ANNEX 10: INDIRECT BENEFIT ASPECTS AND INDICATORS

While assessing the indirect benefits, the following main steps and guiding questions were considered:

- **Decision context**
  - Objectives and geographic scope;
  - Affected stakeholders;
  - Important needs of affected stakeholders.
- **Ecosystem services and benefits**
  - relevant ecosystem services to support the selection
  - important benefits of these services
  - general characteristics of each service and its benefits
- **Compile benefit indicators**
  - Are people able to receive benefits?
  - Who receives benefits?
  - How does the value of each benefit compare across sites?
  - How reliable are benefits over time?
- **Engage the public & stakeholders for project success**
  - Finding ways for community members to contribute;
  - Contacting local interest groups;
  - Asking to attend existing community meetings and listening to what stakeholders say about the issues that matter to them;
  - Spending time in your target community, talking with residents and neighbours, and listening to their interests and concerns;
  - Hosting public meetings that feature knowledgeable and approachable speakers who can explain the project in plain language;
  - Engaging schools and local community groups.

Non-monetised benefits may not be applicable to calculations for benefit values. However, they can provide significant insights and indications on the relevant value.

Indirect benefits from RBs could be based on:

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

1. Social

From social point of view, Reed Beds as NBS enable:

- Social cohesion
- Cultural values
- Stakeholders' collaboration
  - Civil engagement;
  - Reuse opportunities.

Nature-based solutions are multi-functional, opposed to single-purpose grey infrastructure options, NBS offer numerous co-benefits in terms of public health, social cohesion, biodiversity, climate change mitigation, etc. creating win-win solutions for society, the environment, and the economy.

Assessment of the indirect social benefits includes the relationship among the place where the service is generated, the place where people can benefit from the service, and the place where people who benefit are located. This information helps to determine the area to consider when making a decision, how many people are impacted, and who those people are.

1.1. Social cohesion

From the literature review of 98 articles and especially the "Social and cultural values and impacts of nature-based solutions and natural areas"[1] , 66 % of the items described some type of social or cultural benefit of ecosystem services, natural areas and structures, as follows:

- Among the social benefits, 52 % of the articles recognized health and well-being as improvement benefits and 41 % found social interaction enhancing impacts;
- Benefits related to education were also mentioned in 20% of the researched articles.

Figure 1 presents the number of articles, which identified various social impact/benefits of natural areas or nature-based solutions.

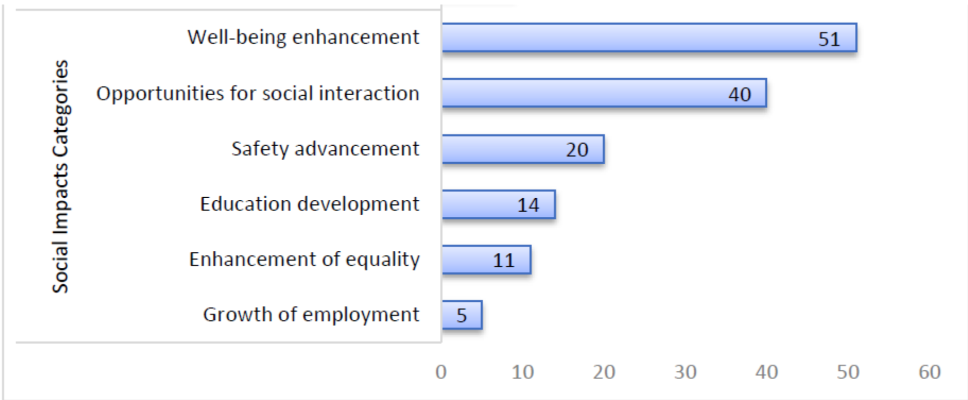

Figure 1 "Number of references to various social impact in the studied literature" [2]

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

- ***Educational*** [3]:

  RBs in Mojkovac are first in the Western Balkan region with great potential for educational activities. Students and civil society structures can provide examples for ecological country, develop eco-tourism in the area, and solve the problem with sludge deposition.

  It is considered an opportunity for further development of educational activities for Green infrastructure, posing a need for Dellach and Mojkovac to start cooperating with local and regional educational institutions.

  Hence, the RBs in Mojkovac provide:
  - opportunity to learn about the environment through observation or experimentation;
  - environmental protection, awareness and greening activities;
  - sharing wisdom and knowledge; research opportunities for educational purposes;
  - formal and informal education; learning from nature;
  - learning from direct experience of nature.

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[1] "Social and cultural values and impacts of nature-based solutions and natural areas, Sara Maia da Rocha, Dora Almassy & Laszlo Pinter (CEU), 1.3 Part IV, Horizont 2020, May 2017.
[2] "Social and cultural values and impacts of nature-based solutions and natural areas, Sara Maia da Rocha, Dora Almassy & Laszlo Pinter (CEU), 1.3 Part IV, Horizont 2020, May 2017.
[3] (Özgüner, Kendle and Bisgrove, 2007) (Sherrouse, Clement and Semmens, 2011) (Plieninger et al., 2013) (Vierikko and Niemela, 2016) (Langemeyer et al., 2015)

- ***Well-being*[4]*:***
  Using nature solutions for water purification/sludge treatment in Mojkovac may be considered as improving the ecological and healthy lifestyle. Although direct contact with RBs is not possible, but they have aesthetic value, which, in turn, can enhance the sense of well-being (physical, mental, and social).
- ***Life sustaining***[5]:
  Nature-based solutions are increasingly deployed to address the multiple challenges urban areas are facing and to accelerate sustainable urban development. They constitute 'smart' green infrastructure solutions aimed at increasing the city's resilience concerning disaster risk reduction and climate change adaptation. They are deployed to advance urban renewal processes and the regeneration of neglected and degraded areas to enhance the livability of a city. RBs as NBS provide, therefore
    - opportunity for future generations to enjoy nature;
    - nature's ability to produce, preserve, purify, and renew the air, soil, and water.
- ***Social inclusion***[6]:
  RBs are expected to have (generally) positive socially inclusive effects through the reduction of environmental burdens. RBs are matching with other goals of urban development, such as urban functionality or health promotion. Inhabitants do not have free access to WWTP but share equal benefits. Project reached inhabitants through dissemination activities, but there is no "hard evidence" that the following benefits occurred or improved due to project implementation:
    - social cohesion and harmony;
    - sense of community and identity;
    - community-based activities;
    - citizen involvement, intercultural communication, communal self-reliance;
    - community involvement;
    - community spirit.

- ***Safety***[7]:
  Implementation of RBs probably improved the general feeling of security in the sense of environmental and health protection.

1.2. Cultural values

A strategically planned and coherently managed network of Green Infrastructure aims at securing the continuous provision of these benefits offered in rural and urban settings for present and future generations. In close collaboration with involved stakeholders and through improving cross-territorial coordination, such a network intends to valorize existing Green Infrastructure elements and support the further deployment or restoration of high-quality environmental spaces to jointly close strategic gaps in the setting up of the Alpine Green Infrastructure network.

Among the cultural benefits, recreational impacts were the most recognized (43 %), followed by spiritual or religious and aesthetic (28 % and 27 %).

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[4] (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)
[5] (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)
[6] (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)
[7] (Özgüner and Kendle, 2006) (Graham et al., 2013) (Demuzere et al., 2014) (Karrasch, Klenke and Woltjer, 2014)

The following figure presents the number of articles, which identified various cultural impact/benefits of natural areas or nature-based solutions.

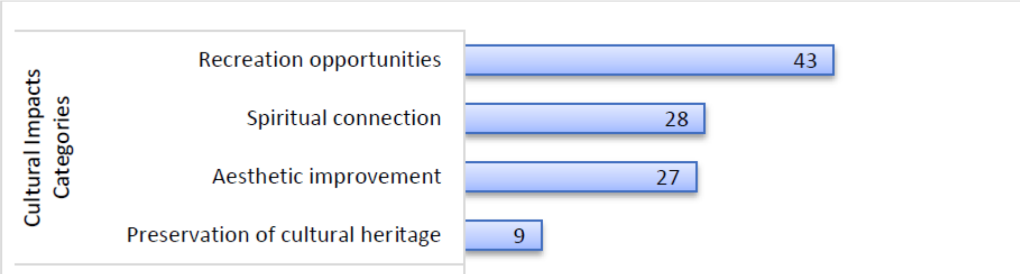

Figure 2: Number of references to various cultural impact in the studied literature [8]

The identification of cultural benefits could be assessed by tourism sustainability based on the development and improvement of various green spaces, green or blue infrastructure elements. Recreational benefits are recognized for active and passive activities, such as walking, hiking, swimming, relaxing.

"Several studies found that recreation was one of the primary reasons why citizens choose to visit an urban park, a community garden or a riverside (Vollmer et al., 2015) (Madureira et al., 2015) (Dou et al., 2017)".[9]

People recognize green spaces as important to human well-being and have even cited a lack of public green space as a reason they moved out of cities[10]. The Alpine region is characterized by a wide range of natural, cultural, and geographic features. Its richness and beauty are values of their own. They are assets for various ecosystem services, thanks to sustainable land use, and thus indispensable components of a green economy and a healthy environment. Current challenges, like climate change, loss of biodiversity, depopulation and land abandonment, agglomeration and landscape fragmentation, call for political leadership for sustainably leading the Alpine region into the future – for the benefits of nature, people and the economy.

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

- ***Aesthetic***[11]:
  Scenic landscapes provide observers with aesthetically scenic view benefits. For observers to enjoy seeing a reed beds, must have an unobstructed view even though the reed beds of the system does not guarantee positive scenic benefits. It is only one of the components among other features and habitats in the view, but the reed beds improve the aesthetics of a landscape.

  The value of NBS as components of scenic landscapes has also been demonstrated in models comparing sales of properties with or without NBS[12]. WWTP through NBS which have been

[8] "Social and cultural values and impacts of nature-based solutions and natural areas, Sara Maia da Rocha, Dora Almassy & Laszlo Pinter (CEU), 1.3 Part IV, Horizont 2020, May 2017.
[9] "Social and cultural values and impacts of nature-based solutions and natural areas, Sara Maia da Rocha, Dora Almassy & Laszlo Pinter (CEU), 1.3 Part IV, Horizont 2020, May 2017.
[10] Tratsaert 1998
[11] (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)
[12] (Sander and Polasky 2009; Walls 2013)

implemented correlate with higher sales prices when compared to technical WWTP, but it is difficult to estimate how much of the price increase is the result of the sight improvement, rather than other benefits.

For those who do not own property and do not live in the vicinity of the site also benefit from scenic views if during daily activities, such as driving and or coming in contact. Scenic views may also add to the quality or value, since they promote outdoor activities trail.

- ***Recreation / Tourism sustainability and development, taking into account the value of Tara river natural assets [13]:***
    - Activity-based values;
    - Outdoor and recreational activities.

  When assessing recreational benefits, it is essential to define the scope of the activities. Recreational benefits encompass a variety of activities, each having specific requirements and user preferences. Recreational benefits often overlap with other benefits[14]. For example, increased aesthetic views along a hiking trail would increase the value of that trail's recreational benefits[15]. The exercise received while hiking provides human health benefits[16]. The hike might even result in educational benefits and tourism sustainability and development.

- **Place-based values**:
    - sense of place within nature;
    - regional belonging, how people feel about their surroundings, community cohesion;
    - sense of belonging in natural areas.

1.3. Stakeholders' collaboration

Using RBs for wastewater treatment process can engage local municipal utility operators and the citizens for long term collaboration practices improving civic engagement, and reuse of wastewater derived resources, as:

- the increased economic activities made possible with biosolids reuse would, in turn, lead to social benefits such as employment.
- Biosolids reuse could improve food security by providing an alternative source for irrigation and, in turn, supporting rural communities and businesses.

1.4. EU policy

Implementation of RBs supports EU environmental objectives and contribute to setting the stage towards the visions of sustainability of which they are part of. Developing a framework for assessing support for NBS across numerous EU policy instruments is necessary to ensure consistency and enable comparability between the reviewed documents. This requires clarifying a system is defined and what qualifies as a NBS. Accordingly, support is defined as the extent to which the regulatory framework addresses NBS and related concepts and fosters their deployment across the European Union. This can come in various forms, including e.g., providing information or knowledge, developing capacities (through training, providing access to resources, etc.), legislative or regulatory support, or financial support.

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[13] (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)

[14] Church et al. 2011

[15] Loomis and Paterson 2014

[16] Bassuk and Manson 2005; Bedimo-Rung et al. 2005

The EU policy instruments of highest relevance for enhancing the use of NBS, i.e. different directives, strategies, programmes and financing instruments at EU are shown in the table below.

Table 1: EU policy instruments

Policy	EU policy instrument
Biodiversity	• Habitats Directive (1992) • Birds Directive (1979/2009) • Biodiversity Strategy to 2020 (2011) • Green Infrastructure Strategy (2013)
Water	• Water Framework Directive (WFD) (2000) • Floods Directive (2006)
Marine environment	• Marine Strategy Framework Directive (MSFD) (2008) • Blue Growth Strategy (& Guidance) (2012) • European Maritime and Fisheries Fund (EMFF) (2014)
Forestry	• Forest Strategy (2013)
Agriculture and regional policy	• Urban Agenda for the EU (i.e. Pact of Amsterdam, 2016)
Adaptation	• Climate Change Adaptation Strategy (2013)
Cohesion and Growth	• Europe 2020 Strategy (2010) • Circular Economy Action Plan (2015)
Environmental assessment	• Environmental Impact Assessment Directive (EIA) (1985) • Strategic Environmental Assessment Directive (SEA) (2001) • Protocol on Strategic Environmental Assessment (2008)

The Circular Economy (CE) philosophy based on the 3Rs; Reduce, Reuse and Recover[17] has emerged as an alternative to the wastefulness of the current linear "take-make-use-dispose" practices of urban areas. Nutrient recovery from WWTPs has a positive impact on the environment by reducing the demand for conventional fossil-based fertilizers and, consequently, reduce the consumption of water and energy. It is possible to recover nutrients from raw wastewater, semi-treated wastewater streams, and sewage sludge (biosolids).

2. *Environmental*

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

- Habitats;
- Balance air quality and emissions (CO_2, CH_4 and, etc.);
- Use of biosolids;
- Contribute to wastewater retention capacity.

2.1 Habitats

One environmentally friendly method for complete water treatment is the installation of RBs. Studies have shown that a reed bed may support over 700 invertebrate species and provide a home to small mammals such as water shrews.

In the European Union, many wetlands are included in the EU 'Natura 2000' network. Birds are excellent umbrella species; therefore a management targeted at increasing habitat suitability for focal bird species would likely benefit broader reed beds biological communities.[18] [19] [20]

[17] EC, 2014; Winans et al. 2017,
[18] The EU Birds and Habitats Directives
[19] Natura 2000 in the Alpine Region
[20] Conserving Wild Birds in Montenegro, A first inventory of potential Special Protection Areas, 2019

Urban areas often lack the large and pristine habitats that certain species of birds require[21]. Still, bird species that can tolerate or adapt to urban environments can be drawn to neighbourhoods near parks and green spaces that provide appropriate habitat for nesting or foraging[22]. Although these species are not likely to attract more serious ornithologists from other locations, they can positively affect the attitudes and well-being of local urban residents[23].

2.2 Greenhouse gas emissions

RBs can be considered a feasible alternative technology to dewater and mineralize the bioproducts generated by the sludge treatment. In RBs system, the organic matter is decomposed by various microbial reactions. This process generates gases such as CO2 and CH4 emitting to the atmosphere although emitted, when compared to energy demanding systems RBs produce less.

When compared, the global warming potential of methane emissions is 13.3 and 15.02 g CO_2eq m^{-2} d^{-1} from RBs, respectively, which is much lower than values for traditional sludge centrifugation and transport.[24]

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 spreading;
  - Incineration;
  - Incineration with household waste;
  - Landfilling.
- Indirect emissions are due to:
  - Energy and chemical consumptions (combustible or electricity) to operate each process.
  - Transport emissions (for consumables, sludges and ashes), and
  - Construction emissions.

The first indirect emissions can be calculated for one ton of goods transported on one kilometer (t.km). Renou (2006)[25] considers that the most applicable methodology for defining GHG is to consider the mass of all civil engineering and electrical/mechanical equipment.

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[21] Marzluff et al. 2011

[22] Barbosa de Toledo et al. 2012; Fontana et al. 2011; McKinney and Nightingale 2014

[23] Belaire et al.2015; Bjerke and Ostdahl 2004

[24] Greenhouse gas emissions from sludge treatment reedbeds, Yubo Cui, Shunli Zhang, Zhaobo Chen, Rui Chen and Xinnan Deng

[25] Renou, S. (2006). Analyse du Cycle de Vie appliquée aux systèmes de traitement des eaux usées. Institut National
Polytechnique de Lorraine, 258 pages.

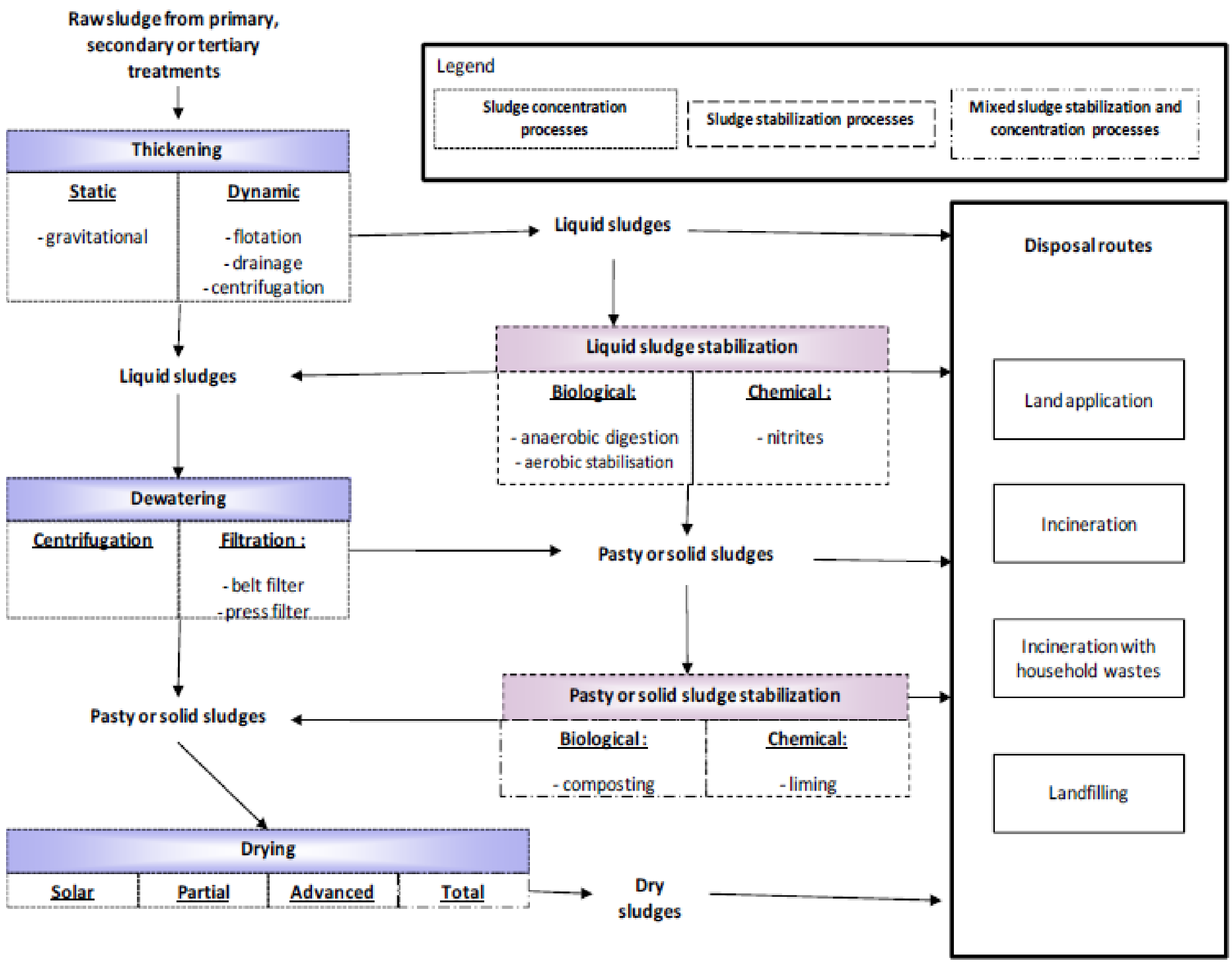

Figure 3: Studied sludge treatment processes and disposal routes[26]

GHG emissions for studied process

Direct GHG emissions generated for:

- storage;
- reed drying beds;
- anaerobic digestion;
- composting;
- land application;
- incineration;
- incineration with household wastes; and
- landfilling.

Indirect GHG emissions, expressed in CO_2eq, are generated for each process using inputs such as:

- electricity;
- gas;
- light;
- heavy fuel;
- lime;
- soda;

[26] Assessing GHG emissions from sludge treatment and disposal routes: the method behind GESTABoues tool Marilys Pradel, A.L. Reverdy

- polymer;
- active carbon.

The emissions considered take into account the GHG emissions released during the input production as well as those occurring during their transport up to the WWTP. The mineral fertiliser production generates indirect GHG emissions ranging from 0.121 to 1.693 kg of CO2eq/kg of nutrient (N, P or K)[27]. Direct GHG emissions impacted by the sludge process are presented in the table below.

Table 2: Direct GHG emissions regarding the sludge treatment and disposal routes studied processes[28]

Processes	Emissions	Unit	Emission factor	Source
Storage	CH_4	Kg/kg BOD_5	Open silo: 0 < 2 m silo in anaerobic condition: 0.12 < 2 m silo in anaerobic condition: 0.4	Sylvis, 2009 Mallard et al, 2007 Gac et al, 2006 Record, 2008 ADEME, 2005 IPCC, 2006 Citepa, 2010 Pacaud et al, 2009 Gac et al, 2010 EPE, 2006 Shimizu et al, 2007 Doka, 2007
Reed drying beds	N_2O CH4	Kg/PCE/an	0.0518 0.0453	
Anaerobic digestion	CH_4	Kg/ton	0.18	
Composting	CH_4 N_2O	Kg/ton	2.9 0.4	
Land application	N_2O	Kg/ton	Liquid sludge: 0.0294; Solid limed sludge: 0.05; Composted sludge: 0.05; Dry sludge: 0.2875	
	N_2O	Kg/ha	Other type of sludge and mineral fertilisers: $N_{applied}$* [0.0157 + 03.*0.0118 + 0.2*0.0157]	
Incineration	N_2O	Kg/ton	If combustion temperature (t°) is known: [N_{total}* (161.3 - 0.14 * t°)/100]*1,57 If t° is unknown: 1.64	
Incineration with household wastes	CO_2 N_2O	Kg/ton	390 0.092	
Landfilling	CH_4	Kg/ton	If biogas is captured: sludge C * 0.13 If biogas is released: sludge C * 0.43	

Indirect GHG emissions of inputs used for each sludge process are presented in the **Error! Reference source not found.**.

Table 3: Indirect GHG emissions regarding the inputs used for each process[29]

Type of inputs	Type of emissions	Unit	Emission factor	Source
Electricity	CO_{2eq}	Kg/kWh	0.089	IRH, 2009

[27] Assessing GHG emissions from sludge treatment and disposal routes: the method behind GESTABoues tool Marilys Pradel, A.L. Reverdy

[28] Assessing GHG emissions from sludge treatment and disposal routes: the method behind GESTABoues tool Marilys Pradel, A.L. Reverdy

[29] Assessing GHG emissions from sludge treatment and disposal routes: the method behind GESTABoues tool Marilys Pradel, A.L. Reverdy

Type of inputs	Type of emissions	Unit	Emission factor	Source
Gas	CO_{2eq}	Kg/kWh	0.32	OTV, 1997 Degremont, 2005 Pradel, 2010 Hospido et al, 2005 Record, 2008 ADEME, 2010
Light fuel	CO_{2eq}	Kg/kWh	0.24	
Heavy fuel	CO_{2eq}	Kg/l	2.662	
Fuel for tractors	CO_{2eq}	Kg/l	3.2	
Polymer	CO_{2eq}	Kg/kg	4.25	
$FeCl_3$	CO_{2eq}	Kg/kg	0.33	
Slaked lime	CO_{2eq}	Kg/kg	0.975	
Quicklime	CO_{2eq}	Kg/kg	1.04	
Caustic soda	CO_{2eq}	Kg/kg	1.17	
Activated carbon	CO_{2eq}	Kg/kg	6	

GHG emissions for transport

The transport process takes into account the transport of inputs from the suppliers storage place to the WWTP and then from the WWTP to the disposal place (either the field, the incinerator or the landfill). The GHG emissions of transport could be calculated according to the following hypotheses:

- CO_2 emission calculation for the ton.km unit, i.e., the emissions generated to transport one ton of production for one kilometer.
- Assuming that a single type of transport is used for one type of input. For example, the transport of polymer cannot be done with both a 2.5-ton truck and a 12-ton truck.
- Different inputs cannot be transported at the same time with the same vehicle.
- Transport of energetic consumables such as electricity, fuel, or gas is not taken into account as it is already accounted in indirect GHG emissions.

Sludge transport from the WWTP to the field is done according to the method proposed in Pradel (2010). For liquid sludge, transportation is done directly from the WWTP to the field with a tractor and a slurry tanker. The other types of sludge are transported from the WWTP to the intermediate storage with a truck and then to the field with a tractor and a spreader.

GHG emissions for infrastructure

GHG emissions were calculated according to the whole life cycle of the infrastructure and the total amount of produced sludge. They are expressed in kg of CO_2eq /unit/ton. An example of infrastructure calculation is done in the next table. Complete infrastructure GHG emissions can be found in Reverdy and Pradel (2011)[30].

[30] Reverdy, A.L. and Pradel, M. (2011): Evaluation des émissions de gaz à effet de Serre des filières de traitement et de valorisation
des boues issues du traitement des eaux usées. Février 2011. Rapport Cemagref/MEEDDM. 93 pages.

Table 4: GHG emissions for sludge treatment and disposal routes infrastructures[31]

Infrastructure	Capacity	Life span (years)	Description	Modelled processes	Kg CO_{2eq} /unit/ton
Static thickening	Small	30	Thickener, diameter: 5 m, capacity: 70 m^3	Concrete, Steel, Cast iron, Stainless steel	0.0245
	Medium	30	Thickener, diameter: 12 m, capacity: 450 m^3		0.0109
	Big	30	Thickener, diameter: 20 m, capacity: 1.250 m^3		0.0096
Press filter	Small	15	Press filter, 50 plates 500*500 mm, capacity: 290 l, total weight: 3.156 kg	Cast iron, Polypropylene stainless steel	0.2674
	Medium	15	Press filter, 100 plates 1.000*1.000 mm, capacity: 2.400 l, total weight: 12.385 kg		0.2103
	Big	15	Press filter, 150 plates 1.500*2.000 mm, capacity: 10.000 l, total weight: 59.090 kg		0.4943
Incineration	Medium	40	Fluidized bed incinerator, total weight: 65.970 kg, height: 10 m, diameter: 3.45 m	Refractory steel, refractory fireclay, sand, concrete	0.0188

Based on the above observations and analyses, RBS treatment of excess sludge has the lowest environmental impact considering the emission factors.

The following figure presents the basic carbon cycle related emission factor of using reed beds. When comparing the different technologies for dewatering excess sludge and specifically the emissions produced by reed beds, it must be considered that they also use CO2 during their vegetation. Thus, the use of low-carbon best available techniques, such as RBs treatment stage in the Mojkovac wastewater treatment plant, is an additional benefit.

[31] Assessing GHG emissions from sludge treatment and disposal routes: the method behind GESTABoues tool Marilys Pradel, A.L. Reverdy

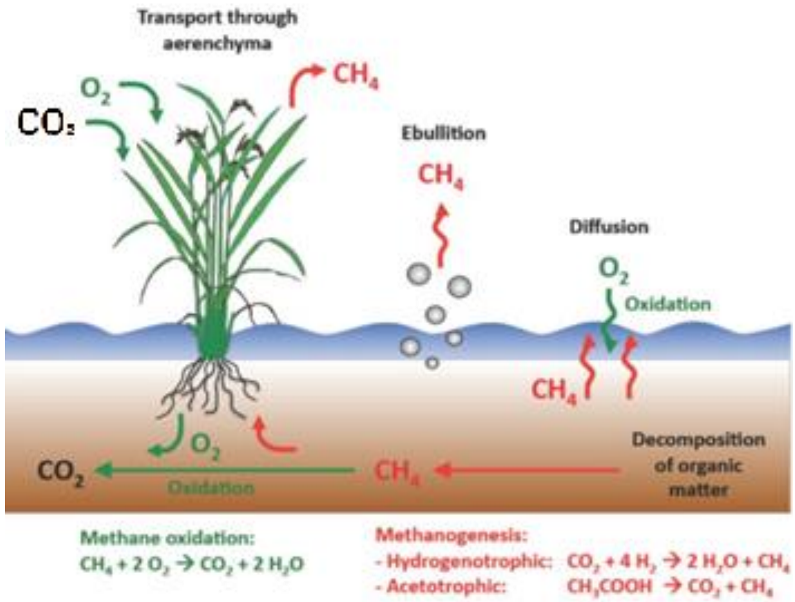

Figure 4: Generation and emission of methane from wet soils and consumption of carbon dioxide by reed beds. (Courtesy of Josef Zeyer, ETH Zurich, Switzerland.)[32]

Error! Reference source not found.5 shows the influence of loading conditions on heavy trucks. Three loading conditions were tested: empty, half-loaded, and fully loaded. In contrast to passenger vehicles, the loading conditions of the MHDVs had considerable influence. For example, the maximum payload of a 40-ton truck (heaviest truck) was 25 tons, which takes 62% of its total weight.

The average CO_2 emissions of a fully-loaded HDV are 12% more than those of the half-loaded conditions, and 25% more than those of the empty conditions.

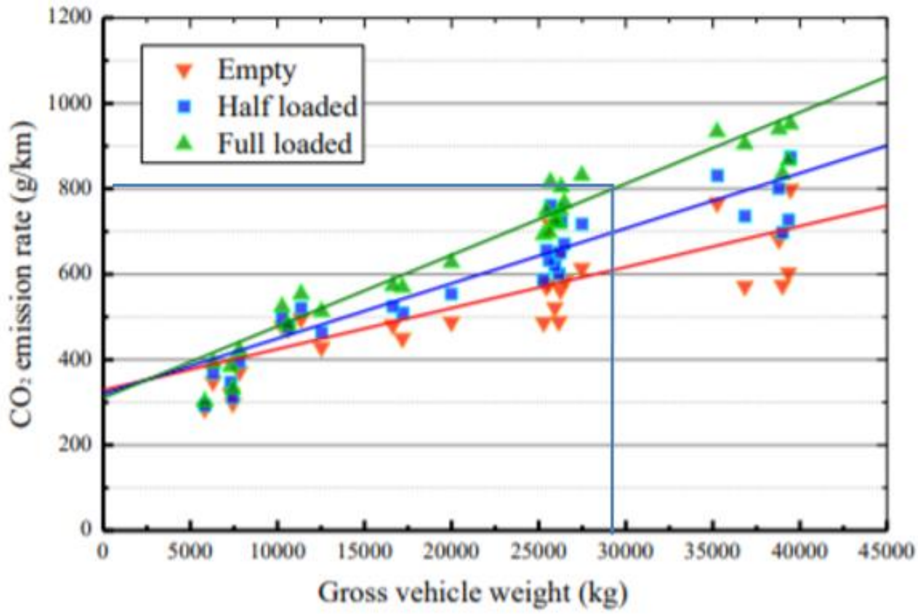

Figure 5: CO2 emission according to loading conditions[33]

Based on the above figure, the following table provides information regarding the truck over one year. The study is based on the load capacity of a trailer of a four-axle dump truck and to transport of dewatered sludge from Mojkovac to Podgorica for incineration.

[32] https://dl.sciencesocieties.org/publications/sh/articles/53/4/12
[33] Estimation of Total Transport CO_2 Emissions Generated by Medium- and Heavy-Duty Vehicles (MHDVs) in a Sector of Korea

Table 5: CO_2 emissions over the period of 1 and 20 years as a function of the type of sludge dewatering and disposal methods.

TYPE OF SLUDGE DEWATERING AND DISPOSAL		**Reed beds + incineration**	**Mechanical dewatering + incineration**
Calculation of the carbon footprint	Unit		
Load capacity of trailer of four-axle dump truck (Scania p420)	m^3	17	17
Load capacity of trailer of four-axle dump truck (Scania p420)	tons	20	20
Own weight of four-axle dump truck (Scania p420)	tons	9	9
Total weight of four-axle dump truck (Scania p420) with load capacity of trailer	tons	29	29
CO2 emission rate of full load four-axle dump truck with trailer	gCO_2 / km	800	800
Transported material distance from WWTP Mojkovac to WWTP Podgorica, Montenegro	km	95	95
Dewatered sludge	t / Y	94	315
Period of years	years	20	20
Dewatered sludge	t / 20 Yr	1.880	6.300
Number of trucks	number / year	4,70	15,75
Transported material distance from WWTP Mojkovac to WWTP Podgorica, Montenegro	km /Y	893	2 993
Carbon footprint of sludge transportation for 1 year	$kgCO_2$ / Y	714	2 394
Transported material distance from WWTP Mojkovac to WWTP Podgorica, Montenegro	km / 20 Y	17.860	59.850
Number of trucks	number / 20 Y	94	315
Carbon footprint of sludge transportation for 20 years	$kgCO_2$ / 20Y	14.228	47.880

The comparison of the two carbon footprints from transportation for one year between RBs and mechanical dewatering shows that the RBs have 3 times lower impact in 1 year and 20 years. Using RBs to treat the produced and treat sludge does not require heavy machinery and extensive amounts of energy that rely on gases that contribute to carbon emissions.

The avoided emissions in sludge treatments and disposal routes can be generated by energy or material substitutions:

- Use of sludge as fertilizers: avoided emissions are those generated by the amount of substitute mineral fertiliser production and its spreading,
- Use of sludge as a combustible or as mineral portion in cement kilns: therefore avoiding emissions ns that will take place for an equivalent non-renewable amount of energy or the production of the substituted raw materials.

2.3 Use of biosolids

The operation of the RBs system in Mojkovac suggests a lower impact on the environment than the alternative mechanical sludge dewatering systems, which require the use of chemicals, incinerators (optionally), transport, and disposal. The final product concerning pathogen removal and mineralization of hazardous organic compounds after the treatment and the resting period makes it possible to recycle the biosolids to:

- Agriculture as an enhanced treated product.
- Use on green areas and parks;
- Use for land recultivation on landfills, tailings, and mining areas.

The indirect benefits are the following:

- Reducing the quantity of commercial fertilizer (limited global resources of mineral phosphate);
- The low-cost and environmental-friendly technology enables improvement of soil conditions (nutrients that are beneficial as a soil amendment for crop production, organic matter improves soil physical properties for microbial activity, and increases water retention capacity, and plant growth support).

For the usage of natural dewatered sludge from RBs, it can be a source of beneficial nutrients to be used in agriculture, although only after laboratory analyses to clarify whether the sludge is suitable, based on the local restrictions.

Sewage sludge contains nutrients and organic matter that could be beneficial for the soil, but can also contain contaminants such as heavy metals, organic compounds, and pathogens. The Directive sets limit values for seven heavy metals (cadmium, copper, nickel, lead, zinc, mercury, and chromium), both in soil and in sludge itself.[34]

Sludge analysis was performed in order to obtain sludge quality information from Mojkovac. The sample taken assures homogeneity and represent physical and chemical quality of sludge treated on reed beds in Mojkovac.

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The analysis was performed for dry matter, total volatile solids, heavy metals, TP, and TN and pathogens. The results from the analysis are presented in the Chapter “Sludge analysis from WWTP Mojkovac.”

Available area for the main three types of biosolids reuse (reuse in agriculture, reuse in forest, green spaces and parks and reuse in land recultivation) is shown below.

Table 6: Energy efficiency indicators

Available Land use in Municipality Mojkovac	%	ha
Biosolids reuse in agriculture	12,18%	4 580
Complex cultivation patterns	1,34%	504
Land principally occupied by agriculture with significant areas of natural vegetation	10,84%	4 076

[34] https://ec.europa.eu/environment/archives/waste/sludge/pdf/part_i_report.pdf

Available Land use in Municipality Mojkovac	**%**	**ha**
Biosolids reuse in forest, green areas and parks	84,58%	31 802
Pastures	0,18%	68
Broad-leaved forest	27,45%	10 321
Coniferous forest	2,50%	940
Mixed forest	16,91%	6 358
Natural grasslands	18,96%	7 129
Moors and heathland	0,54%	203
Transitional woodland-shrub	9,89%	3 719
Sparsely vegetated areas	8,15%	3 064
Biosolids reuse in land recultivation on landfills, tailings and mining areas	0,19%	71
Mineral extraction sites	0,19%	71
Municipality of Mojkovac :	**100%**	**37 600**

Taking into account, the available areas for biosolids reuse a calculation for the potential use of agricultural land was made. Based on the minimum and maximum percentage of nitrogen in the biosolids and nitrogen input per hectare of agriculture land, the maximum required agriculture land of about 100 ha was calculated.

Table 7: Existing and theoretical potential of biosolids in agriculture

Biosolids in agriculture		
Parameters	***unites***	***Design value***
Biosolids production	tons/Y	94
	tons/20 years	1.880
Nitrogen in biosolids		
Nitrogen in biosolids, 3% (t/y)	2,82	
Nitrogen in biosolids, 5% (t/y)	4,70	
1 Scenario: Extensive agriculture		
N input per ha agricultural land	kg N/ha	170
Required agricultural land	ha (min)	332
	ha (max)	553
2 Scenario: Intensive agriculture		
N input per ha agricultural land	KG N/ha	800
Required agricultural land	ha (min)	71
	ha (max)	118

The above tables show that the biosolids reuse in agriculture, forestry, green areas, land recultivation on landfills, tailings, and mining areas, have the potential to be used as low-cost/environment-friendly technology that enables improvement of soil conditions.