

Report on life cycle assessments

(Deliverable of Action C.1)

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Abstract

Treatment of waste water results in reduction of environmental impact caused by outflow of the municipal waste waters to the environment, however such treatment has an impact on the environment themselves by consuming resources and energy. Considering solely biological treatment of municipal waste water, the environment is protected from the load of large amount of nutrients and other compounds by complying with water quality parameters. In this study additional treatment of effluent water with use of nZVI was taken into account, meaning that the water is additionally purified and can be used for different purposes (in ideal case even for drinking, however it is not expected). Life Cycle Assessment (LCA) method was applied in order to evaluate the trade-offs related with additional treatment of effluent water.

The results of LCA analysis showed that the environmental burdens in the operation stage are mainly associated with electricity use (the Small Waste Treatment Plant SWTP consumes around ten times more electricity than the pilot remediation system) and with use of nZVI, oxidant and filters required for additional cleaning of effluent water (at the pilot remediation system). Manufacturing of nZVI and oxidant are relatively burdening process from environmental point of view, what affect the impacts such as global warming and acidification for example.

Because of the additional cleaning of effluent water (at the pilot remediation system) effluents to surface stream are reduced for 30% (i.e. 960,000 liters per year). These savings are not only with regard the water as natural resource, but also with regard the energy and materials required for drinking water production. However, environmental benefits related with such savings are relatively minor. Saving of water in practice also means that the emissions of nutrients to surface streams, which are to some degree still present in effluent water after the waste water treatment at SWTP (considering COD and BOD emissions), are reduced. These emissions would have an impact on eutrophication, but as they are reduced it is considered as a benefit. For this reason additional cleaning of effluent water at the pilot remediation system yields a benefit in respect to eutrophication of local surface waters.

Rough comparisons of treatment of effluent water with use of nZVI with reverse osmosis showed that each technique has some environmental benefits and some environmental weaknesses. Treatment with use of nZVI shows much lower impact on global warming, abiotic depletion of fossil fuels, also on eutrophication, but higher impact on categories related with toxicity. It should be emphasized, that caution is needed when comparing environmental performance of these two treatment techniques. Reverse osmosis cannot clean water to the same extent as discussed nano-remediation. In order to do so, additional pretreatment of effluent water would be required before carrying reverse osmosis. In latter case, the environmental footprint of the treatment technique would increase.

General conclusion is that the additional treatment of effluent water with use of nZVI results in significant water saving (i.e. saving of groundwater reserves) and in reduction of eutrophication affect in local streams. Environmental benefits for local environment are significant. On other hand, globally related impacts (such as global warming, acidification,

photochemical ozone creation etc.) are increased for 70 – 160 % (considering life cycle of small-scale wastewater treatment plant). But such an increase of emissions from SWTP is still of negligible importance compared to total emissions released to the environment throughout the world from various industries and activities. Globally speaking, it means that discussed treatment of waste water is environmentally somehow more efficient in those countries, which face with lack of drinking water, than in those countries, which are rich with water resources. The latter results are totally expectable.

Another aspect is treatment with solid waste (i.e. waste sludge) obtained from small-scale wastewater treatment plant and from nano-remediation tank. Utilization of organic sludge from the SWTP for production of geotechnical composites yields only low impact on the environment, especially compared with traditional treatment scenarios (incineration of organic sludge with heat recovery, or use in agriculture). Moreover, composites with utilization of organic sludge and the waste iron suspension show lower environmental footprint than traditional composites, and thus fulfil sustainability requirements.

Expected results of Action C.1

An expected result of this action is proved environmental efficiency and sustainability of the pilot remediation systems through life cycle with traditional systems for water treatment and traditional composites.

1. INTRODUCTION

The goal of waste water treatment plants is to reduce the environmental impact caused by the municipal waste waters to the environment (i.e. to protect aquatic ecosystems and human health). At the same time, waste water treatments plants have an impact on the environment themselves by consuming resources for their construction and operation. The impact of waste water treatment plant on the environment can be analyzed by Life Cycle Assessment (LCA) method. This method is described in various literatures and is based on ISO standard of series 14040.

LCA is an environmental tool which allows calculation of environmental loads related to processes or product or services. In this study, LCA is applied to analyze the environmental performance of a small waste water treatment plant (SWTP) for 100 PE at Šentrupert (Poštaje). The SWTP is a biological treatment facility, that is coupled with the pilot remediation system, in which remediation of effluent water is conducted with use of zero-valent iron nanoparticles (nZVI).

Considering biological treatment of municipal waste water, the environment is protected from the load of large amount of nutrients and other compounds by complying with water quality parameters. For example chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of the effluent water from the SWTP should not exceed certain values as indicated in the national legislation, 150 mg O₂/L and 30 mg O₂/L for COD and BOD, respectively.

Considering additional treatment of effluent water with use of nZVI, it means that water is additionally purified and can be used for different purposes, such as for watering of gardens, for fire fighting, concrete production etc. and in ideal case even for drinking. In such cases, the exploitation of groundwater reserves is reduced, as well as production of drinking water, which is typically used for watering of gardens, fire fighting and even for concrete production. Reduction in drinking water consumption has positive effect on the environment, especially considering saving blue water (i.e. groundwater and surface water) as natural resource. However, additional amount of electrical energy is consumed during the additionally cleaning of effluent water; chemical reagents are required and additional amount of sludge is generated. Additional cleaning in the pilot remediation system thus brings significant benefits for the environment related with saving reserves of blue water, but also additional environmental burdens needs to be properly evaluated. For this purpose Life Cycle Assessment was applied. The study was carried out by using GaBi 6.115 software.

The LCA is four stage process, which includes:

- Goal of the study (with definition of system boundaries and the functional unit).
- Inventory analysis: LCA takes into account all relevant inputs and outputs of a product system through its whole life cycle. Based on inputs and outputs, the associated environmental impacts can be evaluated.
- Impact Assessment (impact on various environmental indicators can be studied such as impact on global warming - associated with greenhouse gas emissions, impact on eutrophication - associated with emissions of phosphates, nitrates and other nutrients in surface waters, impact on resource depletion for example on consumption of blue water (surface water and groundwater) etc.
- Interpretation of the results is the final stage of the LCA study.

1.1. Goal of the study

The goal of this study is to assess environmental performance of the SWTP at Šentrupert (Poštaje), which is biological treatment facility, and the pilot remediation system. Benefits and also weaknesses of such treatment were assessed.

In this study, the **functional unit** is the operation of SWTP and the pilot remediation system at Poštaje (Šentrupert municipality) over a period of one year. In this period, around 3,200 m³ of municipal waste water is biologically treated by the SWTP, of which 960 m³ additionally with the use of nZVI by the pilot remediation system.

System boundaries include construction stage of the SWTP and the pilot remediation system along with their operation stage (treatment of waste from water remediation processes is included).

1.2. Data Inventory

Life cycle inventory (LCI) data of materials (building materials, chemicals, filters, etc.) were obtained from databases integrated in GaBi software. Data were primarily searched in Professional+extensions database (thinkstep). Data not found in this database were searched in Ecoinvent 3.3 database. Some data were obtained also in the literature as mentioned later in this report. LCI data on transportation and production of energy (diesel, electricity) were taken from Professional+extensions (thinkstep) database.

Life cycle inventory data for operation of the SWTP and the pilot remediation system over a period of 1 year are as follows:

- Inflow of municipal waste water to the SWTP at Šentrupert (Poštaje):

around 3,200,000 L of waste water per year (3,200 m³).

- Biological treatment of municipal waste water by the SWTP:

around 3,200,000 L of municipal waste water treated at the SWTP per year (3,200 m³).

Electricity consumption: 21,900 MJ (6083 kWh) per year

Effluent to surface stream: 2,240,000 liters per year (2,240 m³)

Chemical in biochemical parameters of effluent water:

- COD: 114.2 kg O₂ per year
- BOD: 16.8 kg O₂ per year

Generation of organic sludge: around 33,200 kg per year

Dry matter content of organic sludge is 3%.

- Additional treatment of effluent water from the SWTP by the pilot remediation system:

Inflow: 960,000 liters of effluent water per year (i.e. water leaving the SWTP)

Electricity consumption: around 600 kWh per year

Consumption of consumable materials (i.e. chemicals):

- Nanoscale Zero valent iron: 96 kg per year
- Oxidant: 26.9 kg per year

Use of filters:

- Activated carbon: assuming life span of 7 years
- Ion-exchange resin: assuming life span of 5 years

Regeneration of filters:

- NaCl: 180 kg per year

- Drinking water: 52,800 liters per year

Benefits related with additional cleaning of effluent water (avoided effluents):

- Avoided COD emissions: 48.96 kg O₂ per year
- Avoided BOD emissions: 7.2 kg O₂ per year

Generation of waste iron suspension at nano-remediation tank: 9000 kg per year

Delivery of consumable materials:

- Zero-valent iron (nZVI) from Rajhrad (Czech Republic) to Šentrupert (Slovenia): 470 km
- Oxidant: 50 km

- Treatment of organic sludge:

Transport from Šentrupert to central municipal waste water treatment plant at Trebnje (MWTP): 12 km

Scenario: Treatment at the MWTP and incineration of organic sludge at incineration plant. LCI data for treatment at the MWTP refers to dataset from thinkstep database (dataset: "municipal waste water treatment"), while LCI data of organic sludge incineration refers to literature data (Hong et al., 2009). Per year, 5000 kg of organic sludge with 20% dry matter is generated at MWTP (considering only the organic sludge originating from the SWTP at Šentrupert). This is also the amount of organic sludge that is subjected to incineration.

Scenario: Treatment at MWTP and application in geotechnical composites.

- Geotechnical composite 1: use of organic sludge with 35% dry matter content (2857 kg of organic sludge annually deriving from SWTP in Poštaje).
- Geotechnical composite 2: use of organic sludge with 58% DM (1724 kg of organic sludge annually deriving from the SWTP at Šentrupert).
- Saving of clay as natural resource: 1818.8 kg (in case of production of Geotechnical composite 1).
- Saving of clay as natural resource: 2626.4 kg (in case of production of Geotechnical composite 2).

- Treatment of the waste iron suspension from the nano-remediation tank:

Transport from Šentrupert to concrete production plant: 120 km

Application in composites (concrete): 9000 kg of sludge per year.

Saving of drinking water: 9,180 liters per year

1.3. Impact Assessment

CML 2001 (version Jan. 2016) evaluation method was applied to assess the environmental impacts of the SWTP and the pilot remediation system. This method uses 12 midpoint categories defined for the problem oriented approach. CML 2001 method involves the environmental impacts associated with:

- climate change or global warming potential - GWP (kg CO₂ equiv.),
- acidification potential - AP (kg SO₂ equiv.),
- eutrophication potential - EP (kg PO₄ equiv.),
- photochemical ozone creation potential - POCP (kg Ethene equiv.),
- ozone layer depletion potential - ODP (kg R11 equiv.),
- marine aquatic ecotoxicity potential – MAEP (kg DCB equiv.),
- freshwater aquatic ecotoxicity potential – FWAEP (kg DCB equiv.),
- terrestrial ecotoxicity potential - TETP (kg DCB equiv.),
- human toxicity potential - HTP (kg DCB equiv.),
- depletion of abiotic resources (elemental) in kg Sb equiv. – ADP-e and
- depletion of abiotic resources (fossil) in MJ – ADP-f.

Additionally primary energy demand (from renewable and non-renewable resources considering net calorific value in MJ) and total blue water consumption (kg) related with life cycle of the SWTP and the pilot remediation system were evaluated.

2. RESULTS AND DISCUSSION

2.1. Construction stage

The construction stage of the SWTP and the pilot remediation system includes (i) manufacturing of all raw and building materials, and of all constituent parts, (ii) the delivery of these materials to the construction site (with use of trucks) and (iii) the construction activities on the site (with use of different machineries).

The construction activities on the site began with earthworks, such as excavation of construction pit (an excavator was used), followed by site leveling, foundation works, freight elevating (building materials and other constituent parts) and concreting. The use of following materials was considered for the construction of foundation: natural aggregate, geotextile, concrete and steel rebar. The main constituent materials/parts of the SWTP and the pilot remediation system are concrete wells with metal (cast iron) covers, PVC pipes, and plastic reservoirs. The amount of various constituent materials needed for the construction is shown in Table 1.

Use of all relevant machineries was also taken into account, including energy consumption of the machineries and associated emissions. Energy consumption during the construction activities was estimated based on the study of Zhang et al. (2010):

- Energy for earthwork: 1.703.000 kJ (diesel)
- Energy for site leveling: 20.600.000 kJ (diesel)
- Energy for freight elevating: 3.975.000 kJ (diesel)
- Energy for foundation works and concreting: 2 426 000 kJ (diesel, electricity)

Table 1: Raw materials used in construction stage.

Material	Amount
Geotextile	8 kg
Natural aggregate	230,120 kg
Lean concrete C8/10	21,876 kg
Concrete C25/30 (concrete plate and wells)	49,452 kg
Steel rebar	1,950 kg
PVC pipes	120 kg
Concrete wells (concrete C20/25)	4,860 kg
Metal (cast iron) covers	560 kg
Plastic reservoirs	1,400 kg

Environmental burdens associated with construction of the SWTP and the pilot remediation system were evaluated based on the data inventory available in GaBi database (Professional+extensions). Taking into account this database, environmental footprints of main materials, which were required for construction, were evaluated. Moreover, emissions from trucks and non-road mobile machineries were also evaluated by means of GaBi database. The results, which show the impact of the construction stage on the global warming (associated with greenhouse gas emissions), are presented in Figure 1. Construction of

concrete foundation contributes the most to the greenhouse gas emissions. However, it is well known that the carbon footprint of concrete is relatively high, due to use of Portland cement. Production of plastic reservoirs, use of non-road mobile machinery and manufacturing of products from cast iron (steel rebar, metal covers) are other processes, which contribute important share of greenhouse gas emissions attributed to the construction stage. Results with regard to impact on eutrophication, acidification and consumption of blue water are presented on Figures 2 to 4. Results for all impact categories are presented in Table 2.

Craftsman works such as carpentry, plumbing works, part machining were omitted from the system boundaries of construction stage. Also manufacturing of pumps and other specialized machineries was omitted, due to the lack of inventory data. No relevant data can be found neither in available LCA databases, neither in the literature.

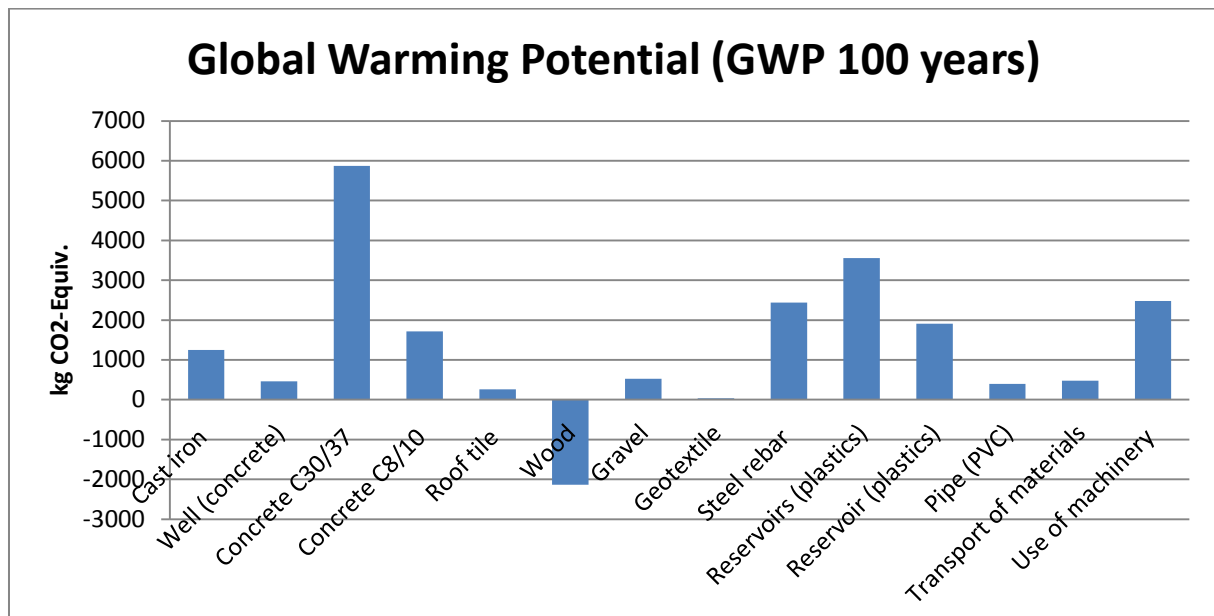


Figure 1: Impact on Global Warming related to the production of materials, their delivery and use of various machinery (the main processes involved in construction).

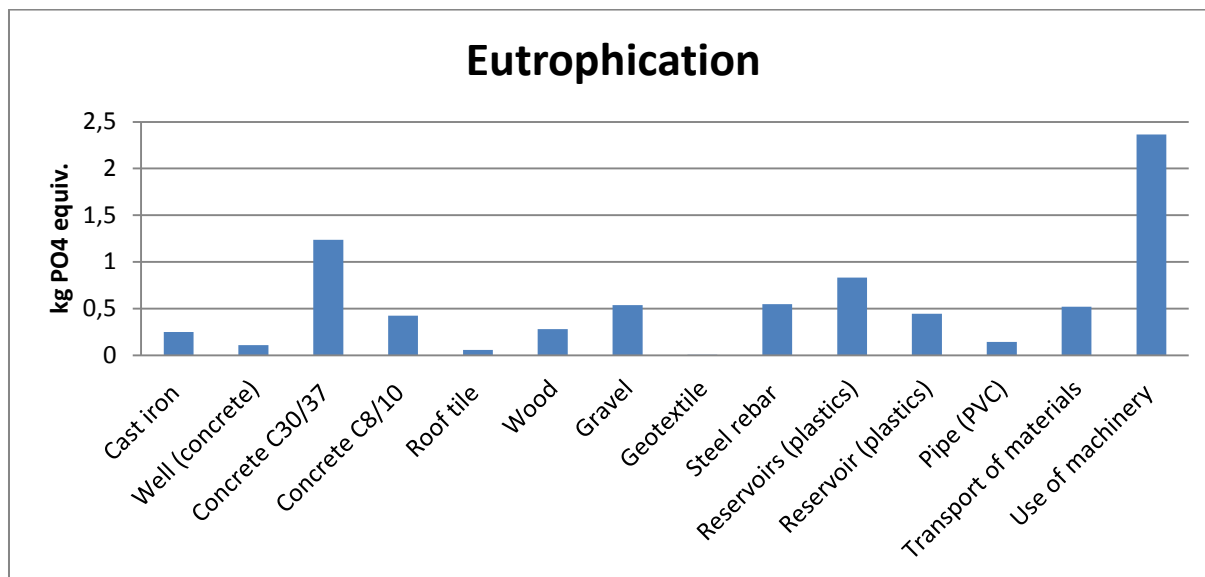


Figure 2: Impact on eutrophication related to the production of materials, their delivery and use of various machinery (the main processes involved in construction stage).

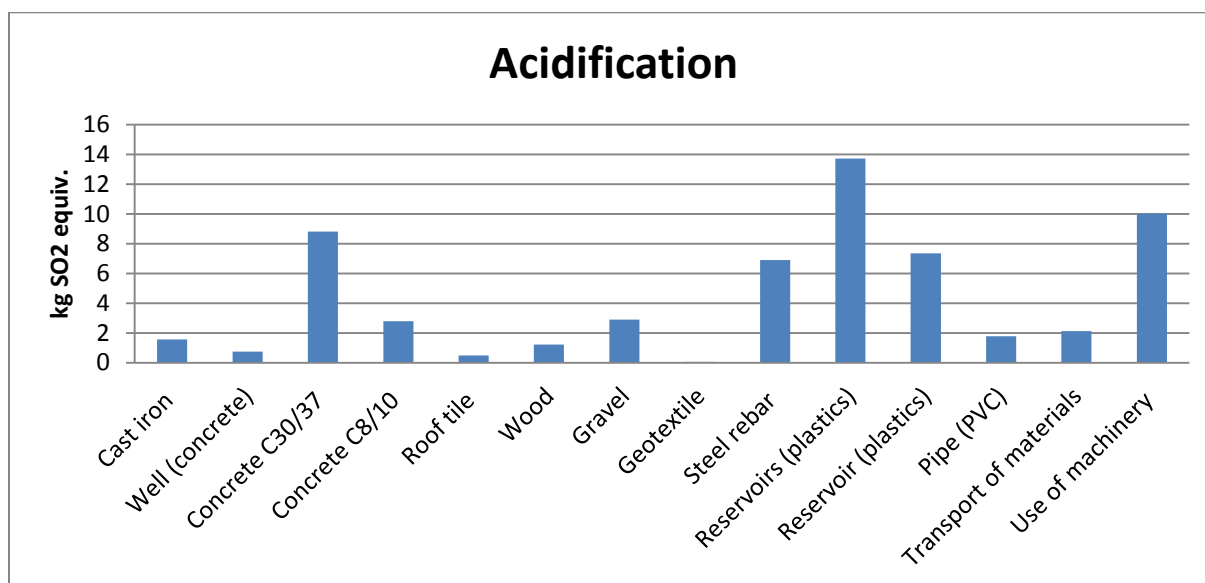


Figure 3: Impact on acidification related to the production of materials, their delivery and use of various machinery (the main processes involved in construction stage).

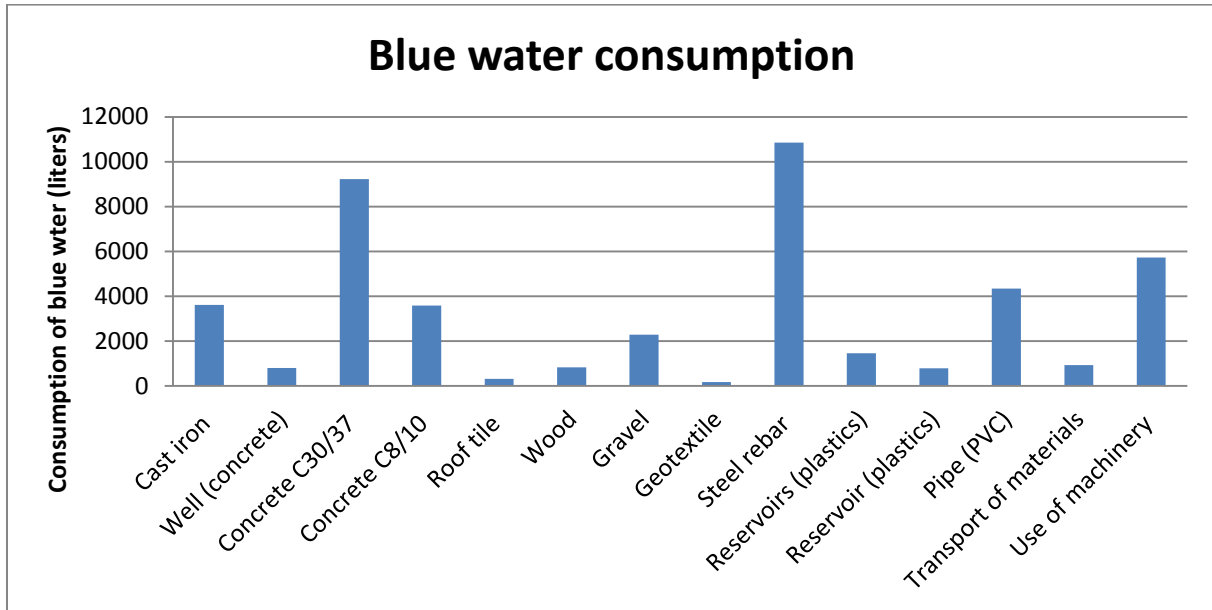


Figure 4: Consumption of blue water related with production of materials, their delivery and use of various machinery, considering the construction stage.

Table 2: Environmental footprint of main materials and activities involved in construction stage.

	Cast iron	Well (concrete)	Concrete C30/37	Concrete C8/10	Roof tile
ADP elements [kg Sb-Equiv.]	0.000425	0.000672	0.00935	0.002584	5.31E-05
ADP fossil [MJ]	13380.75	1690.48	17292.62	6096.34	3476.84
AP [kg SO2-Equiv.]	1.55	0.74	8.81	2.79	0.49
EP [kg PO4-Equiv.]	0.25	0.11	1.24	0.42	0.06
FAETP [kg DCB-Equiv.]	4.14	0.50	5.90	2.21	0.55
GWP 100 years [kg CO2-Equiv.]	1249.91	463.45	5874.03	1716.66	261.51
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	1249.28	437.93	5515.49	1620.06	262.51
HTP [kg DCB-Equiv.]	207.29	84.91	1163.76	324.92	101.65
MAETP [kg DCB-Equiv.]	244570.90	13937.71	162550.2	48555.67	1341152
ODP [kg R11-Equiv.]	5.56E-08	2.87E-09	3.76E-08	1.14E-08	3.71E-09
POCP [kg Ethene-Equiv.]	0.14	0.022	0.41	0.35	0.08
TETP [kg DCB-Equiv.]	42.66	0.72	8.72	2.91	0.09
Primary energy demand [MJ]	20901.22	2098.79	22600.74	7767.87	3983.58
Blue water consumption [kg]	3616.61	808.84	9228.07	3589.31	311.55

Table 2 continued

	Wood	Gravel	Geotextile	Steel rebar	Reservoirs (plastics)
ADP elements [kg Sb-Equiv.]	8.15E-05	0.000141	9.22E-06	174.5002	7.1E-05
ADP fossil [MJ]	3621.34	6496.553	744.49	26518.97	103801.3
AP [kg SO2-Equiv.]	1.21	2.88	0.064	6.90	13.71
EP [kg PO4-Equiv.]	0.28	0.54	0.0064	0.55	0.83
FAETP [kg DCB-Equiv.]	1.24	2.50	0.17	22.06	239.20
GWP 100 years [kg CO2-Equiv.]	-2138.33	523.48	34.93	2437.19	3558.48
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	318.91	529.68	34.79	2483.52	3558.48
HTP [kg DCB-Equiv.]	15.00	28.64	1.54	392.20	1206.28
MAETP [kg DCB-Equiv.]	30837.19	56728.28	1591.57	595056.4	176325.70
ODP [kg R11-Equiv.]	9.7E-09	1.45E-07	7.52E-09	2.16E-05	0
POCP [kg Ethene-Equiv.]	0.02	0.33	0.018	1.071	2.08
TETP [kg DCB-Equiv.]	0.69	6.88	0.798	9.59	0.17
Primary energy demand [MJ]	55417.6	9330.34	868.60	32021.22	110754.90
Blue water consumption [kg]	826.96	2293.18	172.98	10859.88	1458.47

Table 2 continued

	Reservoir (plastics)	Pipe (PVC)	Transport of materials	Use of machinery	SUM
ADP elements [kg Sb-Equiv.]	3.8E-05	0.00206	3.54E-05	0.000246	174.51
ADP fossil [MJ]	55607.82	6546.97	6517.25	32630.54	284422.2
AP [kg SO2-Equiv.]	7.35	1.78	2.12	10.00	60.4
EP [kg PO4-Equiv.]	0.45	0.14	0.52	2.36	7.75
FAETP [kg DCB-Equiv.]	128.15	137.49	2.88	13.68	560.68
GWP 100 years [kg CO2-Equiv.]	1906.33	398.44	475.50	2476.75	19238.35
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	1906.33	398.44	480.75	2506.96	21303.15
HTP [kg DCB-Equiv.]	646.22	752.39	15.21	79.66	5019.66
MAETP [kg DCB-Equiv.]	94460.21	23639.17	6651.33	41979.63	2838036
ODP [kg R11-Equiv.]	0	0	3.42E-09	1.76E-08	2.19E-05
POCP [kg Ethene-Equiv.]	1.12	0.14	-0.72	-2.87	2.19
TETP [kg DCB-Equiv.]	0.09	1.14	1.06	5.09	80.63
Primary energy demand [MJ]	59333	7517.57	6929.09	38294.69	377819.3
Blue water consumption [kg]	781.32	4341.75	929.61	5730.45	44948.99

2.2. Operation stage of the SWTP and the pilot remediation system

The SWTP and the pilot remediation system at Šentrupert (Poštaje) were evaluated separately in LCA analysis.

Biological purification of municipal waste water by the SWTP requires electricity for its operation. Electricity is consumed for water pumping and steering. Average annual consumption of electricity is around 21,900 MJ (6083 kWh).

The pilot remediation system also requires electricity for its operation. Moreover, chemicals (nZVI, oxidant) and filters (activated carbon, ion exchanger) are required. Chemicals are consumable goods. Moreover, filters need to be replaced after certain period of time. Average annual consumption of electricity at the pilot remediation system is significantly lower than at the SWTP, it is around 2,180 MJ (600 kWh).

The results of LCA analysis showed that the environmental burdens in the operation stage are mainly associated with electricity use (the SWTP consumes around ten times more electricity than the pilot remediation system) and with use of nZVI, oxidant and filters required for additional cleaning of effluent water. Production of electricity at power plants is associated with emissions, which depend on type of power plant (nuclear, thermal power etc.). Electricity in Slovene grid mix mostly derives from nuclear plant (around 40%), thermal plants (35 %) and hydropower plants (25%). Manufacturing of nZVI and oxidant are relatively burdening process from environmental point of view. Taking into account information obtained from the producer, around 9 kg of CO₂ equivalent emissions are released to the air during the manufacturing of 1 kg of nZVI. Around 96 kg of nZVI is consumed per year, for the additional cleaning of effluent water at the pilot remediation system that is coupled with the SWTP at Šentrupert (Poštaje).

Major part (around 70%) of the waste water treated at SWTP is discharged to the surface stream Bistrica. The parameters of the effluent water satisfy all requirements according to Slovene legislation. Average chemical oxygen demand (COD) of effluent is 51 mg O₂/l and biochemical oxygen demand (BOD) is 7.5 mg O₂/l. However, these effluents contribute to eutrophication, considering the COD and BOD emissions to the surface stream. These are the only direct emissions from the SWTP, while indirect emissions are associated with electricity production, as electricity is required for proper operation of the biological purification system of the SWTP, and with production of consumable materials required for additional cleaning of effluent water at the pilot remediation system.

Part of the effluent water (i.e. 30%) is not discharged to surface stream, but instead of that additionally treated at the pilot remediation system. Per year, around 960,000 liters of effluent water is additionally treated. Remediated water is stored in a special reservoir in order to be reused for different purposes instead to use drinking water. Thus savings are not only with regard the water as natural resource, but also with regard the energy and materials required for drinking water production. On other hand, it is logical that environmental burdens associated with remediation process of 960,000 liters of effluent water exceed the burdens associated

with pumping of the same amount of groundwater from aquifer and treatment of pumped water in order to be safe for drinking (i.e. drinking water production).

Additional cleaning of effluent water at the pilot remediation system is associated with use of chemical reagents: nZVI (around 96 kg per year) and oxidant (around 26.9 kg per year) and use of additional filters such as ion exchange column and activated carbon. Life time of the ion-exchange resin is 5 years (according to data in Ecoinvent 3.3) and life time of the activated carbon is around 7 years. After these periods, the filters need to be replaced with new ones. Environmental burdens associated with production of such filters refer to their entire life time. In this study, the functional unit is the operation of the SWTP and the pilot remediation system over a period of one year, thus the environmental footprint of filters were recalculated for a period of one year (total footprint of filters was divided by life time of filters – 5 in case of ion exchange column and 7 in case of activated carbon). Moreover, regeneration of filters is required to maintain their functionality during their life time. This is another aspect that needs to be account for in LCA study. Regeneration is conducted with sodium chloride (NaCl) dissolved in water. 180 kg of sodium chloride dissolved in 24,000 liters of water per year is used for regeneration of ion-exchanger and 28,800 liters of water per year is used for regeneration of activated carbon.

Because of the additional cleaning of effluent water (at the pilot remediation system) effluents to surface stream are reduced for 30% (for 960,000 liters per year). In practice it also means that the emissions of nutrients, which are to some degree still present in effluent water after the waste water treatment at SWTP (considering COD and BOD emissions), are reduced. These emissions would have an impact on eutrophication, but as they are reduced it is considered as a benefit. For this reason additional cleaning of effluent water at the pilot remediation system yields also some benefit in respect to eutrophication.

Impacts on global warming associated with operation of the SWTP and the pilot remediation system are shown in Figure 5. Consumption of electricity is responsible for most of the greenhouse gas emissions, considering the operation stage. It is the electricity, which is required for operation of biological purification at the SWTP. Also the production of nZVI, which is a chemical required for additional cleaning of effluent water, is responsible for relatively great amount of greenhouse gas emissions, considering the operation stage. The production of ion-exchange column also show quite significant contribution of greenhouse gas emissions.

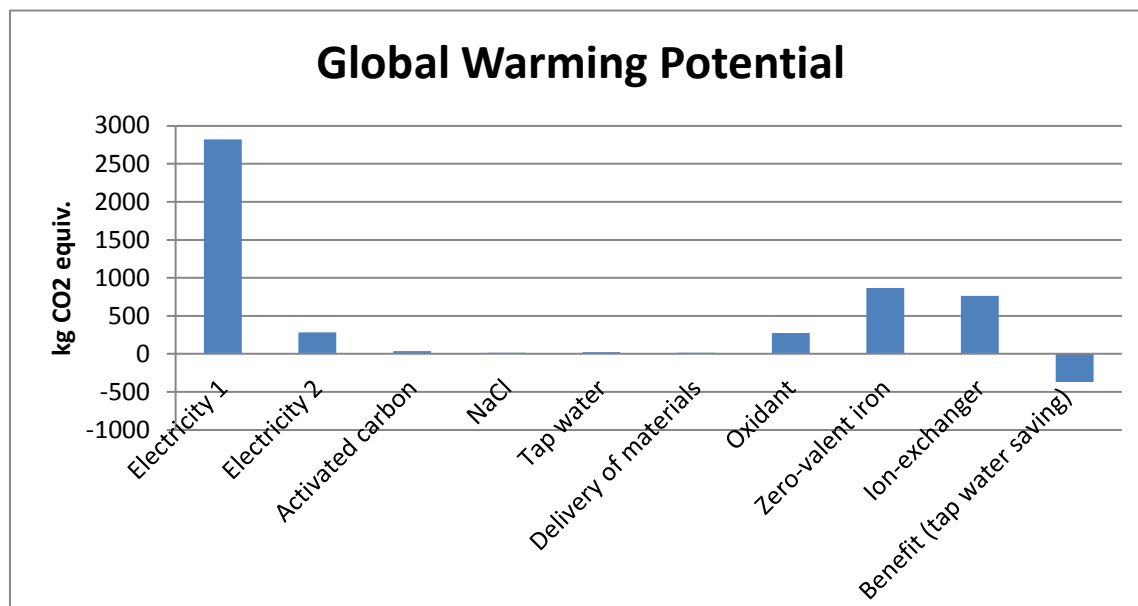


Figure 5: Impact on Global Warming related with operation of the SWTP and the pilot remediation system. Amount of greenhouse gas emissions associated with different processes and use of different consumable materials is shown.

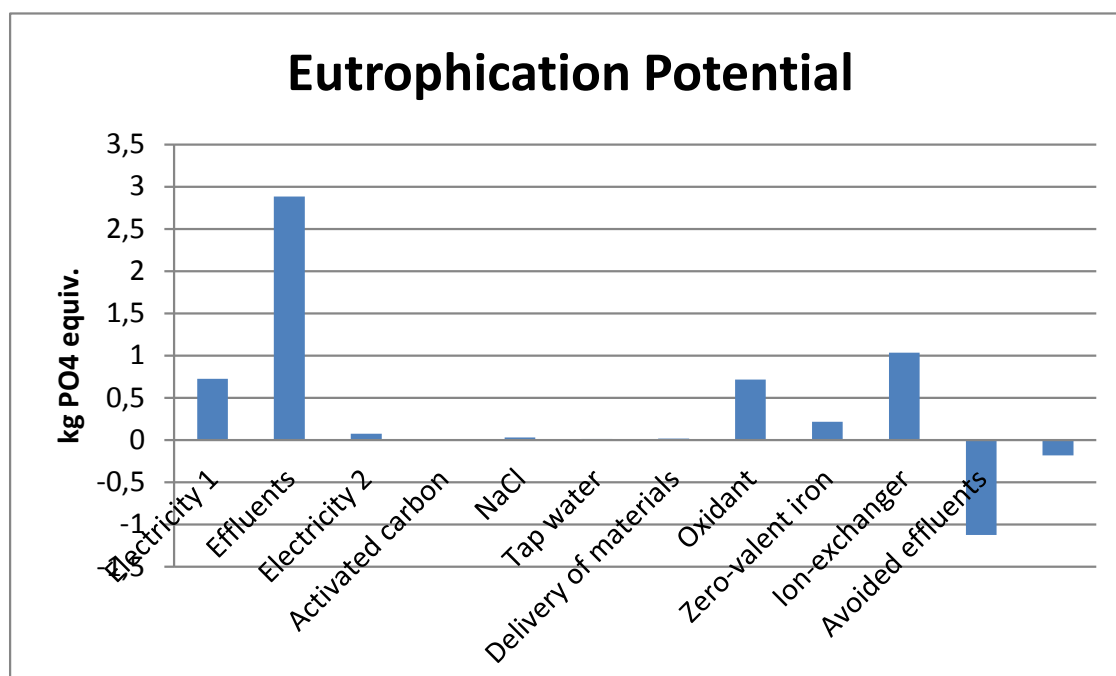


Figure 6: Impact on eutrophication related with operation of the SWTP and the pilot remediation system. Amount of phosphate equivalent emissions associated with different processes and use of different consumable materials is shown.

Figure 6 shows an impact on eutrophication, considering operation of the SWTP and the pilot remediation system. Effluent water to surface stream (the Bistrica) show the most important impact on eutrophication, as expected. However, the values of COD and BOD in the effluent water fulfill the requirements indicated in the national legislation. Production of electricity in power plants and manufacturing of materials required for additional cleaning of effluent water at the pilot remediation system also show relatively significant impact on eutrophication. Benefit related with additional cleaning of effluent water and thus reduction of COD and BOD emissions is also significant, while benefit related with reduced drinking water production due to reuse of remediated water is relatively minor (see negative values in Figure 6). Both benefits reduce the total impact on eutrophication in the operation stage of the SWTP and the pilot remediation system for around 23%. The effect on acidification and consumption of blue water, related with operation of the SWTP at Šentrupert (Poštaje) is shown in Figures 7 and 8.

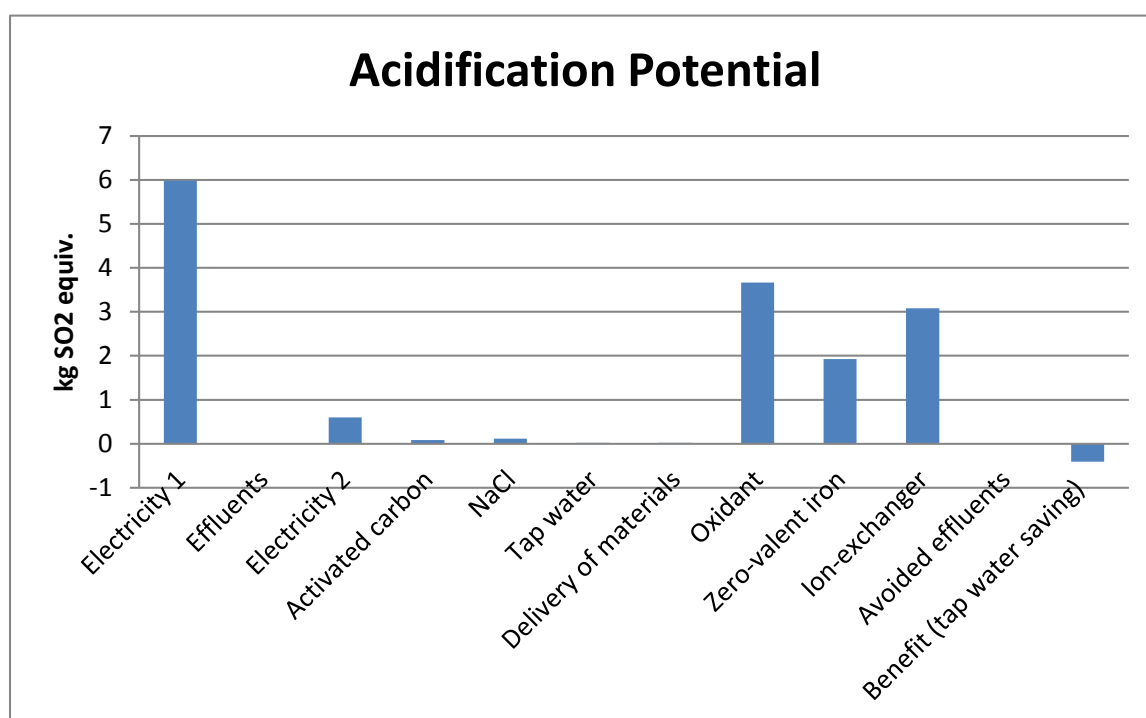


Figure 7: Impact on acidification related with operation of the SWTP and the pilot remediation system. Amount of Sulphur dioxide equivalent emissions associated with different processes and use of different consumable materials is shown.

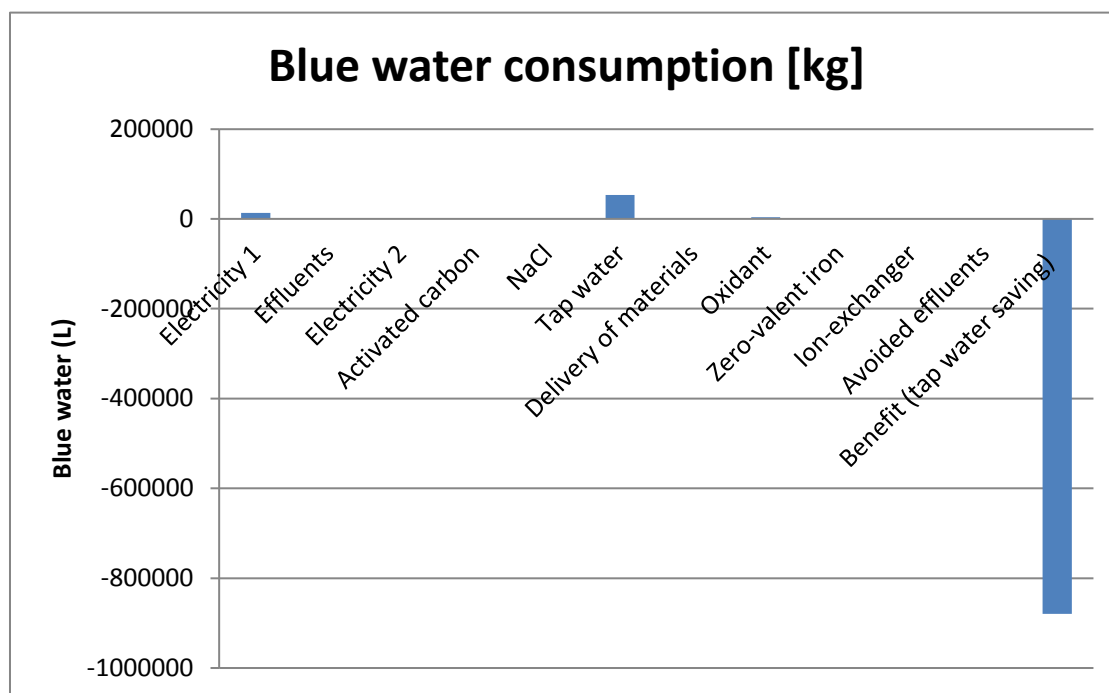


Figure 8: Impact on blue water consumption related with operation of the SWTP and the pilot remediation system. Amount of blue water consumption is associated with different processes and use of different consumable materials, as shown.

Table 3: Environmental footprint of processes and materials involved in operation stage of the SWTP and the pilot remediation system.

	The SWTP	
	Electricity	Effluents
ADP elements [kg Sb-Equiv.]	7.66E-04	0.00E+00
ADP fossil [MJ]	2.68E+04	0.00E+00
AP [kg SO2-Equiv.]	5.98E+00	0.00E+00
EP [kg PO4-Equiv.]	7.24E-01	2.88E+00
FAETP [kg DCB-Equiv.]	5.03E+00	0.00E+00
GWP 100 years [kg CO2-Equiv.]	2.82E+03	0.00E+00
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	2.82E+03	0.00E+00
HTP [kg DCB-Equiv.]	9.11E+01	0.00E+00
MAETP [kg DCB-Equiv.]	1.06E+05	0.00E+00
ODP [kg R11-Equiv.]	1.80E-08	0.00E+00
POCP [kg Ethene-Equiv.]	3.99E-01	0.00E+00
TETP [kg DCB-Equiv.]	2.25E+00	0.00E+00
Primary energy demand [MJ]	6.11E+04	0.00E+00
Blue water consumption [kg]	1.35E+04	0.00E+00

Table 3 continued

	The pilot remediation system					
	Electricity	Activated carbon	Sodium chloride	Drinking water	Delivery of materials	Oxidant
ADP elements [kg Sb-Equiv.]	7.63E-05	6.43E-06	2.96E-03	3.81E-06	1.07E-06	3.45E-02
ADP fossil [MJ]	2.67E+03	7.36E+02	2.09E+02	1.29E+02	1.97E+02	4.15E+03
AP [kg SO2-Equiv.]	5.96E-01	8.40E-02	1.16E-01	2.44E-02	6.40E-02	3.67E+00
EP [kg PO4-Equiv.]	7.21E-02	8.86E-03	2.80E-02	1.10E-02	1.57E-02	7.17E-01
FAETP [kg DCB-Equiv.]	5.01E-01	3.33E-02	8.46E-02	8.38E-02	8.71E-02	1.05E+02
GWP 100 years [kg CO2-Equiv.]	2.81E+02	3.70E+01	1.56E+01	2.22E+01	1.44E+01	2.76E+02
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	2.81E+02	3.71E+01	1.58E+01	1.09E+01	1.45E+01	2.76E+02
HTP [kg DCB-Equiv.]	9.07E+00	1.49E+01	6.63E-01	1.05E+00	4.59E-01	6.32E+02
MAETP [kg DCB-Equiv.]	1.05E+04	1.11E+03	4.07E+02	2.42E+03	2.01E+02	3.11E+05
ODP [kg R11-Equiv.]	1.79E-09	4.98E-10	1.60E-09	3.55E-10	1.03E-10	8.05E-04
POCP [kg Ethene-Equiv.]	3.97E-02	7.33E-03	1.68E-02	2.33E-03	-2.18E-02	2.89E-01
TETP [kg DCB-Equiv.]	2.24E-01	1.01E-02	3.25E-02	3.99E-02	3.21E-02	2.74E+00
Primary energy demand [MJ]	6.08E+03	8.02E+02	2.45E+02	1.44E+02	2.09E+02	5.05E+03
Blue water consumption [kg]	1.35E+03	6.12E+01	4.28E+01	5.30E+04	2.81E+01	3.64E+03

Table 3 continued

	The pilot remediation system				
	nZVI	Ion-exchange column	Avoided effluents	Benefit due to drinking water saving	SUM
ADP elements [kg Sb-Equiv.]	n/a	6.70E-03	0.00E+00	-6.17E-05	4.49E-02
ADP fossil [MJ]	6.75E+03	8.80E+03	0.00E+00	-2.35E+03	4.14E+04
AP [kg SO2-Equiv.]	1.92E+00	3.08E+00	0.00E+00	-4.43E-01	1.32E+01
EP [kg PO4-Equiv.]	2.16E-01	1.03E+00	-1.13E+00	-2.00E-01	4.16E+00
FAETP [kg DCB-Equiv.]	1.03E+01	7.08E+02	0.00E+00	-1.53E+00	8.18E+02
GWP 100 years [kg CO2-Equiv.]	8.65E+02	7.61E+02	0.00E+00	-4.03E+02	4.69E+03
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	n/a	7.60E+02	0.00E+00	-1.98E+02	4.02E+03
HTP [kg DCB-Equiv.]	1.89E+02	2.95E+03	0.00E+00	-1.92E+01	3.68E+03
MAETP [kg DCB-Equiv.]	6.40E+04	1.08E+06	0.00E+00	-4.42E+04	1.47E+06
ODP [kg R11-Equiv.]	1.70E-05	8.92E-03	0.00E+00	-4.72E-10	9.72E-03
POCP [kg Ethene-Equiv.]	1.53E-01	3.69E-01	0.00E+00	-3.76E-02	1.06E+00
TETP [kg DCB-Equiv.]	1.13E+00	9.38E+01	0.00E+00	-7.13E-01	9.84E+01
Primary energy demand [MJ]	1.35E+04	1.00E+04	0.00E+00	-2.63E+03	8.10E+04
Blue water consumption [kg]	n/a	7.05E+03	0.00E+00	-9.63E+05	-8.84E+05

2.3. Organic sludge and waste iron suspension treatment

Wastes are generated during water treatment at SWTP and also later during additional treatment of effluent water at the pilot remediation system.

The amount of organic sludge from primary tank from the SWTP is around 33,200 kg per year. This sludge, which contains around 3% of dry matter, is pumped and transported to the central MWTP at Trebnje, which is located 12 km far away. The organic sludge is then treated at the MWTP in the same way as municipal waste water from sewage system. Environmental burdens related with this treatment were evaluated based on GaBi dataset for an average waste water treatment in EU countries. After the treatment, the organic sludge is dewatered to achieve around 20% of dry matter. In such a case, mass of organic sludge decreases from 33,200 kg to around 5000 kg. Dewatering takes place via squeezing, this process requires electrical energy (40 kWh to squeeze one tone of sludge). Squeezed water (28,200 liters) is treated again at central SWTP.

Currently, the dewatered sludge is taken over and managed by Saubermacher company. The organic sludge is mostly incinerated or used in the agriculture abroad. The sewage sludge management in Slovenia in most cases includes incineration, as indicated in Figure 9.

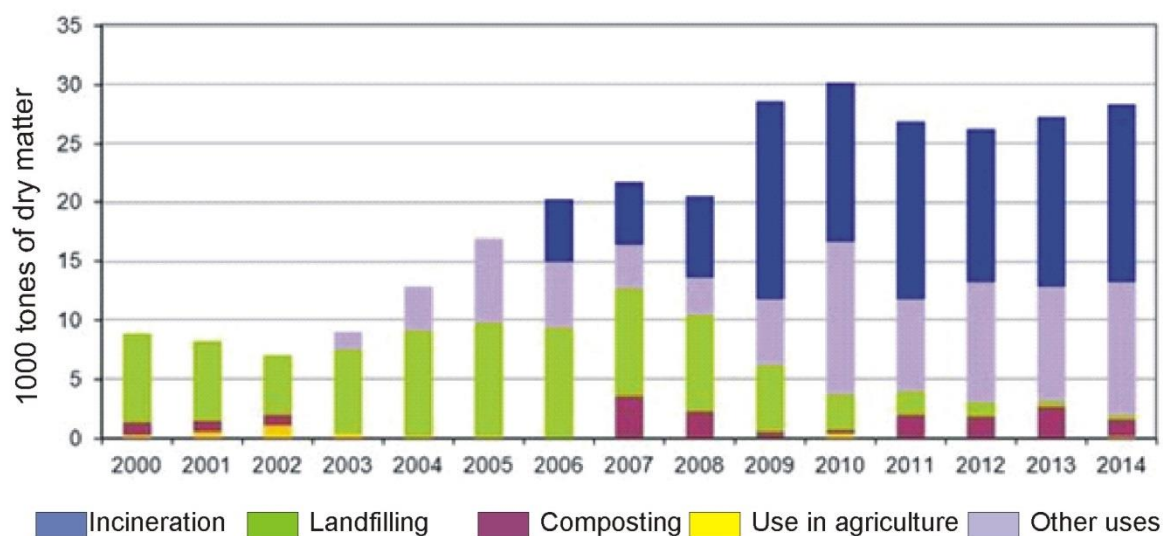


Figure 9: Statistical data for treatment with sludge from waste water treatment plants in Slovenija, for period 2000-2014. As indicated in the graph, most of the sludge was incinerated after the year 2009 (columns of blue color). Data were obtained from Slovenian environmental agency ARSO.

Environmental burdens related with sludge treatment at MWTP in Trebnje (transport of the sludge to the MWTP is included) are shown in Figures 10 to 13. After the dewatering, the squeezed water is treated again, what generates quite similar magnitude of burdens as organic sludge treatment (see Figures 10 to 13).

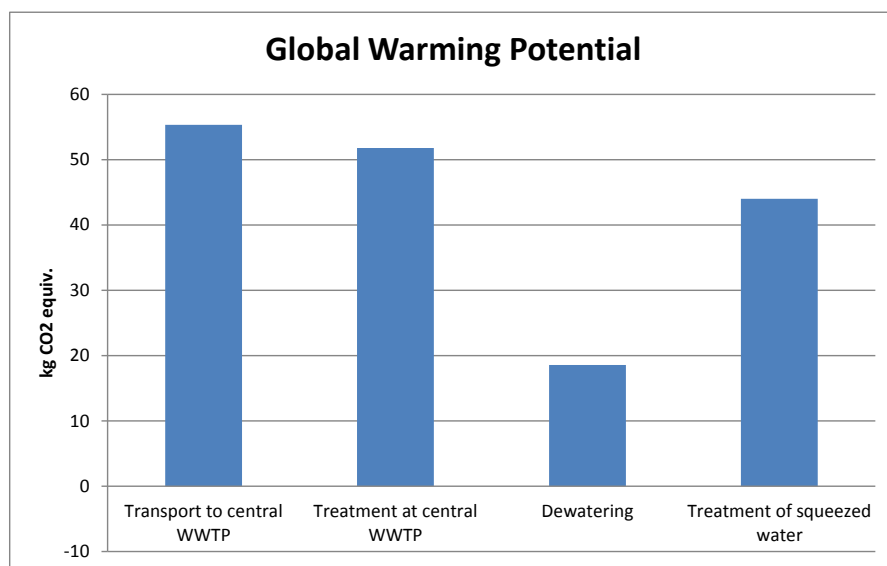


Figure 10: Impact on Global Warming related with transportation of organic sludge from the SWTP at Šentrupert (Poštaje) to the MWTP at Trebnje and therein additional treatment. After that sludge is squeezed to 20% dry matter and released water is treated again. Amount of greenhouse gas emissions associated with those processes are shown.

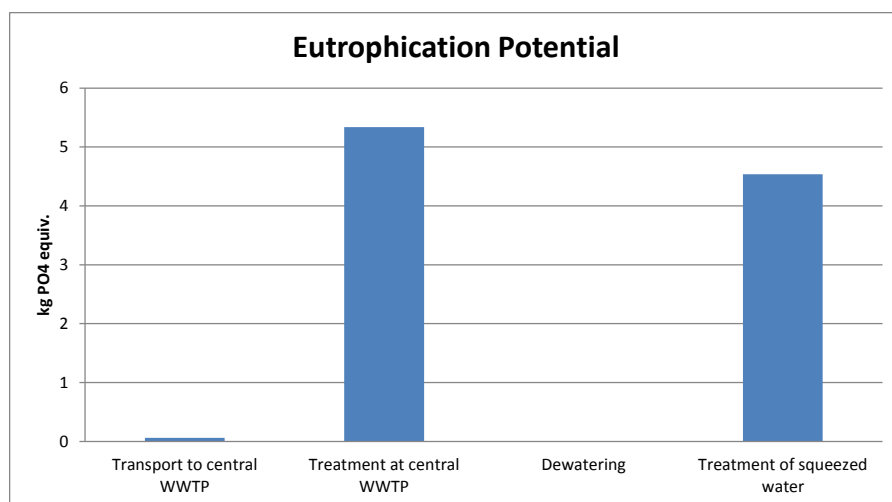


Figure 11: Impact on eutrophication related with transportation of organic sludge from the SWTP at Šentrupert (Poštaje) to the MWTP at Trebnje and therein additional treatment. After that organic sludge is squeezed to 20% dry matter and released water is treated again. Amount of phosphate equivalent emissions to surface water are shown for discussed processes.

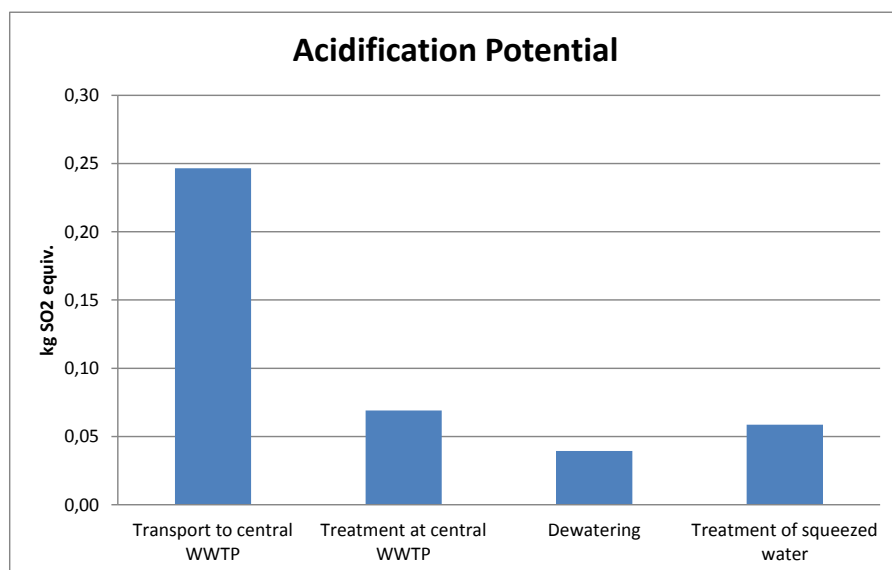


Figure 12: Impact on acidification related with transportation of organic sludge from the SWTP at Šentrupert (Poštaje) to the MWTP at Trebnje and therein additional treatment. After that organic sludge is squeezed to 20% dry matter and released water is treated again. Amount of Sulphur dioxide equivalent emissions to surface water are shown for discussed processes.

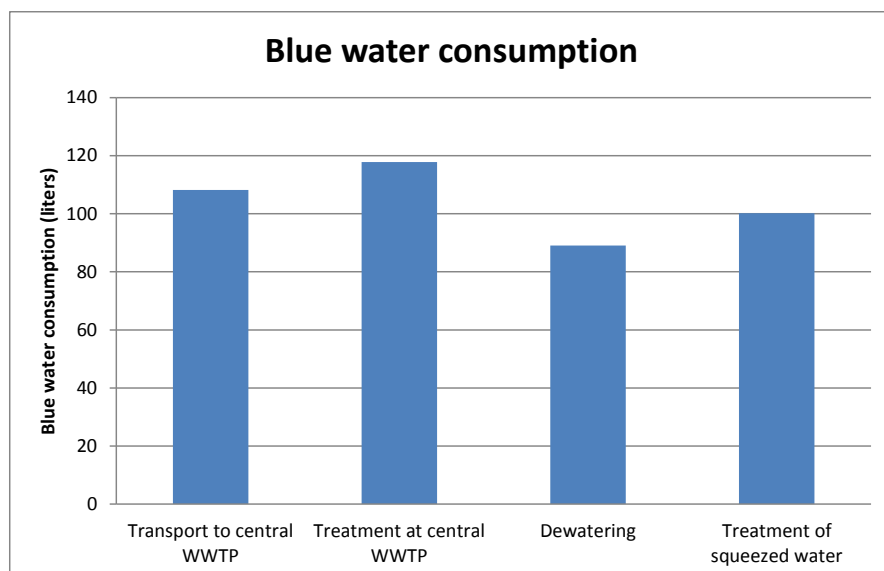


Figure 13: Impact on consumption of blue water, associated with transportation of organic sludge from the SWTP at Šentrupert (Poštaje) to the MWTP at Trebnje and therein additional treatment. After that organic sludge is squeezed to 20% dry matter and released water is treated again. Amount of blue water consumed for the processes involved in sludge treatment is shown.

Organic sludge incineration scenario includes transport of the organic sludge from the central MWTP to the incineration plant. Saubermacher company delivers it to incineration plant in Austria, delivery distance is estimated to be 400 km (two-ways distance). Energy requirements for incineration were estimated based on literature data (Hong et al., 2009). Data on emissions were taken from the same study. Incineration requires use of electricity and natural gas, on other hand, electricity production from waste heat takes place at incineration plant. Incineration of sludge is associated with generation of significant amounts of dioxin, furan and fly ash. Ash, which contains toxic metals is disposed on landfill (Hong et al., 2009).

In RusaLCA project, alternative organic sludge treatment option was developed. The organic sludge is used as a raw material for production of geotechnical composites 1 and Geotechnical composite 2. Geotechnical composite 1 is made from the sludge and from ash generated at incineration of biomass. In geotechnical composite 1, the dry mass ratio of organic sludge versus ash is 30% versus 70%. In geotechnical composite 2, the dry mass ratio of organic sludge versus ash is different, it is 70% versus 30%. Both composites are used to construct impermeable barriers at the base of landfills for non-hazardous wastes.

The alternative organic sludge treatment scenario thus includes transport of the sludge from the central MWTP over a distance of 25 km to a plant for production of geotechnical composites. Dry matter content of the organic sludge as a raw material for geotechnical composite 1 should be 34.5%. In case of production of geotechnical composite 2, dry matter content of organic sludge should be 57.8%. Drying of organic sludge takes place at atmospheric conditions; there are no additional energy requirements and associated emissions. For a production of composites geotechnical composite 1, around 2850 kg of dried organic sludge (primarily generated at the SWTP at Šentrupert) can be used per year, or for C geotechnical composite 2, around 1724 kg of this sludge (dried to 57.8%) can be used (per year).

For the production of geotechnical composite 1 and geotechnical composite 2 in the plant, electrical energy is required (for mixing). Around 4 kWh of electrical power is consumed per production of one cubic meter of a geotechnical composite ready to use. Water required for cleaning the mixer is also accounted in the LCA analysis. Around 560 liters of water for cleaning is required per each cubic meter of produced composite. However, geotechnical composite consists of organic sludge and ash mixed together in certain ratio, meaning that environmental burdens associated with production of the geotechnical composite (electricity consumption) and cleaning of the mixer (use of water) needs to be partitioned to organic sludge and ash. With other words, considering life cycle of organic sludge, it takes over some portion of burdens related with production of geotechnical composite and the rest of burdens takes over ash in its life cycle. The ratio between organic sludge with 34.5% dry matter content and ash is 55.4% versus 44.6% for production of geotechnical composite 1. In case of production of geotechnical composite 2, the ratio between organic sludge with 57.8% dry matter content and ash is 80% versus 20%. Above mentioned ratios were used in order to partite environmental burdens associated with production of geotechnical composites to the

life cycle of organic sludge and to the life cycle of ash, the latter one not being relevant for this study.

Because the geotechnical composite replaces use of natural clay, which is typical material used for construction of low permeable barriers in base of landfills, the need for clay extraction is decreased. Avoided extraction of this natural resource is considered as a benefit from LCA perspective. However, this benefit should again be partitioned to life cycle of organic sludge and life cycle of ash, as sludge and ash are both raw materials in the geotechnical composite. Construction of the geotechnical composite on the landfill is conducted in a similar way as construction of clay barriers, for this reason, the construction can be omitted from system boundaries.

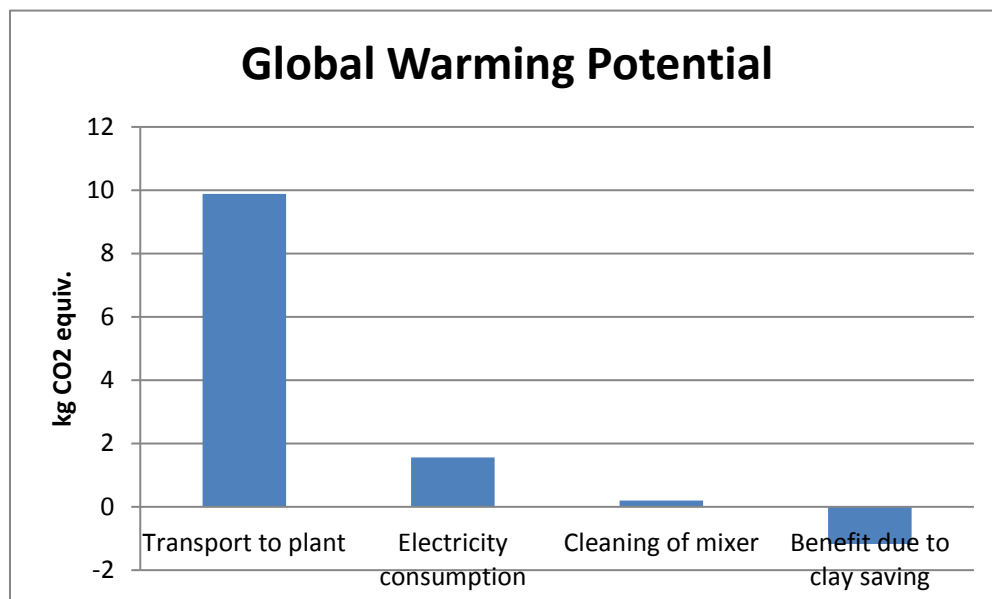


Figure 14: Impact on Global Warming related with life cycle of organic sludge after the treatment at the MWTP at Trebnje. Life cycle includes transport of organic sludge to composite production plant, electricity consumption for production of the geotechnical composite 1, cleaning of the mixer and benefits associated with preserving natural resources of clay. Amount of greenhouse gas emissions associated with those processes is shown.

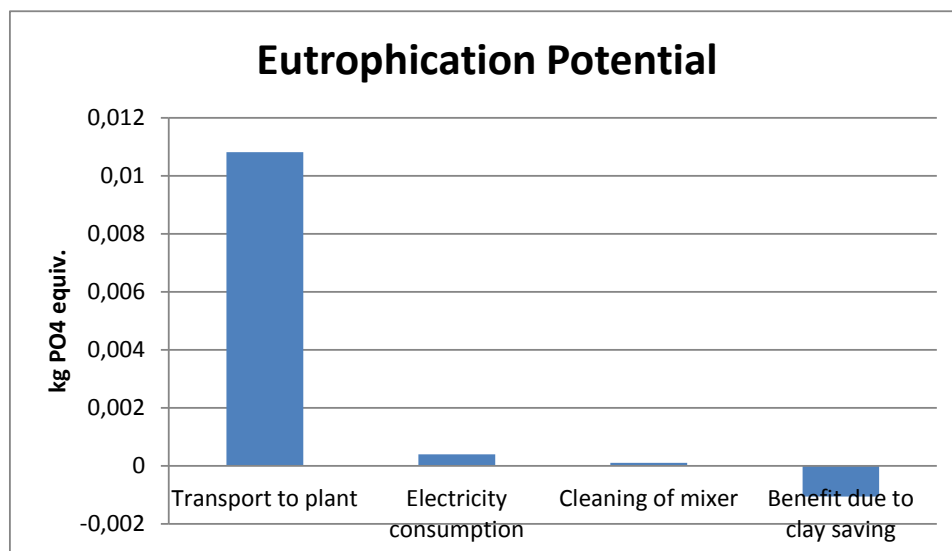


Figure 15: Impact on eutrophication related with life cycle of organic sludge after the treatment at the MWTP at Trebnje. Life cycle includes transportation of organic sludge to composite production plant, electricity consumption for production of the geotechnical composite 1, cleaning of the mixer and benefits associated with preserving natural resources of clay. Amount of phosphate equivalent emissions associated with those processes is shown.

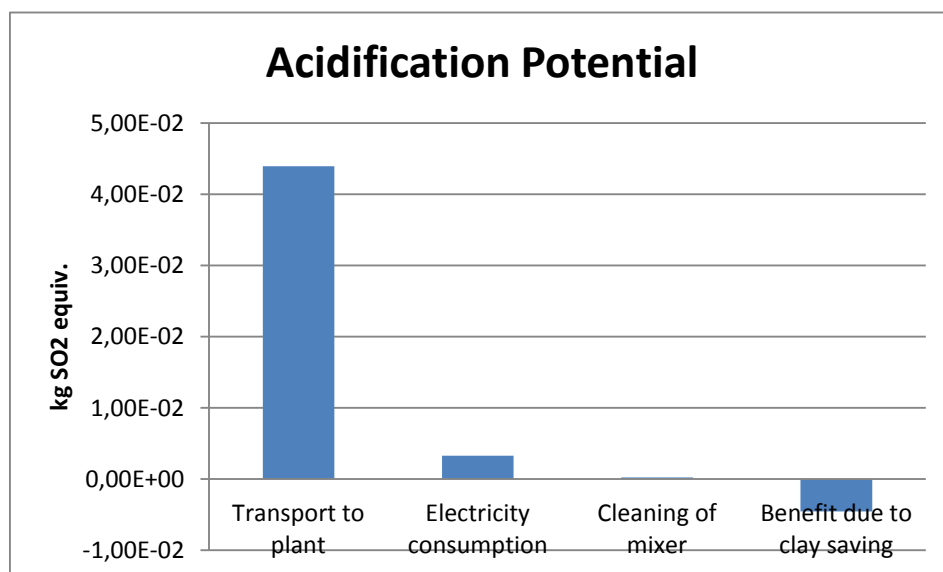


Figure 16: Impact on acidification related with life cycle of organic sludge after the treatment at the MWTP at Trebnje. Life cycle includes transportation of organic sludge to composite production plant, electricity consumption for production of the geotechnical composite 1, cleaning of the mixer and benefits associated with preserving natural resources of clay. Amount of Sulphur dioxide equivalent emissions associated with those processes is shown.

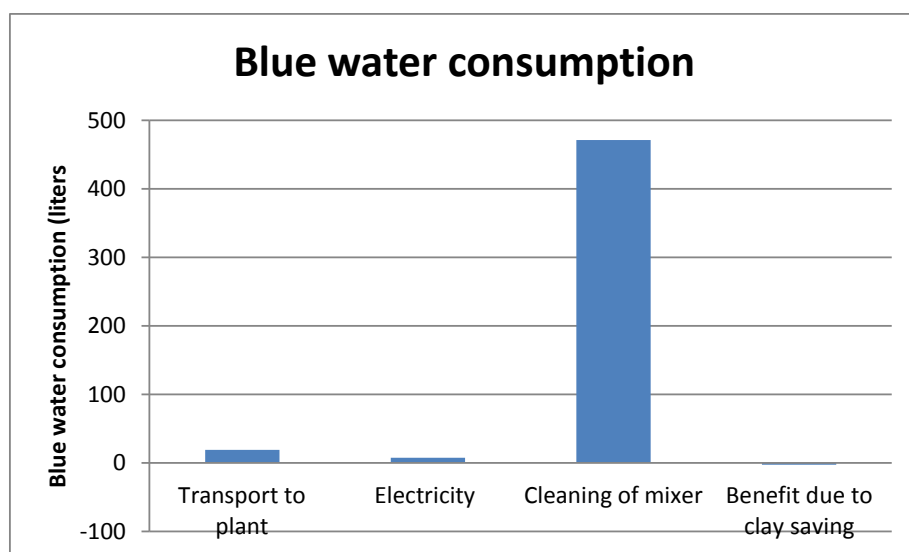


Figure 17: Consumption of blue water considering life cycle of organic sludge after the treatment at the MWTP at Trebnje. Life cycle includes transportation of organic sludge to composite production plant, electricity consumption for production of the geotechnical composite 1, cleaning of the mixer and benefits associated with preserving natural resources of clay. Amount of blue water consumed for the processes involved in sludge life cycle is shown.

Detailed environmental footprints of processes related with treatment of organic sludge (generated at SWTP) at the central MWTP at Trebnje and further use of the sludge for production of geotechnical composite are shown in Tables 4 to 6. Environmental burdens of organic sludge incineration scenario compared to burdens of scenario of organic sludge utilization for production of geotechnical composite are shown in Table 7.

Table 4: Environmental footprint of processes involved in treatment of organic sludge (generated at SWTP Poštaje) at the central MWTP at Trebnje. Transport of the sludge is included.

	Transport of organic sludge to the MWTP	Treatment of organic sludge at the MWTP	Dewatering to 20% DM	Treatment of squeezed water at the MWTP
ADP elements [kg Sb-Equiv.]	4.12E-06	1.01E-04	5.04E-06	8.58E-05
ADP fossil [MJ]	7.58E+02	2.66E+02	1.77E+02	2.26E+02
AP [kg SO ₂ -Equiv.]	2.47E-01	6.90E-02	3.93E-02	5.86E-02
EP [kg PO ₄ -Equiv.]	6.06E-02	5.34E+00	4.76E-03	4.54E+00
FAETP [kg DCB-Equiv.]	3.36E-01	2.70E+03	3.30E-02	2.29E+03
GWP 100 years [kg CO ₂ -Equiv.]	5.53E+01	5.18E+01	1.86E+01	4.40E+01
GWP 100 years, excl biogenic carbon [kg CO ₂ -Equiv.]	5.59E+01	5.18E+01	1.86E+01	4.41E+01
HTP [kg DCB-Equiv.]	1.77E+00	2.81E+04	5.99E-01	2.38E+04
MAETP [kg DCB-Equiv.]	7.74E+02	4.25E+06	6.95E+02	3.61E+06
ODP [kg R11-Equiv.]	3.98E-10	2.80E-07	1.18E-10	2.38E-07
POCP [kg Ethene-Equiv.]	-8.41E-02	4.48E-03	2.62E-03	3.81E-03
TETP [kg DCB-Equiv.]	1.24E-01	6.53E+01	1.48E-02	5.55E+01
Primary energy demand [MJ]	8.06E+02	4.49E+02	4.01E+02	3.82E+02
Blue water consumption [kg]	1.08E+02	-3.32E+04	8.91E+01	-2.82E+04

Table 5: Environmental footprint of processes involved life cycle of organic sludge. Use of organic sludge to produce geotechnical composite 1.

	Transport to composite mixing plant	Electricity	Water for cleaning	Benefit due to clay saving	Total
ADP elements [kg Sb-Equiv.]	7.35E-07	4.22E-07	3.38E-08	-1.19E-07	1.07E-06
ADP fossil [MJ]	1.36E+02	1.48E+01	1.15E+00	-1.60E+01	1.35E+02
AP [kg SO2-Equiv.]	4.39E-02	3.30E-03	2.17E-04	-4.53E-03	4.29E-02
EP [kg PO4-Equiv.]	1.08E-02	3.99E-04	9.77E-05	-1.06E-03	1.03E-02
FAETP [kg DCB-Equiv.]	6.00E-02	2.77E-03	7.45E-04	-7.11E-03	5.64E-02
GWP 100 years [kg CO2-Equiv.]	9.89E+00	1.56E+00	1.97E-01	-1.18E+00	1.05E+01
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	9.99E+00	1.56E+00	9.68E-02	-1.24E+00	1.04E+01
HTP [kg DCB-Equiv.]	3.16E-01	5.02E-02	9.34E-03	-4.29E-02	3.32E-01
MAETP [kg DCB-Equiv.]	1.38E+02	5.83E+01	2.16E+01	-1.64E+01	2.02E+02
ODP [kg R11-Equiv.]	7.13E-11	9.93E-12	3.16E-12	-8.43E-12	7.59E-11
POCP [kg Ethene-Equiv.]	-1.50E-02	2.20E-04	2.07E-05	-5.35E-04	-1.53E-02
TETP [kg DCB-Equiv.]	2.21E-02	1.24E-03	3.54E-04	-2.62E-03	2.11E-02
Primary energy demand [MJ]	1.44E+02	3.37E+01	1.28E+00	-1.71E+01	1.62E+02
Blue water consumption [kg]	1.93E+01	7.46E+00	4.71E+02	-2.29E+00	4.95E+02

Table 6: Environmental footprint of processes involved life cycle of organic sludge. Use of organic sludge to produce geotechnical composite 2.

	Transport to composite mixing plant	Electricity	Water for cleaning	Benefit due to clay saving	Total
ADP elements [kg Sb-Equiv.]	4.44E-07	3.07E-07	4.12E-08	-1.72E-07	6.20E-07
ADP fossil [MJ]	8.17E+01	1.08E+01	1.40E+00	-2.32E+01	7.07E+01
AP [kg SO2-Equiv.]	2.66E-02	2.39E-03	2.65E-04	-6.54E-03	2.27E-02
EP [kg PO4-Equiv.]	6.53E-03	2.90E-04	1.19E-04	-1.53E-03	5.41E-03
FAETP [kg DCB-Equiv.]	3.62E-02	2.01E-03	9.07E-04	-1.03E-02	2.88E-02
GWP 100 years [kg CO2-Equiv.]	5.96E+00	1.13E+00	2.40E-01	-1.70E+00	5.63E+00
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	6.03E+00	1.13E+00	1.18E-01	-1.79E+00	5.48E+00
HTP [kg DCB-Equiv.]	1.91E-01	3.65E-02	1.14E-02	-6.20E-02	1.77E-01
MAETP [kg DCB-Equiv.]	8.34E+01	4.23E+01	2.62E+01	-2.36E+01	1.28E+02
ODP [kg R11-Equiv.]	4.29E-11	7.21E-12	3.84E-12	-1.22E-11	4.18E-11
POCP [kg Ethene-Equiv.]	-9.06E-03	1.60E-04	2.52E-05	-7.73E-04	-9.65E-03
TETP [kg DCB-Equiv.]	1.33E-02	9.02E-04	4.31E-04	-3.79E-03	1.09E-02
Primary energy demand [MJ]	8.69E+01	2.45E+01	1.66E+00	-2.46E+01	8.84E+01
Blue water consumption [kg]	1.17E+01	5.42 E+00	5.74E+02	-3.30E+00	5.87E+02

Table 7: Comparison of two scenarios with regard to organic sludge treatment: incineration scenario versus utilization of organic sludge in geotechnical composites. Burdens of three scenarios are shown.

	Incineration	Utilisation in geotechnical composite 1	Utilisation in geotechnical composite 2
ADP elements [kg Sb-Equiv.]	-9.05576E-05	1.07E-06	6.2E-07
ADP fossil [MJ]	2598.41	135.41	70.70
AP [kg SO2-Equiv.]	0.46	0.04	0.02
EP [kg PO4-Equiv.]	0.36	0.010	0.005
FAETP [kg DCB-Equiv.]	194.15	0.056	0.029
GWP 100 years [kg CO2-Equiv.]	747.27	10.46	5.63
GWP 100 years, excl biogenic carbon [kg CO2-Equiv.]	748.76	10.40	5.48
HTP [kg DCB-Equiv.]	227.90	0.33	0.17
MAETP [kg DCB-Equiv.]	2064.16	201.71	128.34
ODP [kg R11-Equiv.]	6.99E-10	7.59E-11	4.18E-11
POCP [kg Ethene-Equiv.]	-0.2	-0.0153	-0.0096
TETP [kg DCB-Equiv.]	690.4	0.021	0.011
Primary energy demand [MJ]	174.61	161.82	88.36
Blue water consumption [kg]	-1657.98	495.39	587.37

2.3.1. Waste iron suspension from nano-remediation tank

Around 9000 kg of waste iron suspension from nano-remediation process is generated per year. This waste iron suspension, which is actually a water suspension containing nano-particles of iron oxides is treated separately of organic sludge from primary tank (generated at SWTP). Waste iron particles settled down in nano-remediation tank and then waste iron suspension is pumped and transported to concrete production plant (delivery distance 120 km) and it is directly used as a raw material for concrete production. The waste iron suspension does not need any pre-treatment. Each cubic meter of concrete is produced according to certain mix proportions of natural aggregate, cement, plasticizer and water (Table 8). Using the waste iron suspension in concrete production process, the mix proportions of raw materials is changed. Actually, amount of all original raw materials remains unchanged, except the amount of water, which is reduced (Table 8). Adequate consistency of the concrete mix can be achieved by replacing some amount of water with waste iron suspension (water suspension containing nano-particles of iron oxides).

Table 8: Mix proportions for production of one cubic meter of etalon, or alternative mixture with use of the waste iron suspension from nano-remediation tank.

	Etalon	Alternative mixture
Natural aggregate (kg/m ³)	1922	1922
Cement (kg/m ³)	350	350
Plasticizer (kg/m ³)	1.6	1.6
Water (kg/m ³)	163	112
Sludge from nano-remediation tank (kg/m ³)	0	50

Considering life cycle of waste iron suspension generated in nano-remediation tank, there are no environmental burdens except those related to delivery of the waste iron suspension to the concrete production plant. The nano-particles of iron oxides are immobilized in the concrete, meaning that the product is considered as an inert. From the perspective of Life Cycle Assessment, the use of the waste iron suspension in concrete production process yields environmental benefits associated with reduction of drinking water content in the concrete mix. Environmental benefits related with avoided production of drinking water from groundwater were evaluated by means of LCA. For example, Figure 18 show potential impact on global warming related with delivery of the waste iron suspension to the concrete production plant and benefit related with avoided use of drinking water. Burdens and benefits with regard to other impact categories are indicated in Table 9.

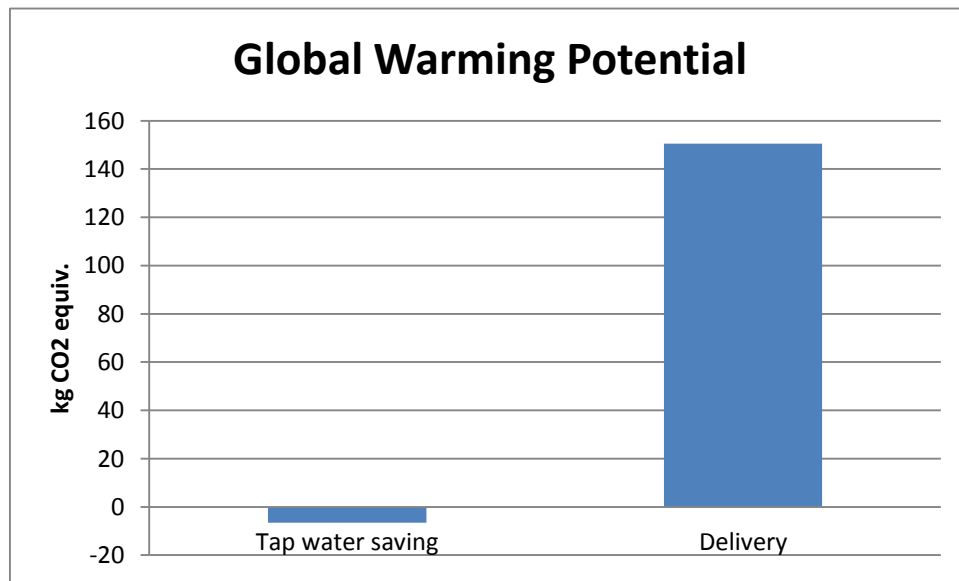


Figure 18: Impact on Global Warming related with utilization of the waste iron suspension generated in nano-remediation tank in concrete production. This kind of utilization results in reduced use of drinking water (considered as an environmental benefit) in concrete production process.

Table 9: Environmental footprint of processes involved in life cycle of the waste iron suspension from nano-remediation tank. Burdens and benefits associated with use of the waste iron suspension to produce concrete are evaluated.

	Transport to concrete production plant	Benefit related with saving of drinking water	Total
ADP elements [kg Sb-Equiv.]	1.12E-05	-1.1E-06	1.01E-05
ADP fossil [MJ]	2.06E+03	-37.76	2.02E+03
AP [kg SO ₂ -Equiv.]	7.20E-01	-0.0071	7.13E-01
EP [kg PO ₄ -Equiv.]	1.20E-01	-0.0032	1.17E-01
FAETP [kg DCB-Equiv.]	9.60E-01	-0.024	9.36E-01
GWP 100 years [kg CO ₂ -Equiv.]	1.50E+02	-6.48	1.44E+02
GWP 100 years, excl biogenic carbon [kg CO ₂ -Equiv.]	1.52E+02	-3.18	1.49E+02
HTP [kg DCB-Equiv.]	4.80E+00	-0.31	4.49E+00
MAETP [kg DCB-Equiv.]	2.10E+03	-707.74	1.39E+03
ODP [kg R11-Equiv.]	1.08E-09	-1E-10	9.80E-10
POCP [kg Ethene-Equiv.]	-2.40E-01	-0.00068	-2.41E-01
TETP [kg DCB-Equiv.]	3.60E-01	-0.012	3.48E-01
Primary energy demand [MJ]	2.19E+03	-42.01	2.15E+03
Blue water consumption [kg]	2.94E+02	-9180	-8.89E+03

2.4. Comparison of effluent waste treatment at the pilot remediation system with reverse osmosis

For a comparison, LCA was conducted also for remediation of waste water via reverse osmosis. Treatment of the same amount of water was assumed (i.e. 900 m³). LCI data from Professional+extensions database (thinkstep) were used to evaluate environmental performance of reverse osmosis.

Treatment of effluent water at the pilot remediation system was found to be environmentally more acceptable process than hypothetical treatment via reverse osmosis in many aspects. As shown in Table 10, effluent water treatment at the pilot remediation system shows lower global warming impact, lower impact on abiotic depletion of both fossil resources, lower

impact on eutrophication etc. Impact is significantly greater only in case of human toxicity and eco-toxicity categories; however, assessment of toxicity impacts in LCA methodology is still problematic and the results can be to some extent relatively less reliable. It should be also emphasized, that water treated solely with reverse osmosis cannot be remediated to the same extent as water treated at the pilot remediation system. To achieve this, reverse osmosis would require some pre-treatment of the water, which is associated with additional environmental burdens (not included in Table 10).

Table 10: Environmental performance of the pilot remediation system compared to reverse osmosis.

	Reverse osmosis	The pilot remediation system	Difference (%)
ADP elements [kg Sb-Equiv.]	0,04	0,12	33,33
ADP fossil [MJ]	48697,04	23382,11	208,27
AP [kg SO ₂ -Equiv.]	8,88	14,83	59,88
EP [kg PO ₄ -Equiv.]	2,15	2,06	104,37
FAETP [kg DCB-Equiv.]	13,68	1030,92	1,33
GWP 100 years [kg CO ₂ -Equiv.]	4209,86	1993,26	211,20
GWP 100 years, excl biogenic carbon [kg CO ₂ -Equiv.]	3800,34	1787,09	212,66
HTP [kg DCB-Equiv.]	136,99	4900,20	2,80
MAETP [kg DCB-Equiv.]	445227,79	2009415,68	22,16
ODP [kg R11-Equiv.]	9,01265E-07	0,01	0,01
POCP [kg Ethene-Equiv.]	0,80	1,26	63,49
TETP [kg DCB-Equiv.]	5,36	101,85	5,26
Primary energy demand [MJ]	74997,00	30644,78	244,73
Blue water consumption [kg]	895283,86	-801228,19	-111,74

3. CONCLUSIONS

An expected result of action "Assessment of project action impact on the environmental issue" was to prove environmental efficiency and sustainability of the pilot remediation systems through life cycle compared with traditional systems for water treatment and utilization of generated wastes in composite materials for civil engineering versus traditional composites.

All environmental burdens related with the SWTP at Šentrupert (Poštaje) and the pilot remediation system were evaluated in this study. As expected, the additional cleaning of effluent water at the pilot remediation system yields significant benefit for blue water saving, but also additional environmental burdens. The latter mostly relate to production of chemicals required for nano-remediation. Production of nZVI, which are consumed during the additional cleaning of effluent water, is responsible for relatively high impact on global warming, considering the life cycle of the SWTP at Šentrupert (Poštaje) and the pilot remediation system. However, the system is environmentally efficient. The efficiency is significant in case of the use of the pilot remediation system in those countries and regions, which are facing with water scarcity problem. Considering increasing concern of water scarcity problem around the world, the pilot remediation system will contribute to sustainability in recycling of municipal waste water. Despite the fact that the pilot remediation system generates environmental burdens, which can not be ignored in Slovenian conditions (Slovenia is among the countries richest with blue water), the latter can be considered as environmentally efficient compared to alternative processes such as reverse osmosis with some pre-treatment.

Innovative waste treatment processes were developed in the frame of RusaLCA project. Utilization of organic sludge from the SWTP for production of geotechnical composites yields only low impact on the environment, especially when comparing with traditional treatment scenarios (incineration of organic sludge with heat recovery for example). Alternative organic sludge management processes thus show much more friendly option from environmental point of view than traditional management scenarios (incineration, use in agriculture etc.).

Moreover, composites with utilization of organic sludge and the waste iron suspension show lower environmental footprint than traditional composites, and thus fulfill sustainability requirements.

4. REFERENCES

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