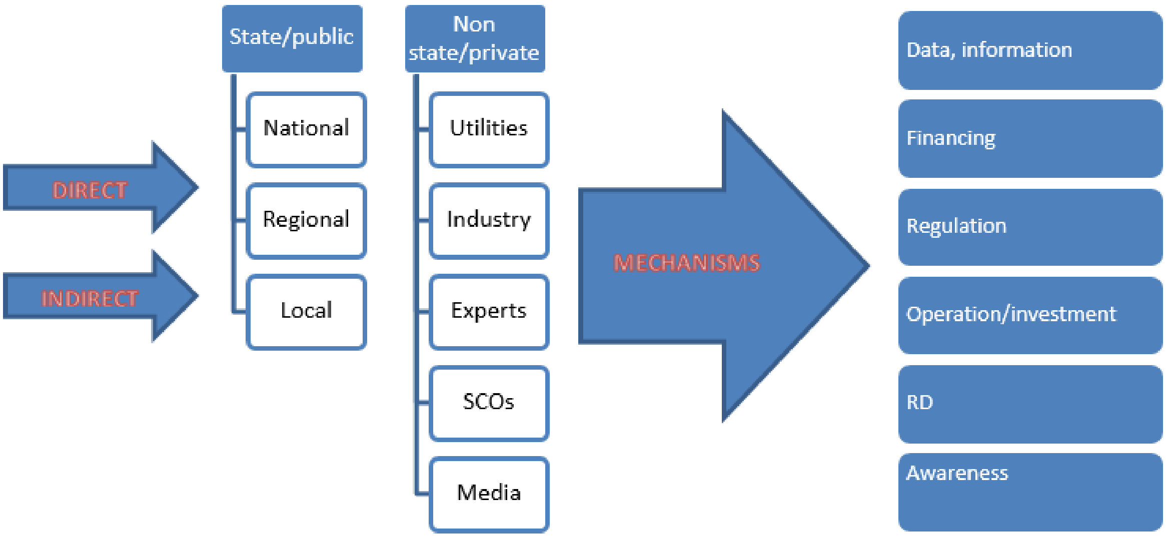

Figure 48: Involved actors and mechanisms for efficient and high-quality sewage sludge agenda

To boost RBs implementation, the value chain of circular economy actors must overcome high fragmentation of sludge management across sectors and address potential health risks drawbacks for sludge reuse. R&D/educational activities can enable higher visibility of RBs, also expert organizations and cross-sectoral collaboration, stimulation of users of the final product (farmers), and funding mechanisms (tariff system, subsidies).

It would also be beneficial to have gathered biosolids legislation, technical resources, information, studies, guidelines, good practices, and frequently asked questions (FAQ) on a national biosolids platform. In the US, The Environmental Protection Agency already published such a platform: epa/gov/biosolids.

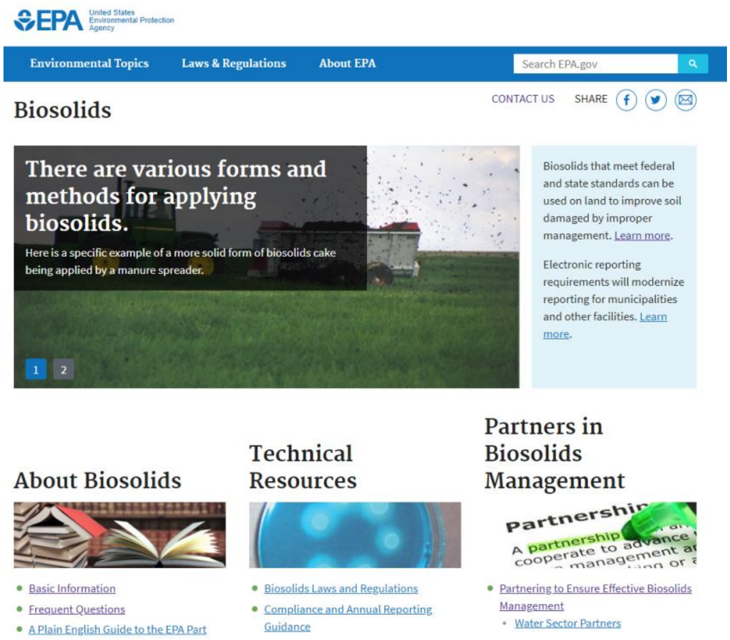

Figure 49: EPA platform for biosolids[113]

[113] https://www.epa.gov/biosolids

7 BUSINESS MODEL

Given the prevailing situation of publicly financed waste and sanitation services, the term "business" model might appear out-of-place in this sector. However, with increasing calls for cost recovery and private sector participation, the thinking is changing, and business models are needed to conceptualize sustainable sanitation service chains. The theoretical framework for the business model is presented in ANNEX 11.

7.1 Description of business model

Business models emphasize biosolids use at the end of the service chain. Sludge treatment technology in Mojkovac enables the possibility to generate revenue from biosolids. It also offers incentives for business development and cost recovery.

Two assumptions made about the BM for biosolids reuse are:

1.) **We have a product that consumers will want;**
Business plan should demonstrate the need for biosolids in the marketplace (competition analysis) or desire for the benefit of biosolids (quality analysis).
2.) **Business owner can sell the product profitably.**
Every entrepreneur assumes he will be profitable, but that assumption must be borne out by market research, budgeting, and sales projections. Profitability does not depend only on sales – it is focused on cost to make and sell products[114] (e.g. biosolids).

Service and financial flows

Sanitation services in Mojkovac are provided by the local government (Municipality of Mojkovac) and operated by the public utility DOO "Komunalne usluge Gradac" Mojkovac (concession contract). Biosolids' reuse business can start at the initiative of the Municipality of Mojkovac. A service delivered has a corresponding financial flow. The various financial flows discussed in the business model are presented in Figure 50.

There are several variations to the business model that could be developed based on the context. The business models presented have associated features that could benefit or limit the successful implementation of RBs in a region:

- **BM 1: Contractual partnership (municipality/operator – business entity)**
Business entity (e.g. private company) signs a contractual agreement with the municipality/operators to collect biosolids at the WWTP site and transport them to the (approved) storage site from where distribution or sale of biosolids products is permitted. Municipality/operator charges a business entity collection fee for biosolids in EUR/ton. Business can be profitable with revenue earned from the biosolids selling to end-customers.
- **BM 2: Local-public partnership (municipality-operator-farmer truck)**
WWTP operator is contracted by the municipality to apply biosolids reuse in the Municipality. This might require the plant operator to enter the strategic partnership with partners (e.g., community-based organizations) who can advise on market demand and (take over) sales strategies. Community mobilization and campaigns are necessary to sell biosolids to farmers or local businesses. The biosolids can bring the additional income for the municipality/operator.
- **BM 3: Subsidizing biosolids use**
To overcome the unwillingness of users to use biosolids, one can subsidize their use. It is not unusual that biosolids use application would require incentives. A strategy with subsidies payable to consumers (e.g., farmers) for biosolids could be one of the mechanisms to distribute biosolids' benefits in the region.

[114] https://smallbusiness.chron.com/key-assumptions-business-plan-60273.html

Reasonable subsidies could reduce O&M costs for the final disposal of biosolids. The model is dependent on government support.

- **BM 4: Biosolids free of charge**
  Municipality of Mojkovac may decide to give biosolids free of charge in compliance with valid conditions, standards, regulations, and legislation. Biosolids give away would reduce O&M costs for the final disposal of biosolids.

  When considering approving an application or granting funds for biosolids use, consents and legal requirements included in the funding schemes must be considered.

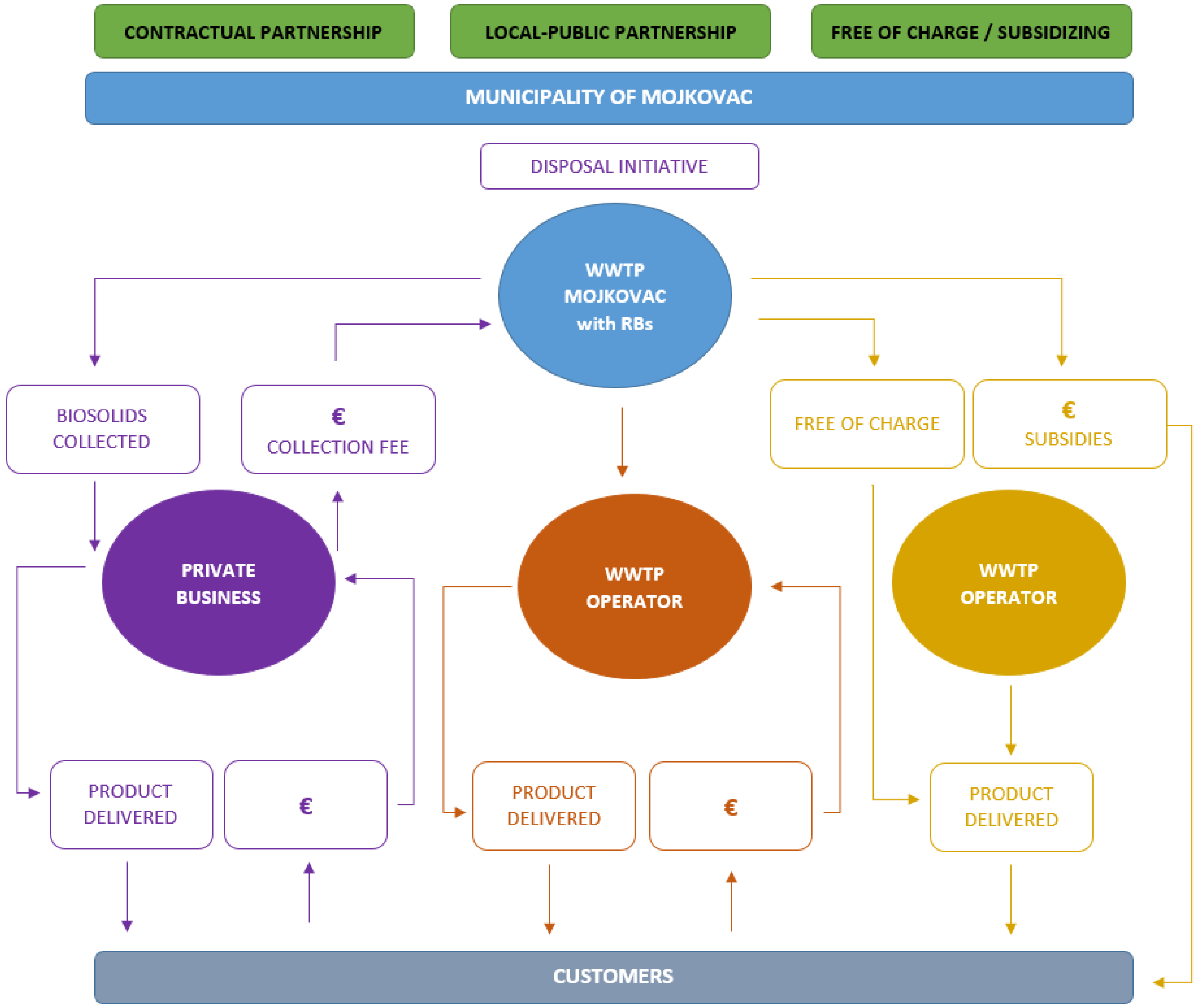

Figure 50: Service and financial flows of three BM for biosolids use

7.2 Competitive analysis

A competitive analysis is the analysis of competitors' market position. It can vary significantly depending on the information we try to gather about the competitors, such as:

- Who their target customers are;
- What market share do they currently own;
- Key features/benefits competitors highlight in sales materials;

- How competitors approach shipping/delivery.

Generally, competitive analysis can take many forms depending on the individual situation. The relevant parameters for BM in Mojkovac:

- Main competitors (sellers);
- Price range of fertilizer (natural and artificial).

Competitors

Biosolid competitors are farmers selling manure and stores selling artificial/mineral fertilizers. Farmers are selling manure at a price around 50 EUR for a cart ≈ 50 EUR/ton (Table 54).

Table 54: Manure prices in Montenegro (3.3.2020)[115]

Manure	Price	Municipality
Goat manure (Figure 51)	1-1,5 € / 25 kg	Podgorica, Rogami
Manure	1,5-2,0 / 25 kg	Danilovgrad, Grlić
Manure	50 € / tractor trailer	Nikšić
Manure	50 € / tractor trailer	Podgorica
Manure	40 € / tractor trailer	Danilovgrad
Cow manure	15 € / m^3	Kakaricka gora
Manure	40 € / tractor trailer	Danilovgrad
Manure	12 € / m^3	Župa Nikšićka
Manure	10€ /m3 or 1.50€ /25 kg	Nikšić
Manure	20 € / m^3	Tuzi
Ship manure	2 €/25 kg	Podgorica
Manure	50 € / tractor trailer	Golubovci

Figure 51: Manure[116]

Mineral fertilizers are being sell at a price around 10 / 25kg (N:P:K =15:15:15).

Table 55: Manure prices in Montenegro (3.3.2020)[117]

Manure	Price
Eliksir Zorka (Figure 52)	10,49 € / 25 kg
Kalija	22 € / 40 kg

[115] https://www.seljak.me/kategorija/dubrivo/
[116] https://www.seljak.me/kategorija/dubrivo/
[117] https://www.seljak.me/kategorija/dubrivo/

Manure	Price
Garden Lux	11 € / 25 kg

Figure 52: Mineral fertilizer[118]

Biosolids compete with animal manure and mineral fertilizer. To sum up, fertilizer prices in Montenegro are:

- 40-60 EUR/ton for animal manure;
- 400 EUR/ton for mineral fertilizer.

7.3 Cost and revenues projections

All cost and revenue projections are derived from availability of sludge. In the RBs will accumulated 900 m^3 of sludge per operating cycle.

7.3.1 Contractual partnership

In the table below, cost and revenue projections for Contractual partnership (BM 1) are presented. The operator excavates biosolids after the end of the first operating cycle. The business entity pays collection fees and arranges to collect biosolids at the WWTP site. Costs for excavation are estimated at 2.250 EUR for each cell of RBs. Collection fee should at least cover excavation costs, everything above the cost recovery price is revenue for operator/municipality. The operator/municipality could earn 676 EUR by collection fee of 5 EUR/ton.

Table 56: Cost and revenues projections for contractual partnership (BM 1)

PROJECTIONS	RB-1	RB-2
COSTS		
Excavation cost (EUR)	2.250	2.250
Total cost (EUR):	**2.250**	**2.250**
REVENUES PROJECTIONS FROM COLLECTION FEE		
Scenario 1 - min. collection fee (5 EUR/ton)		
Total revenue (EUR):	2.588	2.588

[118] http://kips.me/media/uploads/2015/12/poljoprivredni.pdf

PROJECTIONS	RB-1	RB-2
Scenario 2 - collection fee (7 EUR/ton)		
Total revenue (EUR):	3.623	3.623
Scenario 3 - collection fee (10 EUR/ton)		
Total revenue (EUR):	5.175	5.175
COST RECOVERY		
Cost recovery price (EUR/ton):	4,35	4,35

7.3.2 Local-public partnership

The second business model Local-public partnership (BM 2) predicts that operator excavates, stores and sells biosolids. Storage site in Mojkovac could be within the WWTP cadastral parcel, next to the RBs. Excavation costs of biosolids are estimated at 2.250 EUR for each cell of RBs, while establishment costs for on-site storage facility amount to 9.882 EUR. Selling price should be at least determined to recover investment costs for biosolids selling. The cost recovery price for the biosolids is 11,72 EUR/ton. It should be emphasized that since the sludge is excavated every ten years or more, the investment should return after the successful sale of material from both cells of RBs. The operator/municipality could earn 18.918 EUR by selling biosolids at 30 EUR/ton. Calculations are shown in Table 57.

Table 57: Cost and revenues projections for local-public partnership (BM 2)

PROJECTIONS	RB-1	RB-2
COSTS		
Excavation cost (EUR)	2.250	2.250
Establishment of on-site storage facility for biosolids (EUR)		9.882
Total cost (EUR):		12.132
REVENUES PROJECTIONS FROM COLLECTION FEE		
Scenario 1 – selling price (20 EUR/ton)		
Total revenue (EUR):	10.350	10.350
Scenario 2 – selling price (30 EUR/ton)		
Total revenue (EUR):	15.525	15.525
Scenario 3 – selling price (40 EUR/ton)		
Total revenue (EUR):	20.700	20.700
COST RECOVERY		
Cost recovery price (EUR/ton):		11,72

7.3.3 Subsidizing biosolids use

In the analysed business model Subsidizing biosolids reuse (BM 3), the following claim is considered right - it is cheaper to subsidize the use of biosolids than to incinerate material or transport and deposit it. It is essential to arrange pick up of the material in parallel to the excavation that happens to avoid establishment costs of an on-site storage.

Experience from Denmark[119]

In Denmark, subsidies for biosolids use are given by the operator of the system if the service is under concession or municipal office. Subsidised range from 0 to 6 kr./kg P (0,8 EUR/kg P) for the person that receives the biosolids. The amount varies in several factors, including area, season, location in the country, transport distance for the place of production, and possibilities for storage. Biosolids analysis is being covered by the water company and not by the farmer. The Danish law nr 1650 of 13. December 2006 does not require soil analysis. Sewage sludge will be typically analysed against the phosphorus-based limit values (Table 58):

Table 58: Limit values in Denmark

	Mg/kg TS	Mg/kg TP
Cadmium	0,8	100
Mercury	0,8	200
Lead	120	10.000
Nickel	30	2.500
Chromium	100	
Zink	4.000	
Copper	1.000	

	Mg/kg TS
LAS	1.300
PAH	3
NPE	10
DEHP	50

Incineration costs of sludge treated on RBs in Mojkovac are estimated at 62.100 EUR (1.036 tons x 60 €/ton) per operating cycle, while excavation costs and subsidizing the use of biosolids at 8 EUR/ton would amount to 12.780 EUR (Table 59). Cost savings from this source are 53.820 EUR every time RBs are emptied.

Table 59: Cost and funding projections for subsidizing biosolids use (BM 3)

PROJECTIONS	RB-1	RB-2
COSTS		
Excavation cost (EUR)	2.250	2.250
Total cost (EUR):		**4.500**
SUBSIDIES TO CONSUMERS (farmers,)		
Scenario 1 - subsidizing use of biosolids (2 euro/ton)		
Total funding (EUR):	1.035	1.035
Scenario 2 - subsidizing use of biosolids (4 euro/ton)		
Total funding (EUR):	2.070	2.070

[119] Carlos A. Arias

PROJECTIONS	RB-1	RB-2
Scenario 3 - subsidizing use of biosolids (8 euro/ton)		
Total funding (EUR):	4.140	4.140

7.3.4 Biosolids free of charge

Municipality can decide to give biosolids away to farmers, who can use it as a free-soil amendment instead of other commercial products. One of the most expensive components of fertilizer is phosphate, and biosolids are very high in phosphate. The excavation costs of biosolids for both RBs are 4.500 EUR (Table 60). It is also necessary to organize the collection by the customers on the same day as excavation is performed.

Table 60: Cost projections for giving biosolids free of charge (BM 3)

PROJECTIONS	RB-1	RB-2
COSTS		
Excavation cost (EUR)	2.250	2.250
Total cost (EUR):		**4.500**
GIVE AWAY		
Give away of biosolids		**0**
Total cost (EUR):		**0**

7.4 Assessment of feasibility

The profitability of biosolids use can be a challenge, and private entities will be cautious about investing or about using biosolids without conducting a feasibility study. Governments could provide incentives to encourage private sector investments and strategic partnerships between WWTP operators and business entities. The key revenue for WWTP operators is from the biosolids selling, while strategic business partner (BM 1: contractual partnership) can sell biosolids products. In Table 61 benefits and limiting factors of various business models for biosolids use are presented. It must be noted that treatment on RBs is not only a resource recovery mechanism, but a business necessity to reduce the waste volume and facilitate its productive 'disposal'[120]. Revenue created from biosolids based on the prevailing market price can help to maintain the treatment plant. All models for biosolids use contribute to socioeconomic benefits from reduced dumping of sludge.

Table 61: Benefits and limiting factors of business models for biosolids use

	Contractual partnership	**Local-public partnership**	**Subsidizing biosolids use**	**Biosolids free of charge**
FINANCIAL IMPLICATIONS				
Creates revenue	Y/N	Y	N	N
Reduces costs	Y	Y	N	N
Requires subsidy	N	N	Y	N
Cost recovery of use	Y	Y	N	N
REGULATORY AND MONITORING IMPLICATIONS				
Requires sludge analysis	Y	Y	Y	Y

[120] https://www.afwakm.com/wp-content/uploads/2019/06/Business_models_for_fecal_sludge_managem-1.pdf

	Contractual partnership	Local-public partnership	Subsidizing biosolids use	Biosolids free of charge
Requires soil analysis	Y/N	Y	Y	Y
INSTITUTIONAL IMPLICATIONS				
Requires public sector involvement (producers)	Y	Y	Y	Y
Requires private sector involvement (consumers)	Y	Y	Y	Y
ENVIRONMENTAL AND HEALTH IMPLICATIONS				
Reduces indiscriminate disposal of sludge	Y	Y	Y	Y
Concerns of public health and environmental safety	Y	Y	Y	Y

The challenge of presented BM lies in the availability of the resource after app. every ten years, so every time all involved parties must be joined together. As this period among operating cycles is so long, it is hard to rely on long-term partnerships with consumers; thus it is highly recommended to establish a locally relevant system to ensure successful implementation of the model. Guidelines on the biosolids use and public awareness activities should be part of the system.

From a regional perspective, there is a potential for the establishment of a business, that would buy biosolids from all municipal WWTPs, turn them into products, and sell them on the market. That kind of business needs regular and sufficient quantities, which WWTP Mojkovac alone cannot provide. Biosolids do not need to be a significant source for business; they can also be a complementary resource (e.g. floriculture).

Biosolids are an opportunity for entrepreneurs that recognize the commercial value of biosolids. As the global population continues to increase, the volume of sewage produced continues to rise. It is estimated that global biosolids market size will increase to 9.030 Million US$ by 2025, from 5.740 Million US$ in 2018[121]. Currently, biosolids are widely used in the United States (US). A well-known biosolids compost firm is Synagro, which allegedly contracts with more than 600 municipal wastewater treatment plants in 37 states. Key players operating in the biosolids Market include Casella Organics, Alka-Tech, Biodisk Corp., GeoEnvironmet Technologies, and Wm. H. Reilly & Company.[122]

The idea behind BM for biosolids use is to turn challenges into success and help communities benefit from waste-reducing technologies[123]. In the long-term, the municipal target should be to reach full cost recovery of capital and O&M WWTP costs, whereby biosolids use can contribute to achieve this goal.

[121] https://www.marketwatch.com/press-release/biosolids-market-2019-business-revenue-future-growth-trends-plans-top-key-players-business-opportunities-industry-share-global-market-size-analysis-by-forecast-to-2025-2019-09-03
[122] https://www.transparencymarketresearch.com/biosolids-market.html
[123] http://www.synagro.com/

7.4 Conclusion of the business model for biosolids use

Business model conclusions for biosolids use based on pilot case in Mojkovac:

- Local-public partnership is the most profitable BM, followed by the contractual partnership BM;
- Biosolids free of charge or subsidizing biosolids use does not make revenue, but reduce costs for final disposal;
- The presented business models attempt to provide a perspective on the differences between various business models for biosolids use (BM 1: contractual partnership, BM 2: local-public partnership, BM 3: subsidizing biosolids use, BM 4: biosolids free of charge), but at the same time draw out similarities and common traits of strategic sludge management in a dynamic and complex environment;
- Biosolids use is a social process involving various actors, so the chances are that unexpected issues (e.g., social acceptance, (food) safety, availability and ownership of agricultural land, public anxiety and civil initiatives) will arise during the planning process, regardless of the analysis that supports biosolids use. It is necessary to adapt to emerging issues on time. Municipality of Mojkovac is well aware of that, but the long operational cycle moves the problem into the future. To avoid social bottlenecks a constant and transparent communication is required with all target groups concerning:
    - Resource quality (safety);
    - Main benefits (nutrients and cost savings);
    - Resource cycle (closing the material cycle).
- Biosolids can compare in cost with commercial fertilizer under the assumption that municipality bears the cost of biosolids production. What can be cost-effective for one municipality might not be for another.
- To safely apply biosolids to land, BM should be built around the health issues. Rules governing biosolids use should be supported by the enforcement or monitoring of the marketing procedure;
- Business models Contractual partnership and Local-public partnership can generate revenue every ten or more years. For any revenue generation along the sanitation service chain, market-based approaches are required, and this indicates the need for resource recovery and reuse inter-sectoral collaboration with stakeholders to avoid the common shortfalls of supply-driven market approaches. Generated revenue could theoretically be used to reduce charges for using the sanitation service[124];
- All presented business models can reduce O&M costs because biosolid land application is a less expensive option than final disposal with transport to incineration;
- BM for biosolids use done well it can utilize limited resources;
- The process of establishment of BM in Municipality of Mojkovac would require initiative, development and operational team, and involvement of stakeholders.

[124] https://www.afwakm.com/wp-content/uploads/2019/06/Business_models_for_fecal_sludge_managem-1.pdf

ANNEXES